THE HONG KONG POLYTECHNIC UNIVERSITY

INSTITUTE OF TEXTILES AND CLOTHING

PATTERN ENGINEERING FOR FUNCTIONAL DESIGN OF TIGHT-FIT RUNNING WEAR

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A thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy

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CERTIFICATE OF ORIGINALITY

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ABSTRACT

When people run, their bodies have very different physical, mechanical and physiological characteristics compared with normal static state. Running wear is essential for every runner. In high-performance sportswear design, style design, material application, layer assembling, pattern construction and fit design are all important factors in determining the final performance of the garment. Numerous research studies have discussed about the relationships between the product functional performance and the use of materials, product design or construction method. The number of investigations related to clothing pattern or fit design is relatively rare. The objective of this research is to establish a comprehensive knowledge framework of pattern engineering in functional design of tight-fit running wear, and to develop a systematic dynamic pattern construction method for high-performance clothing. In this project, an integrative research study has been undertaken that involves seven parts: (1) Body measurements in static, dynamic postures and running progress; (2) Development of static block patterns with just-fit design; (3) Understanding physical properties of the human body during running; (4) Development of dynamic block patterns; (5) Investigation of the change of material properties at different stretching levels; (6) Functional evaluation of running wear of different fit designs; and (7) Development of a scientific system for functional dynamic pattern construction.

The first part of the research is a systematic anthropometric study of the human body in different motion states. Different methods have been developed for the investigation on body dimensional change in different states, such as manual tape measurement, 3D body scanning and body motion capture. In the

second part, static block patterns with just-fit design have been constructed based on the findings of the previous step, and a fit evaluation method has been developed to analyse and improve the fit of the static block patterns. In the third part, experiments on the body's physical properties in running state have been carried out to examine the skin surface changes. The results have been used to determine the functional districts and structural lines design in dynamic patterns. In the fourth part, the optimal wearing ease values have been determined by analysing body measurements in static state, dynamic postures and running state. The obtained optimal wearing eases have been used in dynamic block pattern development. With dynamic block patterns and structure lines design of running wear, dynamic patterns of one-piece running wear with different tight-fit designs have been constructed. In the fifth part, the physical testing of material has been conducted to examine the basic characteristics and mechanical-physical properties of elastic knitted fabrics at different stretching levels. The influences of fabric material properties at different stretching levels on shape, thermal and moisture functions have been investigated to determine the applications of fabric material in running wear design. The final knitted patterns have been designed for one-piece running wear. In the sixth part of the research, wearing trial experiments have been carried out, subjective and objective evaluation methods have been used to investigate the effects of dynamic patterns and fit designs on the ergonomic functional performance of the running wear. Finally, a scientific method for dynamic pattern construction has been concluded. Different from traditional methods, dynamic pattern construction method can be used to develop sportswear that meets the ergonomic functional requirements of the human body in sports.

This research advances the knowledge of pattern engineering and its relationship to sportswear functional performance. It provides a framework for scientific design and development of high-performance sportswear.

PUBLICATIONS ARISING FROM THE THESIS

Refereed Journal Articles

1. **Y. J. Wang,** P. Y. Mok, Y. Li, Y.L. Kwok, 2011. Body Measurements in Dynamic Postures and Application, Applied Ergonomics, Vol.42, Issue.6，pp.900-912.

2. **Y. J. Wang**, P. Y. Mok, Y. Li, Y.L. Kwok, 2010. A New Technique for Objective Fit Evaluation of Just-fit Clothing (under review) ---- Textile Research Journal.

3. **Y. J. Wang**, P. Y. Mok, Y. Li, Y.L. Kwok, 2010. Effects of waist and lower limb movement on clothing ease design, Journal of Textile Research, Vol. 31 (3), pp. 92-97.

Book Chapter

1. **Y. J. Wang**, P. Y. Mok, Y. Li, and Y.L. Kwok, 2010, Analysis of Lower Limb Measurements in Running Progress for High-performance Slacks Design, Conference books by published by CRC Press / Taylor & Francis, Ltd.

Conference Papers

1. **Y. J. Wang**, P. Y. Mok, Y. Li, and Y.L. Kwok, 2010. Analysis of Lower Limb Measurements in Running Progress for High-performance Slacks Design, 3rd

International Conference on Applied Human Factors and Ergonomics, Miami, USA.

2. **Y. J. Wang**, P. Y. Mok, Y. Li, and Y.L. Kwok, 2009. Effects of Waist and Leg Movements on Clothing Ease Design, 7th Chinese Academicals Conference of PhD Candidates, ShaoXin, ZheJiang, China.
3. **Y. J. Wang**, P. Y. Mok, Y. Li, and Y.L. Kwok, 2008. Case Analysis: Computer Simulation of Thermal Function of Three-Layer Winter Outdoor Sportswear, The 86th Textile Institute World Conference, Hong Kong, China.
4. **Y. J. Wang**, P. Y. Mok, Y. Li, and Y.L. Kwok, 2008. Geographical Difference of Product Knowledge and Functional Requirements on Winter Outdoor Sportswear, The 86th Textile Institute World Conference, Hong Kong, China
5. **Y. J. Wang**, P. Y. Mok, Y. Li, and Y.L. Kwok, 2008. A Comparative Study on Product Knowledge and Functional Requirements of Winter Sportswear between Professional and Non-professional Consumers in China, First TBIS International Conference, Hong Kong, China.
6. **Y. J. Wang**, P. Y. Mok, Y. Li, and Y.L. Kwok, 2008. The Analysis of Properties of Materials in Three-layer Sportswear, First TBIS International Conference, Hong Kong, China.

Patents

1. Y. Li, L. Yao; S. Sun, J.Y Zhou, J. Y Hu, **Y. J. Wang**, X. Y Cao, J. Jiao, K. W Lau, High Performance Running Wear, China Patent Office, Filing date: 14 Oct 2010, RIP-25A, Filing number 201010507140.X.

2. Y. Li; L. Yao; J. Luo, Y.P Guo, J.Y Zhou, J. Y Hu; H. Cao; **Y. J. Wang**; X. Y Cao; High Performance Cycling Wear, China Patent Office, Filing date: 22 Oct 2010, RIP-31A，Filing number 201010255317.1.

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CHAPTER 1 INTRODUCTION

1.1 Introduction

People are becoming increasingly health conscious and realize the importance of participating in sports and exercises to maintain a healthy lifestyle. In the United Kingdom, 45 per cent of adults exercise by walking regularly (Ruckman, 2005). In America, there are over 9 million running sports enthusiasts, whilst the number has exceeded 10 million in Japan and Southern Korea (Cai & Gong, 2007). With the increasing number of people participating in sports, the sportswear market has grown remarkably. In the year 2000, sales of outdoor sportswear were valued at £380 million in the UK, which is equivalent to 24% of the total sports clothing market share. In 2002, consumers spent £4.06 billion on sportswear, representing 10.3% of the total UK clothing market. In 2005, the sale of outdoor sportswear was over $10 billion in USA and €55 billion in Europe (Ruckman, 2005).

Sportswear includes different categories such as outerwear, tops, trousers, and footwear. Different specialised clothing products are designed for outdoor expedition or specific activities. In sportswear product design, aesthetic and functional designs are the most important considerations, which determine the wearing comfort and eventually the sales (Foster, 1998). Aesthetic design comprises of the style, colour, accessory and material used in the sportswear products and these aspects are required to follow the fashion trend. Functional design requires that the sportswear properties should meet the body mechanical and physiological requirements in exercise. For example, a good functional design can prevent athletes from injury by keeping the correct body postures in exercise, and it also provides excellent thermal comfort by effectively transmitting excess body heat and moisture out of the body.

Numerous research have been carried out to develop high performance sportswear, which include the improvement of style design, use of materials, pattern construction as well as manufacturing operation. Among which, pattern construction is one of the most critical areas (Fan & Chen, 2002). For sportswear, even though the fabric is engineered to have optimum values of heat, water or air transmission, the sportswear may not be regarded as physiologically comfortable if it does not have the correct pattern construction. Sportswear with poor pattern construction can restrict cardio-vascular flow, cause skin abrasion, create unpleasant thermal/moisture conditions or introduce irritation that manifest to wearers in the form of discomfort (Milenkovi & Kundri , 1999). Therefore, designing excellent patterns does not only enhance functional performance of the sportswear, but also bring wearer positive perceptions of comfort.

This research aims to study scientific pattern engineering design for tight-fit running wear based on clothing function, body mechanical characteristics and material property requirements. Tight-fit running wear is chosen to explain the proposed method for sportswear pattern design due to two reasons. The first reason is that running, as one of the first activities in sport history, is one of the most popular sports in the world (Lakomy, 2000). Another reason is that tight-fit design is the most popular garment shape and pattern structure for training and competition running wear. However, it is important to note that the proposed method is also applicable not only for the pattern design of high-performance running wear, but also for the design of other high performance sportswear clothing, such as protective apparels, fitness garments and underwear.

This chapter introduces the background of research, which covers general information about running, the importance of specialized clothing, body characteristics during running, as well as the functional requirements on fit and pattern in running wear design. The research objectives of this study are then defined and also the significances are addressed. According to the defined research objectives, research method is outlined. The chapter ends with an outline of the thesis and definition of the clothing pattern terminology used in the thesis.

1.2 Background of the Research

1.2.1 Running Exercises and the Importance of Running Wear

Running is defined as a gait in which at some point all feet are off the ground at the same time (Jeff, 2008). Running can be classified into three different categories: sprinting, middle-distance and long-distance running, respectively. Sprinting is defined as running activities up to 400m. Running between 800m to 5000m is usually classified as middle-distance running, and long-distance running refers to running over 10,000 m (Hawley, 2000) . Sprinting, middle-distance and long-distance running have different characteristics. In middle-distance and long-distance running, people run at steady speed for a long period of time. In contrast, people constantly change running speed in sprinting, usually with an initial rapid acceleration followed by a subsequent decline in speed as fatigue develops. The maximum speed cannot be maintained even for the shortest distance sprinting.

In general, T-shirts, vests and shorts are the typical product types for running wear. With the advancement of research in clothing materials and construction technology, new styles are adopted in functional sportswear design.

Among which, one-piece running wear with tight-fit design is a popular style in recent international competitions. For example, Cathy Freeman, the champion of women 400m in 2000 Sydney Olympic Game, wore one-piece running wear with tight-fit design. In 2008 Beijing Olympic Game, Steve Hooker also wore one-piece sportswear with tight-fit design and won the champion for the pole vault.

High-performance running wear is an indispensable necessity for an athlete to champion in a competition and in his daily training. On the one hand, high-performance running wear should be able to exert proper pressure to the body to assist muscle movement. At the same time, it should provide sufficient protection against wind, sun, rain, and snow. On the other hand, high-performance running wear should fulfill the requirements of comfort, drape and ease of movement, which affect athletes' performance and health. Poorly designed running wear could increase the wearer's heart rate, rectal temperatures and muscle activities (Umbach, 2001, 2002). On the contrary, wearing breathable running wear can enhance wearer's performance, enabling a longer duration of active exercise.

1.2.2 Changes of Body Characteristics during Running and Running Wear Functional Requirements

It is important to understand the mechanical and physiological characteristics of the human body in running exercise, so that the appropriate functional designs of running wear can be determined. When a person takes part in middle and long distance running, his body would change significantly in various aspects. The extension and contraction of body skin surfaces and the transmission of heat and moisture from the body to the environment are the two most significant changes. As a result of high degree body movements, the skin surfaces, especially those around joints, would extent and contract accordingly (Watkins, 1995). Simple body movement, such as bending the elbows or knees, can stretch the skin surface by as much as 50%. The extension and contraction of the skin surface during body movements alter the corresponding body measurements. If clothing restrains body movements, discomfort may result because of the undesired garment pressure on body.

In addition to the body's skin surfaces and shape, running affects human physiological functions as well. The human body generates metabolic heat to support the internal biological and physical activities of muscles and organs. When people conduct physical activities like running, muscles require energy to carry out the work, and most of the energy consumed is released in the form of metabolic heat. The body skin temperature of human beings should be kept at 37±0.5 °C and the core temperature can change in the interval of 37-39 °C, which are regulated by a homeostasis process called thermoregulation. (ASHRAE, 1977, Butera, 1988, Han & Huang, 2004).

To support the exercise of running more effectively, the functional requirements for tight-fit running wear can be summarised in four aspects: a) Ergonomic wearing comfort; b) Thermo-physiological wearing comfort; c) Skin sensorial wearing comfort; and d) Psychological comfort. Among which, ergonomic wearing comfort is the most fundamental requirement. If a garment cannot provide the ergonomic wearing comfort, the thermo-physiological wearing comfort would be affected and so as the other two wearing comforts. In other words, functional design for ergonomic wearing comfort is the first and foremost important element in high performance running wear design.

1.2.3 Fit Design of Running Wear

Ergonomic wearing comfort depends on fit design, the pattern construction and fabric elasticity (Hawley, 2000). In general, there are three kinds of basic fit designs in sportswear: loose fit, just fit and tight fit. Two techniques are often used to achieve different fit designs. One is by adding or reducing the space between the garment and the body (garment ease), and the other way is by the use of different materials, for example elastic fabrics.

Tight-fit running wear means that the space between the garment and the body is zero. In tight-fit running wear design, elastic fabric is often chosen to provide the necessary room for body movements and to maintain the desired garment size and shape (Shishoo 2005). In relation to section 1.2.2, material properties directly influence running wear functional design, in particular the ergonomic wearing comfort. Therefore, the physical properties of elastic fabrics under different stretching levels must be considered in sportswear design. According to the functional requirements of running wear, special stretching levels of elastic knitted fabric in wale (warp) and course (weft) directions can be used to achieve the desired clothing sizes in length and circumference. Upon defining the clothing sizes, dimension details and structure of each pattern can be decided accordingly. In summary, designing tight-fit running wear is a complicated process that must take into consideration of different requirements on clothing functions, elastic material properties at various stretching levels, clothing size and special pattern structure.

1.2.4 Pattern Construction of General Clothing and Sportswear

Pattern construction of general clothing consists of different processes and they are shown within the dotted region in Figure 1-1: a) body measurement taking; b) body size and ease design; c) pattern construction; d) application of fabric and prototype making; e) pattern evaluation and modification (Nakazawa, 2000). In pattern construction, the first step is to obtain static-state anthropometric data according to the requirements on clothing style and functional design. The next step is body shape analysis and clothing size design, which determines body measurements, wearing ease and design ease. Wearing ease and design ease determine the shape and clothing fit performance (Liu, 2007). Based on the body measurements, ease design and material properties, patterns are constructed to define functional lines and detail pattern structure. With these pattern and selected fabrics, garment prototypes are produced and wearing trial experiment is carried out to evaluate the fit performance of the prototype so as to identify necessary corrections. The final product patterns are developed after iterative efforts on pattern improvement.

Although the described pattern making system is widely used in the industry for mass-produced clothing products, it is not suitable for high-performance running wear pattern design. Firstly, all body measurements used in traditional pattern making system are static-state body measurements. Wearing ease is defined by a trial-and-error approach. Secondly, pattern structures of general clothing are usually determined by designers, not by mechanical characteristics of the body. Thirdly, material property testing is absent. Fourthly, fit is evaluated by subjective method. In short, the simple system of traditional patternmaking is not suitable for pattern construction of high-performance sportswear.

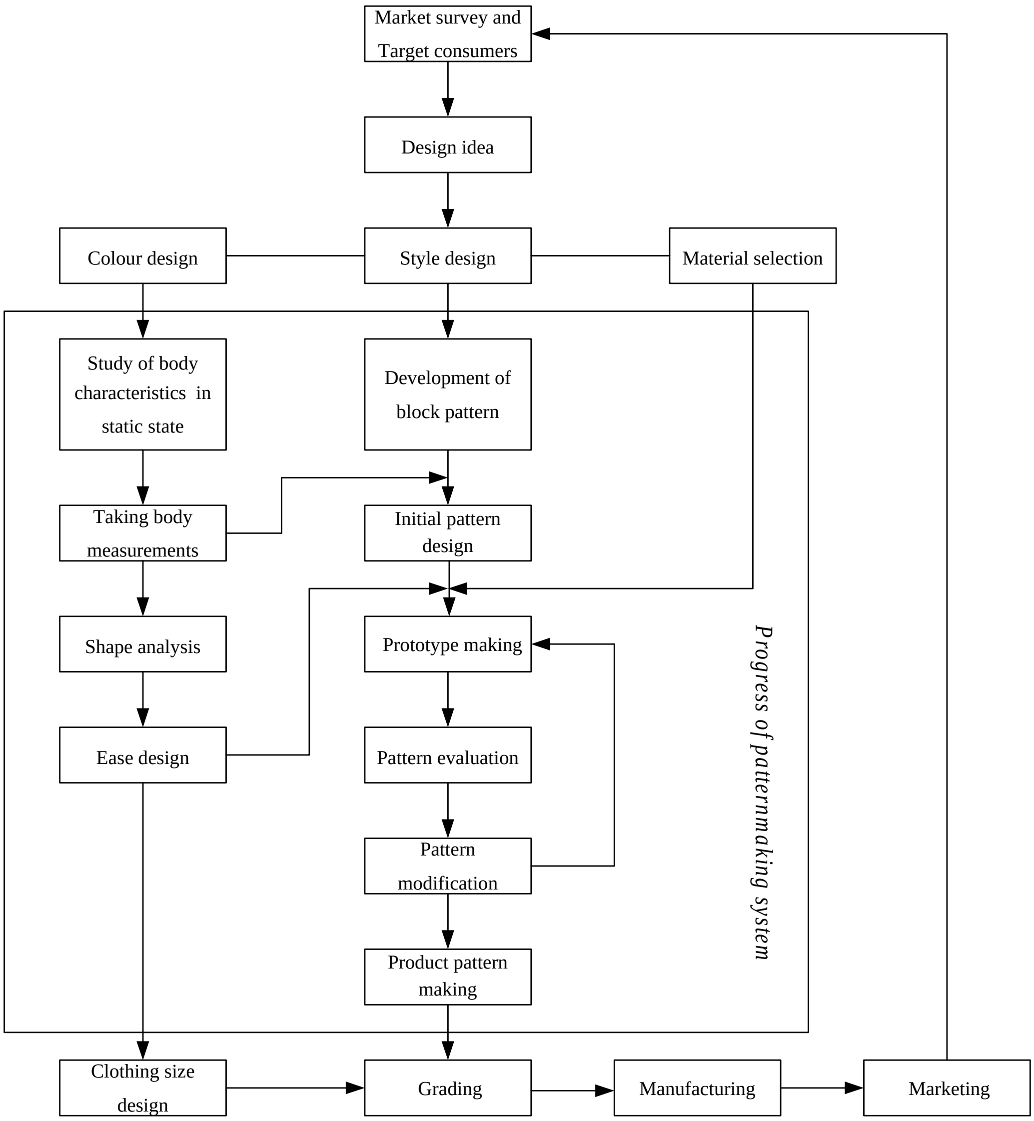


Figure 1-1 Pattern making system of general clothing

An effective patternmaking system for high-performance running wear must include the following:

a. Scientific wearing ease design. In running wear pattern construction, wearing ease is determined based on the changes of body measurements, which are the differences between body measurements in static and running states.

b. Analysis of the body’s shape and skin surfaces changes. It is important to analyse the changes of skin surfaces in running state. Such analysis forms the foundation for effective functional design.

c. Material properties testing of stretched fabrics. Tight-fit running wear requires the fabric used to be stretchable to accommodate body movements during running. Material properties at different stretching levels should be tested. The testing results determine the use of fabrics, the level of tight-fit allowed and the pattern structure to be used in running wear design.

d. Dynamic block pattern design. Dynamic patterns are patterns constructed based on body measurements and thermo-moisture characteristics in running state, and also the material properties testing result. Dynamic pattern is designed to fulfil the needs for body movement.

e. Fit evaluation. The achieved fit of the running wear must be subjectively and objectively evaluated, so as to determine the effectiveness of the pattern making system in running wear pattern design.

1.3 Aim and Objectives of the Research

This research aims to develop a new systematic pattern engineering approach, namely dynamic pattern construction method, for high-performance tight-fit running wear design. The new approach integrates anthropometric study, analysis of body physical characteristics in running motion, and textile material properties investigation. The specific research objectives are as follows:

i. To develop fitted block patterns based on body measurements in static state, and scientifically evaluate fit performance of the fitted block patterns;

ii. To conduct anthropometric survey on human body in static state, dynamic postures and running progress, so as to systematically analyse the changes of body measurement in dynamic movements;

iii. To develop a scientific understanding of the physical characteristics of the human body in running motion, especially in terms of skin surface changes;

iv. To establish a new method to construct dynamic patterns based on the fitted block patterns, optimised wearing ease, analysis result of physical body characteristics in running state;

v. To study the mechanical and physical properties of elastic fabrics, and understand the relationship between material properties and garment fit.

vi. To evaluate the performance of tight-fit running wear by subjective and objective methods.

vii. To propose a scientific system to generate functional dynamic patterns for tight-fit running wear.

1.4 Research Methodology

In order to achieve the objectives outlined above, the following research works are carried out:

Anthropometric Survey on Human Body in Static State, Dynamic Postures and Running Progress

TC^2 3D body scanner is used to collect body measurements in static state. To collect body measurements in dynamic postures, traditional manual method with tape and gonimeter are used based on defined landmarks on the body’s skin. Body measurements in running motion cannot be acquired by 3D body scanning or traditional manual methods. For this reason, body motion analysis system, which is widely used in sports and medicine discipline, is used to obtain body measurements in running state.

Static Block Pattern Construction and Fit Evaluation

Based on body measurements collected in static state, drafting methods are developed for static block patterns with just-fit design. Sample garments are made based on the static block patterns, and wearing trial is conducted for fit evaluation. A new objective fit evaluation method is proposed using 3D body scanning and reserve engineering techniques to obtain a comprehensive evaluation on the fit of the block patterns.

Dynamic Block Pattern Construction

Based on the fitted block patterns and the changes of the body measurements between static and running states, a novel method is proposed to construct dynamic block patterns for running wear.

Analysis of Skin Surface Changes of Human Body in Running Motion

In order to understand the physical characteristics of the human body in running exercises, experiments are designed and carried out to study the physical body characteristics i.e., variation of body skin surface areas in dynamic postures.

Physical and Mechanical Property Investigation on Stretched Knitted Fabrics

Structural characteristics, the physical and mechanical properties of elastic knitted fabrics at different stretching levels are measured, and the relationship between material properties and product functional performance is analysed.

Evaluation of Ergonomic Wearing Comfort of Tight-fit Running Wear

Dynamic patterns at different stretch levels are developed. Sample garments are made, and wearing trial is conducted to assess ergonomic wearing comfort of the tight-fit running wear during running exercise. Both subjective and objective methods are used to evaluate the clothing fit of the dynamic patterns.

Development of Functional Dynamic Pattern Construction Method for High-performance Sportswear

The relationships among ergonomic wearing comfort, fit design and clothing pattern are analysed. A new scientific method for functional dynamic pattern design is developed for high-performance sportswear pattern construction.

1.5 Outline of Thesis

The thesis consists of four parts. Part I, including Chapters 1 and 2, reviews the research background and related literature. Part II, consisting of Chapters 3 and 4, focuses on the development and evaluation of static fitted block patterns. Part III, including Chapter 5 to Chapter 10, discusses the development of functional dynamic patterns. Part IV concludes the thesis. The outline of the thesis is depicted in Figure 1-2.

Chapter 1 discusses the research background, objectives, and methodology. Chapter 2 gives a comprehensive literature review on a) mechanical-physiological characteristics of human body in running progress; b) running wear functional design and evaluation; c) running wear fit design and assessment; and d) running wear pattern design.

In the second part of the thesis, a method for static block pattern with just-fit design is explained in Chapter 3, and the resulted static block patterns are used as foundation for later dynamic block patterns development. The static block patterns are constructed based on careful anthropometric study. In Chapter 4, an objective fit evaluation method is developed for a comprehensive analysis of the resulted static block patterns.

Body measurements vary in different dynamic postures. In order to better understand how dynamic postures affect body measurements, experiments are designed and carried out in Chapter 5. The measurement data are analysed statistically so as to define wearing ease values in different parts of the body. In Chapter 6, changes of body measurement in running motion are studied with a novel approach using the body motion analysis system. By analysing the measurement data, the impacts of running on body measurements are discussed, the changes of body measurement and the wearing eases to be used in different parts of the running wear are determined. In Chapter 7, skin surfaces changes of human body are observed and analysed, which is of paramount importance for effective ergonomic functional design of the running wear. Upon designing the shape of running wear and defining the functional requirements, the choice of materials for high performance sportswear is discussed in Chapter 8. Material properties of elastic knitted fabrics at different stretching levels are investigated, so as to determine the most appropriate material structures for different parts of running wear.

By integrating the results obtained in Chapter 5 to Chapter 8, a dynamic pattern construction method is proposed in Chapter 9. In Chapter 10, the relationships among garment pattern, clothing fit and ergonomic functional performance of the running wear are studied by wearing trial experiments. Finally, a systematic and dynamic pattern construction method is given for high performances running wear pattern design.

In the last part of the thesis, Chapter 11 summarizes the functional dynamic pattern construction method for tight-fit running wear development. Applications of this new patternmaking system to other sportswear design are discussed. Finally, future researches are proposed.

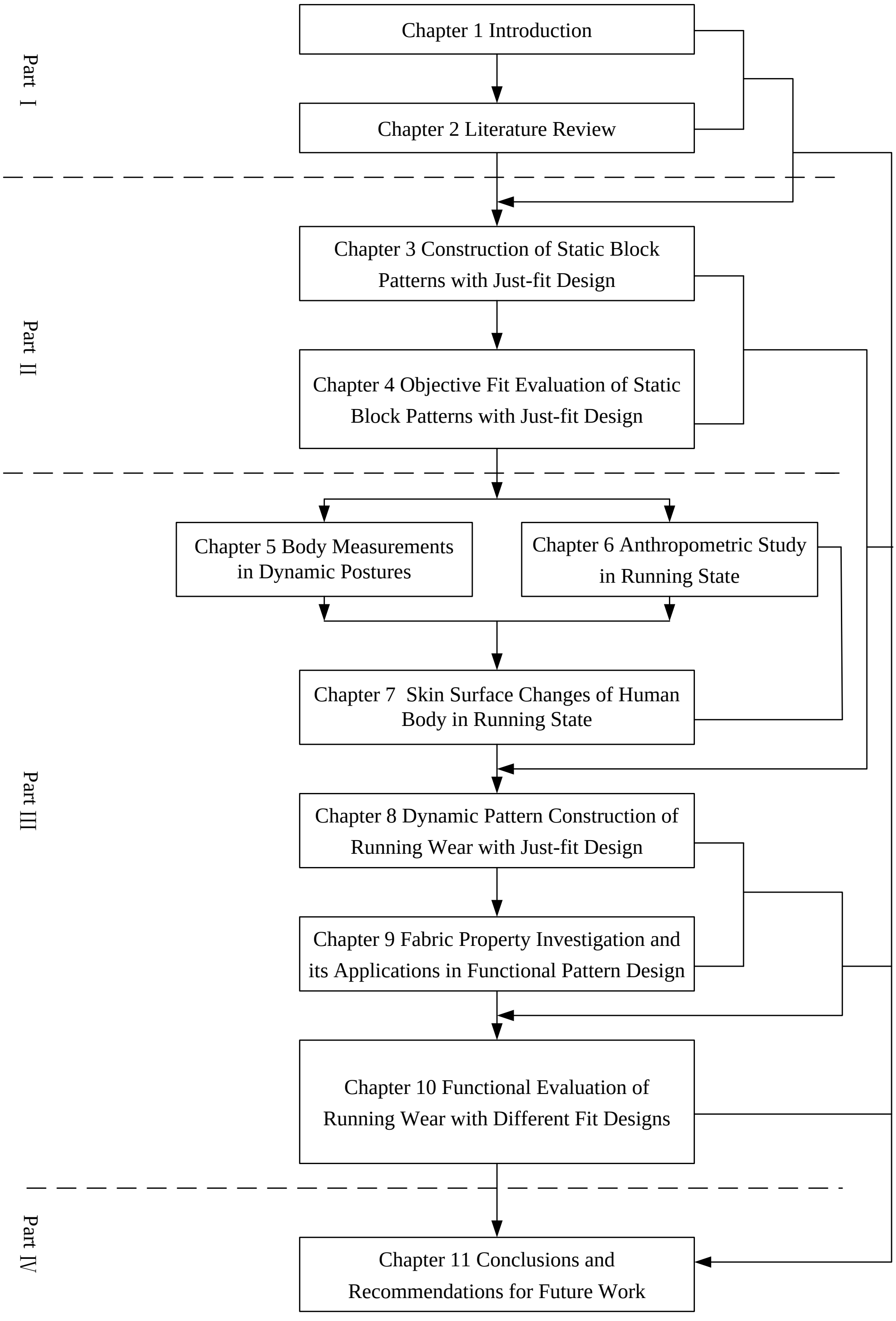


Figure 1-2 Thesis framework

1.6 Nomenclature

In this thesis, three kinds of clothing pattern are studied, which include (1) static block patterns with just-fit design, (2) dynamic block patterns with just-fit design, and (3) dynamic patterns. These pattern terms are utilised throughout the whole thesis, and they are first defined as follows.

Static block patterns with just-fit design

These are basic block patterns constructed based on body measurements collected from a subject's naked body when he is in static state. These static block patterns do not include any ease allowance, and they are regarded as the reproduction of body skin in static state. These patterns need further modifications before a clothing product can be produced.

Dynamic block patterns with just-fit design

These are special block patterns generated by analysing body movements and changes of body measurement in motion state. They are developed from the static block patterns by incorporating the optimal wearing eases for unconstrained body movements. Clothing produced from the dynamic block patterns is loose-fit for wearer in static state and just-fit in motion state. Dynamic block patterns are still basic patterns, from which final clothing product patterns are designed.

Dynamic patterns

These are the patterns of the final high-performance clothing products, which must provide ergonomic wearing comfort. These dynamic patterns are constructed based on the dynamic block patterns with just-fit design.

Figure 1-3 outlines the processes that create these three types of clothing patterns and their interrelationship.

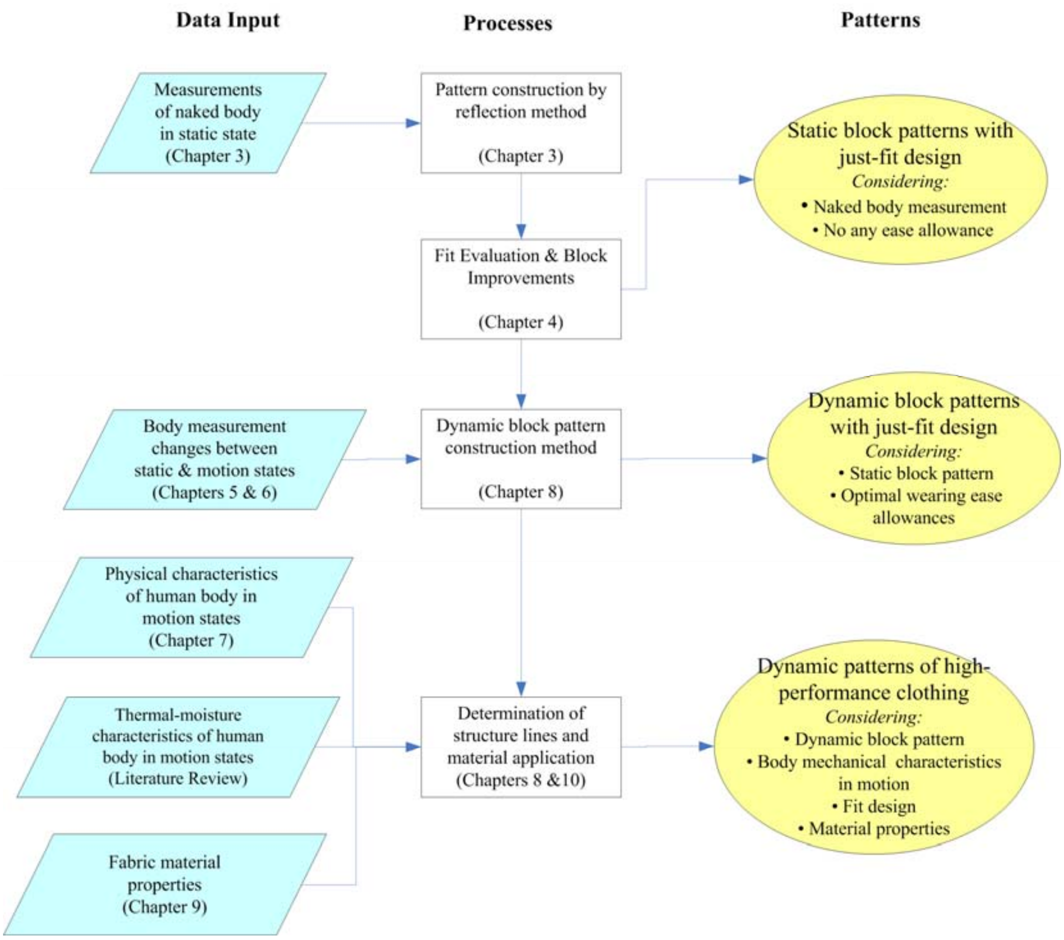


Figure 1-3 Terminology of clothing patterns and the corresponding generation process

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

Chapter 1 highlights the importance of multi-disciplinary knowledge in pattern engineering research for tight-fit running wear design. To have a general understanding, related literatures in the following areas are reviewed:

a. Mechanical-physiological characteristics of human body in running state
b. Clothing ergonomic functional design and assessment
c. Clothing fit design and assessment
d. Clothing pattern construction methods

2.2 Mechanical-Physiological Characteristics of Human Body in Running State

It is essential to have a sound understanding on the mechanical-physiological characteristics of the human body in running state before any high performance running wear is designed. The knowledge on the relationship between the human body and the clothing in turn determines the functional and fit designs of the running wear. The mechanical-physiological characteristics of the human body in running state can be analysed from four aspects: a) body structure and movement, b) postures and skin surface changes of the human body in running state, c) thermoregulation of the human body; and d) thermal-moisture distribution of human body in running state.

2.2.1 Body Structure and Movement

Figure 2-1 The structure of human body (http://bodybrowswer.googlelabs.com)

It has been a long history that researchers study the structure and movement of human body, and there is a large wealth of literature in this area (Hawley, 2000, Tozeren, 2000; Barry et al, 2003, Cohen & Barbara, 2009). The human body is a complex anatomical system. As shown in Figure 2-1, the structure of a human body consists of skeleton, muscle, fat and skin. The skeleton, i.e., skeletal system, is a strong framework that supports the body and determines body volume and proportion. The skeletal system of an adult has around 206 bones, connecting with joints. The majority of the joints are freely movable, making the skeleton flexible and mobile. The skeleton also contains cartilage, a flexible connective tissue that is found in many areas of the body, including the joints between bones. Ligaments are strong strips of fibrous connective tissues that connect bones to other bones at joints, for stabilizing the skeleton during movement. The skeleton is covered with muscle (muscle system), which forms the body shape. Body movement is based on the muscularity and the contraction of muscle (Waested et al., 1991). The muscle system is covered with fat and skin, and the increase of fat will alter the overall shape of the human body. The skin system has a significant influence on the body surface in dynamic state, because the skin has good morphology.

The movement of human body is of great subtlety, because of the elaborate body structure. Watkin (1995) commented that: "Movement is the result of a chain of events: the brain sends signals to the appropriate nerve fibres or motor neurons; they in turn send out impulses - via nerve fibres, which extend from the spinal cord to muscle fibres all over the body - that stimulate the appropriate muscle fibres; these muscle fibres create contacting force on an adjacent bone to produce movement." In ergonomic terminology, body movement is defined in relation to a basic position called the anatomical position of standing. All body movements are described in terms of three bisecting planes (Frontal, Transverse and Sagittal) and the axes (X_1, X_2, and X_3) of rotation of the body, as shown in Figure 2-2. These planes divide the body into the following sections: left and right, anterior and posterior, superior and inferior (Tozeren, 2000). In running state, most body movements involve the rotation of a body part around one of the three axes of a joint, and such movements are called angular movements. As shown in Figure 2-3, the common angular movements of the human body in running state include flexion, extension, adduction, and abduction.

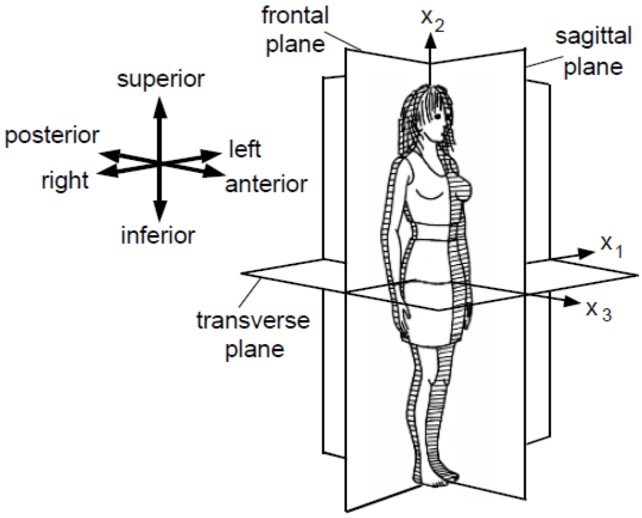
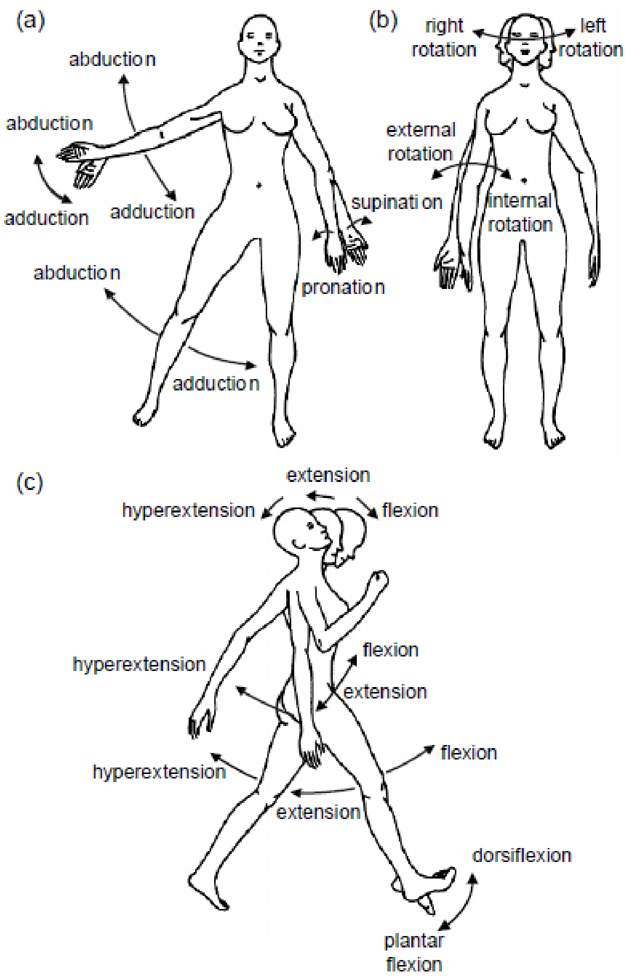


Figure 2-2 The three primary planes of a standing person (Tozeren, 2000)



.

Figure 2-3 The movements of various body segments: a) abduction and adduction, b) rotation, and c) flexion and extension (Tozeren, 2000)

Figure 2-3 (a) indicates that abduction and adduction are the movements of the limbs on the frontal plane. Abduction describes the movement away from the longitudinal axis of the body, whereas adduction is moving the limb back. Swinging the arm to the side is an example of abduction. When an athlete runs, he pulls the arms toward the trunk of the body, and this movement constitutes adduction (Tozeren, 2000). As shown in Figure 2-3 (b), rotation is when a body part rotates along the longitudinal axis of the body or another body part. For example, the head could turn to the left or to the right. Similarly, the forearm and the hand can rotate to a degree around the longitudinal axis of the elbow joint. As shown in Figure 2-3 (c), flexion and extension are movements that occur parallel to the sagittal plane. Flexion is a rotational motion bringing two adjoining long bones closer to each other, and extension denotes rotation in the opposite direction of flexion. For example, flexion at the hip and the shoulder joint is the movement of the limbs forward whereas extension means the movement of the arms or legs backward. Flexion of the wrist moves the palm forward, and extension moves it back.

2.2.2 Postures and Skin Surface Changes in Running State

Many researchers studied the changes of postures and body skin surface in running state. For example, Galloway (2002) analysed different body postures of running based on serial images captured by high-speed camera, and he suggested that runners should maintain certain positions of head, shoulder, arms, torso, hip, legs and feet for safety and health reasons. James (1980) analysed body characteristics and pointed out that the skin surface changes significantly when people run.

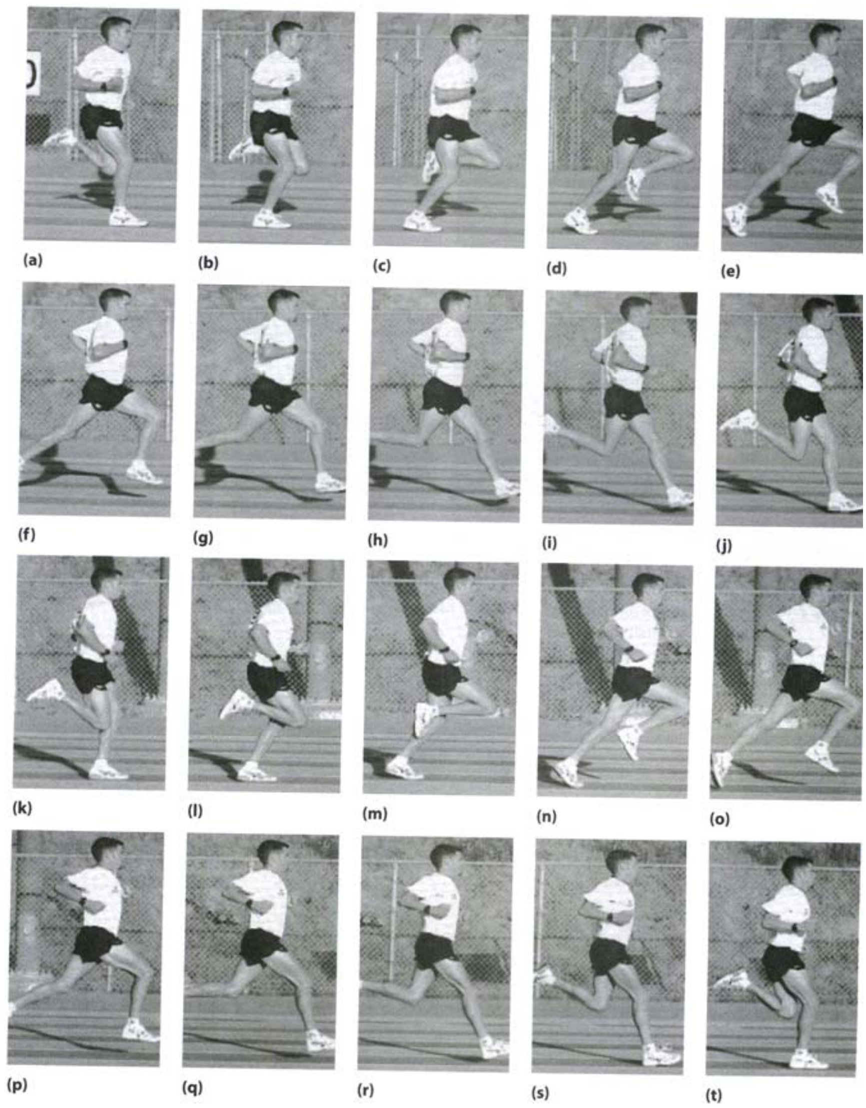


Figure 2-4 Body postures in running progress (Galloway, 2002)

The proper postures of running are that the head should up and look ahead. Shoulders should be low and loose, and the upper body should be relaxed when running. Two arms should swing forward and backward, between the waist and lower chest level. Elbows should be bent at about 90 degrees and hands should be kept in an unclenched fist with the fingers lightly touching palms. Torso and hips are at 90 degree to the ground. To run, people should keep a slight knee lift, a quick leg turnover and a short stride. In each step, the foot should hit the ground lightly - landing between the heel and mid-foot – then quickly rolls forward. The ankles should be kept flexed to create more force to push-off the ground.

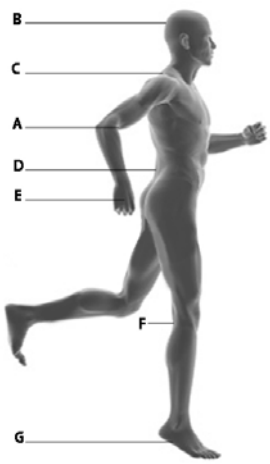


Figure 2-5 Cooperation of body parts in running state

A) arm; B) head, C) torso; D) waist; E) hand; F) leg; and G) foot

(Source: http://www.istockphoto.com)

It is known that different body movements, including running, are the results of the cooperations among body parts by different joint movements. As shown in Figure 2-5, a body is composed of body parts A) arm (upper and forearm); B) head, C) shoulder; D) waist; E) hand; F) leg (thigh and calf); and G) foot. Different body parts are linked with joints: a) shoulder joints link up arms and torso; b) neck connects head and torso; c) waist separates torso between upper part and lower part; d) hips connect torso and legs; d) wrist joints are between the arms and the hand; e) ankle joints are between the legs and the feet; f) elbow joints connect upper arm and forearm; and g) knee joints bridge thigh and calf. Without proper joint movements, body is rigid and people cannot run. For these reasons, understanding the detailed characteristics of joint movements facilitate the analysis of body mechanical properties in running exercise. Figures 2-6 to 2-9 display different joint movements, including the movements of lumbar joint, hip joint, knee joint, shoulder joint and elbow joint.

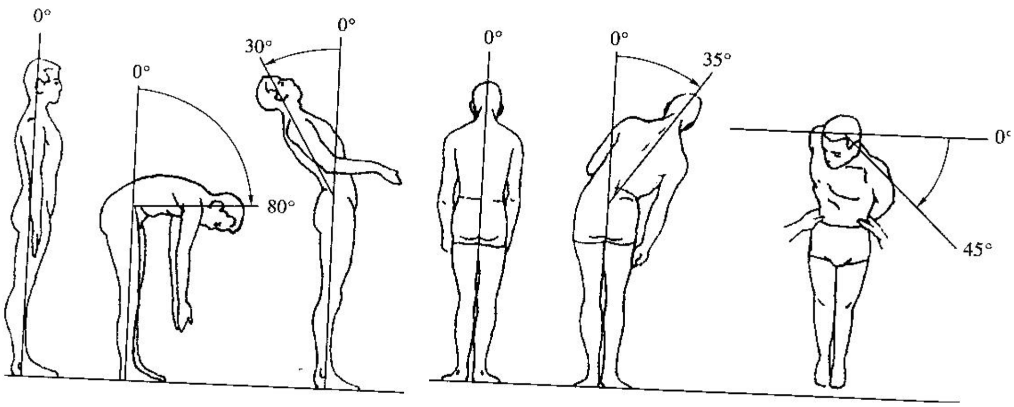


Figure 2-6 The degree of movement for lumbar joint (Liu, 2005a)

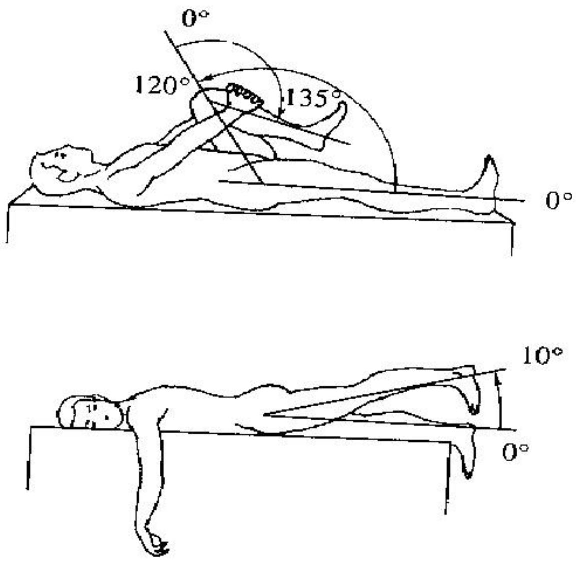


Figure 2-7 The degree of movement for hip joint (Liu, 2005a)

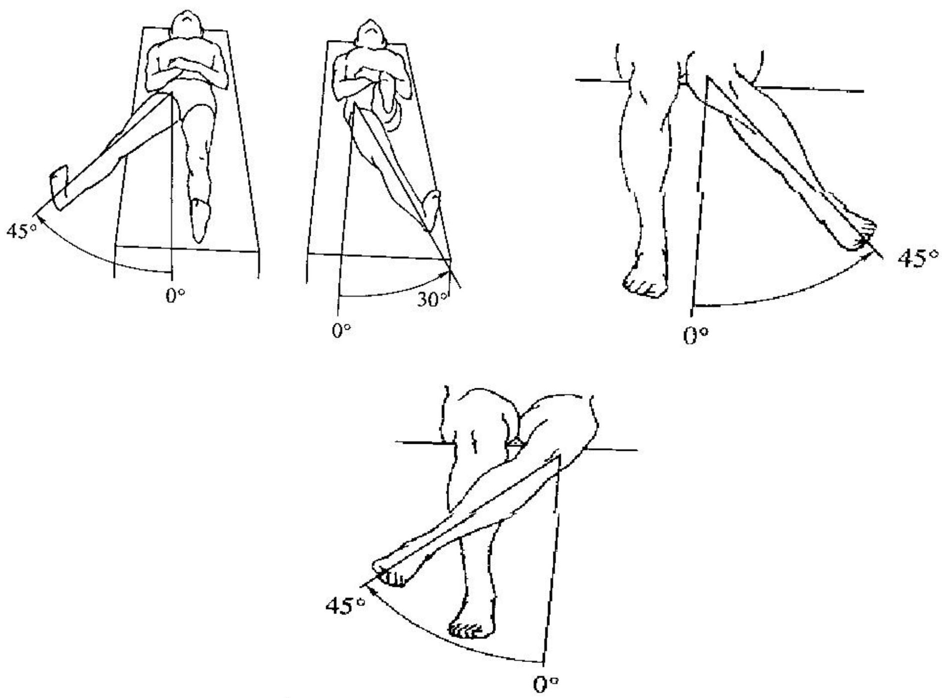


Figure 2-8 The degree of movement for knee joint (Liu, 2005a)

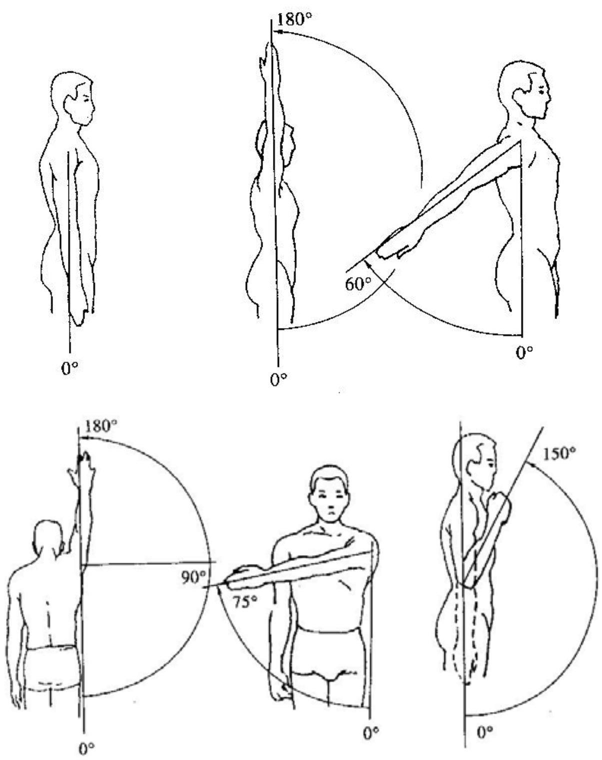


Figure 2-9 The degree of movement for shoulder & elbow joints (Liu, 2005a)

With different degrees of joint movements, the geometric feature of the human body varies substantially in running, which results in continuous extension and contraction of the skin surfaces. There are a number of methods developed to study the movements of joint and the changes of skin surface. Kirk & Ibrahim (1996) investigated body expansion and contraction by observing skin stretch or skin strain. In this method, the degrees of body movement were quantified as stretching percentage of skin surface at certain areas. For example, they found a local skin strain of approximately 42 percent in an isolated area from 6.35 cm above the kneecap to 6.35 cm below the kneecap. Another method that widely used in clothing design is by drawing a grid pattern or circles on an elastic garment before it is worn. The change in dimension of the grid or circle is measured when the body moves (Yuan & Yuan, 2006, Sungmin & Chang, 2007). Apart from these two methods, some experimental methods were also used in clothing pattern design, such as the opening and wrinkle observation methods. By observing the changes of the shape, volume, position and direction of the opening or wrinkle in running state, it can help designers to understand the characteristics of skin surface changes in certain regions of the body. This can be used to modify the line or size in the corresponding patterns in order to achieve good clothing mobility. In addition, computer technology was also used in the research of body skin surface changes in body movements (Zvonko & Snjezana, 2001, Kang et al., 2004). A number of computer systems were developed to measure body movement, such as Vicon. The movement of markers attached on the body surface are captured by the system, and the changes of body skin surface can thus be analysed.

2.2.3 Thermoregulation of Human Body in Running State

In addition to body mechanical properties, the thermoregulation system of the human body is studied here. For the purpose of health and comfort, human body keeps a constant body temperature at 37±0.5°C under different climatic conditions (Moran & Mendal, 2002). On the one hand, as shown in Figure 2-10 and Figure 2-11, human body generates metabolic heat due to internal biological and physical activities of the muscles and organs (Havenith,1999) . On the other hand, the human body can gain and/or lose heat through heat conduction, convection and radiation, as well as evaporation of moisture through perspiration and sweating (Li et al., 2006). Heat-exchange of the human body is a heat balance process, in which the amount of heat produced is equal to the heat loss. The detailed relationship between the body's heat production and heat loss can be described by the heat balance equation below (ASHRAE, 1977, Butera, 1988, Han & Huang, 2004):

$$M = E \pm R \pm C \pm S \qquad (2\text{-}1)$$

where M = metabolic rate

E = rate of heat loss by evaporation, respiration and elimination

R = radiation rate

C = conduction and convection rate

S = body heat storage rate

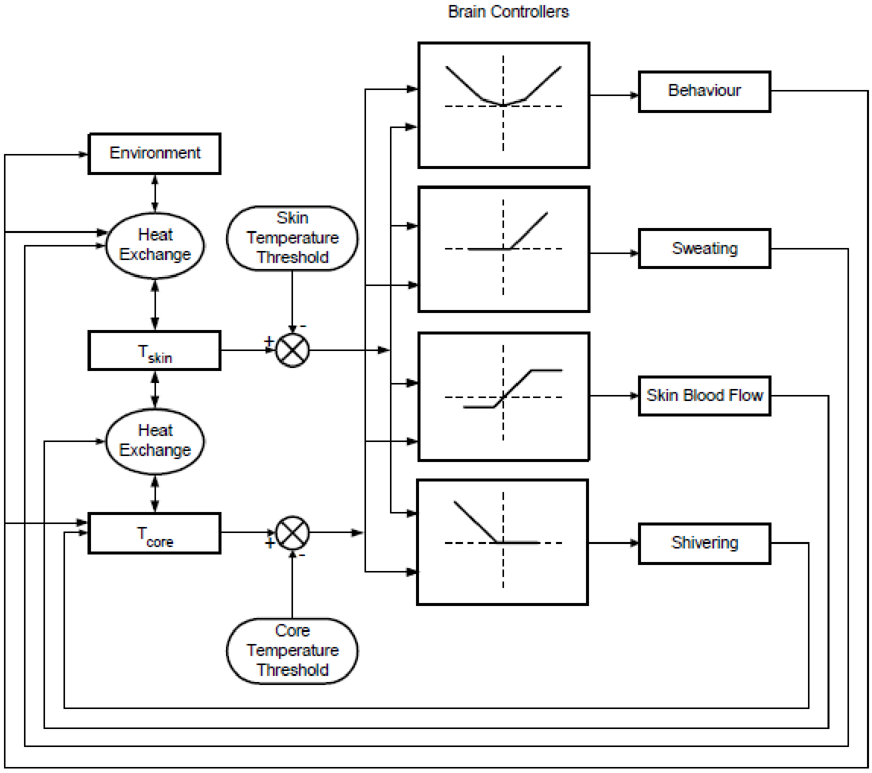


Figure 2-10 Schematic representation of the thermo-regulatory control system:

T_{core} = body core temperature; T_{skin} = mean skin temperature (Havenith, 1999)

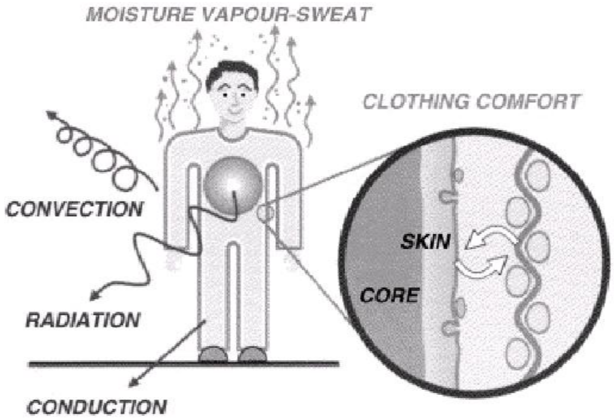


Figure 2-11 Heat-exchange between body and environment (Li et al., 2006)

Sakwka & Wenger (1998) conducted a detailed research on thermoregulation of people in running exercise. During physical exercise, a runner's metabolic heat production can increase by 10- to 20-fold and more than

95% of the energy expenditure become heat. Conversely, more than 70% of metabolic heat generated has to dissipate to the environment through the skin by conduction, convection, radiation and evaporation. If the heat dissipating mechanisms are not able to balance the metabolic heat production, heat starts to accumulate in the body and leads to an increase in body temperature. For example, a study reported that average gastrointestinal (GI) temperature increases from 37.6°C to 39.3°C after 45-min of running. The highest GI temperature can reach to 40.3°C in running exercise (Lim et. al., 2008).

Among four kinds of heat transmission, heat transfer through convection, conduction and radiation is bidirectional. The heat transfer between the skin surface and the environment is driven by the temperature gradient. Heat is transferred from the environment to the skin if the ambient temperature is warmer than skin temperature and vice-versa. Unlike the other types of heat exchange, heat dissipation through evaporation is uni-directional, where heat is transferred only from the skin surface to the external environment (Haymes & Wells, 1986). Evaporative heat loss takes place when sweat changes from liquid state to gaseous state. In running exercise, more than 80% of the heat is dissipated through evaporative heat loss, making it the primary means of heat removal from the body (Gisolfi & Mora, 2000). Therefore, sweating is very important for thermoregulation in running exercise, and the corresponding clothing functional design determines the ability to avoid heat injury.

Body core temperature (°C)	Condition
44	heat stroke, brain damage
41	Fever therapy
	very heavy exercise
38	Exercise
37	Normal resting condition
36	
35	Shivering
33	Reduced consciousness
31	Ventricle fibrillation "death"
14	Lowest measured temperature with full recovery

Mean skin temperature (°C)	Comfort sensation	Skin Wetness (%)
	Very Uncomfortable	60
36		40
35	Slightly uncomfortable	20
34		6
33	Comfortable	
32	Slightly uncomfortable	
31		
30	uncomfortable	

Local Skin temperature (°C)	Condition
>45	Skinburns, time dependent
45	Pain
25	Cool
20	Reduced dexterity
15	Pain
7	Numbness
-0.5	Frostbite

Figure 2-12 Body temperature and skin wetness in relation to comfort and health (Havenith, 1999)

As shown in Figure 2-12, body temperature and skin wetness are the two key indices used for understanding the body thermoregulation in running exercise and for evaluating the wearing comfort (Havenith, 1999, Lotens, 1993). For the human body, the common temperature indices include: rectal temperature (T_{re}) and skin temperature (T_s). Different kinds of thermo-detector have been invented to measure body temperature, including contact and contactless methods. Malcolm et al. (2000) used thermo-resistor temperature probe to measure rectal and skin temperatures to the functionality of army jacket on thermal regulation. Ying et al. (2004) measured body skin temperature with thermal sensor for analysing the thermal regulating functional performance of PCM garment. In these two methods, measuring devices were fixed on the measuring points and the data were collected by computer. Bryan (2007) measured the body skin temperature and assessed thermal performance of base-layer garment with infrared imaging camera. By this method, different body skin temperatures were displayed on one image and shown as different colours. The detailed temperature data of different parts of the body can be acquired and analysed.

The relative humidity of the human body can be measured by a number of instruments and methods (Khurtsilava et al., 2006): a) hygrometer: Relative humidity is measured using the ambient temperature by the dry bulb thermometer and the difference in the temperature shown on the wet bulb; b) psychrometric: Relative humidity is measured by placing the intersection of the wet and dry bulbs on a psychrometric chart; c) electronic sensors: Instruments use electronic means of recording information, and the two most common electronic sensors are capacitive sensors and resistive sensors. A current is applied between two plates in water with capacitive sensors and the change in capacitance due to the amount of water present is measured. Resistive sensors use a polymer membrane that changes conductivity according to water absorbed (Qian & Fan, 2006)

2.2.4 Thermal-moisture Distributions of Human Body in Running State

Body thermoregulation during running exercise is a heat-exchange process (Adams, et al, 2006, MacDougall, et al, 1974). Heat-exchange between the body and the environment results in changes of the body skin temperature and water content in different parts of the body (Pugh et al, 1967, Galloway & Maughan, 1997). Therefore, different materials, as well as different pattern structures, should be applied in different parts of the clothing (Brownlie, 1982, Havenith et al., 2004, Kong et al., 2008, Luo et al., 2008, Yao et al., 2009).

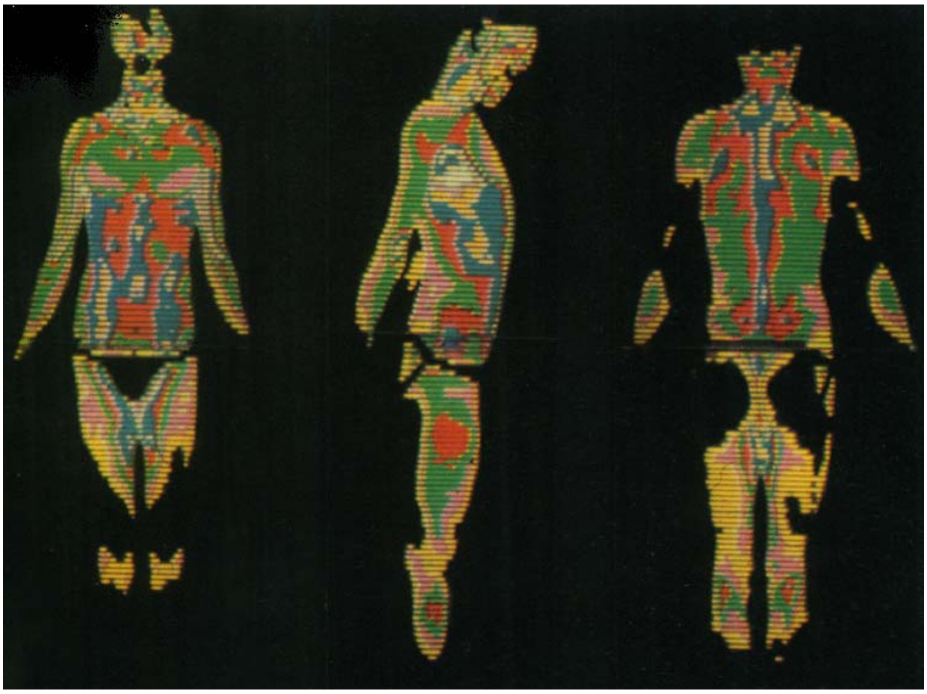


Figure 2-13 Temperature distributions and changes of human body during running (Clark et al., 1977)

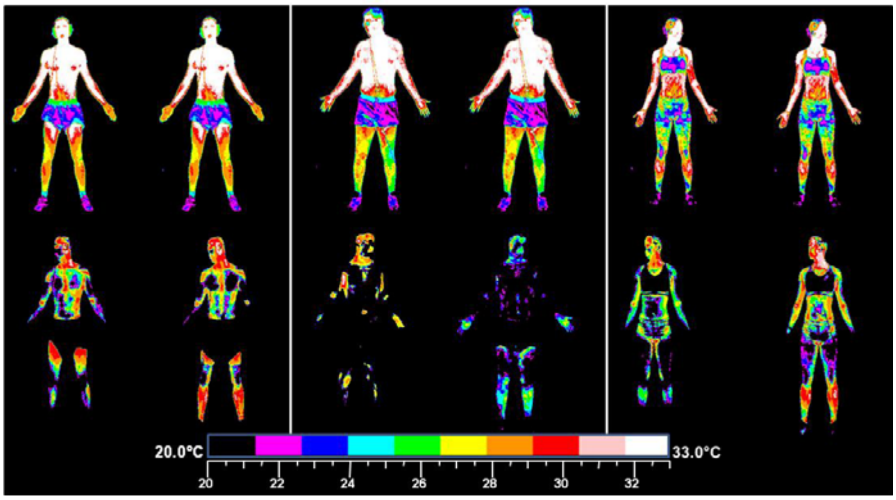


Figure 2-14 Thermograms of skin cooling patterns in three persons: Male lean, Male slight obese, and Female (Havenith et al., 2008)

A number of researches studied the changes of body skin temperature and water content in running state. Clark et al. (1977) studied the body skin temperature using infra-red colour thermograph when subjects stood and ran in an outdoor environment at 20°C and in a climate chamber at 11°C. The experimental results (see Figure 2-13) indicated that skin temperature were higher over muscles than over other structures when people run, and the temperature distribution in running state was very different from that before running. Havenith et al. (2008) analysed subject skin temperature in a cool environment (12°C, 50%rh, 2m/s wind) when subjects ran in moderate speed on a treadmill. They obtained infra-red colour images of the body skin temperature, as shown in Figure 2-13. These pictures revealed the sub-cutaneous fat distribution over the body, because the heavy build subject showed dramatically cooler skin temperature than the lean subject. In these images, the hot areas are either linked to locations where major arterial blood flow close to the skin, or to where muscles with little fat coverage (lower leg). The dark areas indicate cold skin and thus have low heat loss after the initial cooling, while the light areas show warm skin and would continue to have a high heat loss.

In terms of water content of the body skin, Kuno (1956) collected qualitative data and provided a sweat distribution map over a whole body on a small sample of Japanese subjects. Havenith et al. (2008) studied the sweat distribution of the torso when subjects ran at a speed of 10km/h, see Figure 2-15. Smith et al. (2007) studied the sweat distributions of the arms and hands, and Fogarty et al. (2007) investigated the sweat distribution of the feet. They tried to obtain a map for quantitative data of sweating over the whole body surface. Very different rates of sweating are found in different parts of the body.

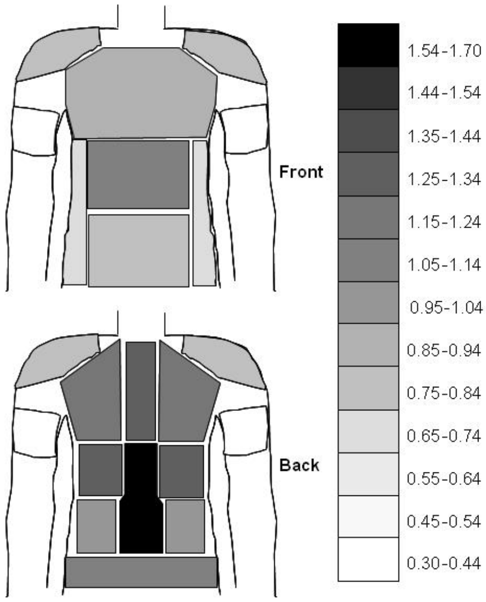


Figure 2-15 Sweat distribution of torso of male athletes in a 10 km run (Havenith et al., 2008)

Yao et al. (2010) conducted a detailed analysis of the thermal and moisture distributions of the human body in rest (20 minutes, standing), walking at 5km/h (20 minutes) and running at 10 km/h (20 minutes). Base on the collected data, thermal-moisture distributions covering the whole body surface were drawn, as shown in Figures 2-16 and 2-17. Figure 2-16 shows that the front leg and back leg has lower temperatures in the rest state. Head, armpit and hand have higher temperatures. The other parts of the body have similar temperature. In walking state, the forearm, lower back, front legs and back legs have lower temperatures. Head, armpit, hands and feet have higher temperatures. Among different body parts, the feet have the highest temperature. By comparing colour maps of the body in rest, walking and running, it can be found that overall skin temperature of the body decreased except for the feet in running. Among different body parts, the head, hand, armpit, knee fossa and feet are areas with higher skin temperature. In contrast, abdomen and low back are areas with lower skin temperature. Figure

2-17 shows the maps of relative humidity of the body in different states. When the body is at rest, the feet, armpit and head have different colour compared with other parts of the body. In walking, the armpit, head, upper back, low back, front leg, knee fossa and feet of the body have different humidity compared with other body parts. In running, the whole body is wet, therefore the whole body have the same colour in the moisture distribution map, and no division lines are found.

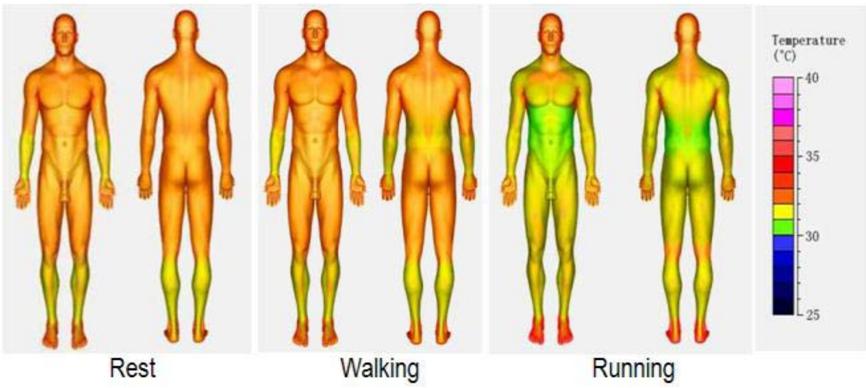


Figure 2-16 Thermal distribution of human body in rest, walking and running states (Yao et al., 2010)

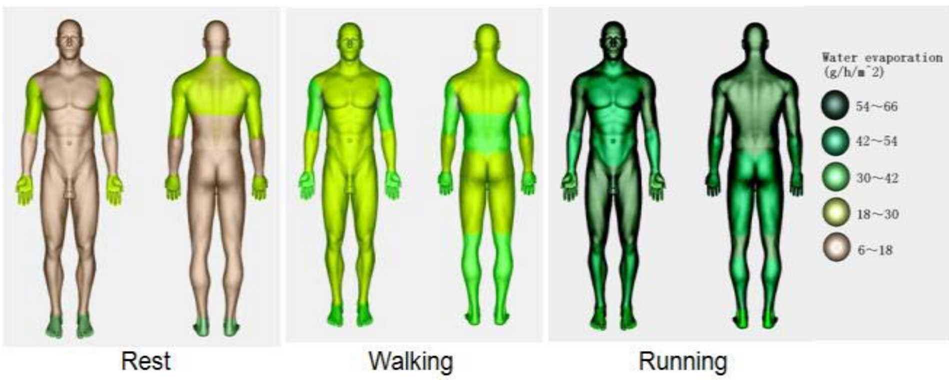


Figure 2-17 Moisture distribution of human body in rest, walking and running states (Yao et al., 2010)

2.2.5 Summary

This section reviewed the related literatures on body structure, body movement and mechanical-physiological characteristics of the human body in running exercise. The knowledge is necessary for effective clothing functional design. It is found that there are still limited research findings on the relationships between mechanical-physiological characteristics of the body in running state, body measurement and clothing structure. The following research gaps are therefore identified:

a) Little research has been conducted to study the effects of different postures on body measurements.

b) Regions of different body skin surface extension and contraction in running state, and the corresponding influences on clothing structure, have not been studied systematically.

c) The effects of thermal-moisture distribution of the human body in running state on clothing pattern structure have not been analysed scientifically.

2.3 Clothing Ergonomic Functional Design and Assessment

As discussed in the introduction, effective running wear is a necessary resource for every athlete. The garment should fulfil four functional requirements: a) ergonomic wearing comfort; b) thermo-physiological wearing comfort; c) skin sensorial wearing comfort; and d) psychological comfort. It has been confirmed in the literature that ergonomic wearing comfort is one of the most important elements in garment functional design, which directly influences the freedom of body movement and the body thermoregulation. In this section, the related works on ergonomic functional design and evaluation methods are reviewed.

2.3.1 Clothing Ergonomic Functional Design

Hui et al. (2007) defined clothing ergonomic function: Clothing should fulfil the requirements of human mechanics. On the one hand, clothing should be designed in accordance with the motion DOF (degree of freedom), range of motion (ROM), force and moment of human joints (Siguang, 1987, Li & Guo, 1996, Ji & Yuan, 1999, Zhou & Wei, 2005). On the other hand, clothing should exert suitable clothing pressure on the body skin, which should not cause bad psychological feeling (Xu & Tao, 2002, Alexander & Laubach, 1973).

Clothing material, clothing fit and structure designs are the important factors to consider in ergonomic functional design. Because of the good stretchability, elastic clothing materials can fit body contour in different movements and are widely used in tight-fit clothing. For clothing made of no-elastic materials, the movements of the human body are constrained if insufficient eases are used in the clothing. When human body movements are restricted, poor ergonomic wearing comfort is resulted. At the same time, the restriction generates excess heat due to poor ventilation and friction, thus thermal exchange between body and clothing is affected. Therefore, poor ergonomic functional design will lower the thermal-physiological wearing comfort either.

Fit and structural designs are important elements of ergonomic function for sportswear design. Loose-fit clothing is often used in hot climates to keep the next to skin microclimate cool. The dynamic air exchange, called pumping effect, keeps the area beneath the clothing cool by means of convection and evaporation. Elastic material is preferable for tight-fit clothing so as to enhance aerodynamic properties of the body in different sports. In addition, clothing structure should be designed based on body characteristics in static and motion states, so as to achieve a good clothing fitting and not to restrain the body movements. For example, high sleeve crown design restricts the raising of the arms, and long crotch structure will restrict the leg from lifting up, and both of which are seldom used in sportswear design.

2.3.2 Evaluation of Clothing Ergonomic Function

Subjective assessment, objective assessment by direct measure and simulation are the major methods used in clothing ergonomic functionality evaluation.

Figure 2-18 Direct measure of the clothing pressure for the assessment of ergonomic wearing comfort (You et al., 2002)

White et al. (1993) used subjective methods to investigate the work efficiency of anti-G suit. A questionnaire was used to assess subjectively the clothing fit achieved and its effects on body movements. Vykukal (1982) and Newman et al. (2000) used direct measure methods to analyse the motion performance of spacesuit. They measured the clothing pressure and rotating levels of joint movement. You et al. (2002) studied the sensation of wearing pressure and the other related sensations by both subjective and direct measure methods for tight-fit clothing, see Figure 2-18. Kozycki (1998) put forward a modelling and simulation approach to examine the ergonomic relationship between clothing and human body. O'hearn (2005) used a video-based motion analysis system to capture the maximum range of motion of the body.

2.3.3 Summary

By reviewing the related literature, a basic understanding of the fit design and functionality assessment of sportswear has been established. Ergonomic function is one of the most important elements in clothing functional design. Clothing material, clothing fit and pattern structure designs, and body movement are the main influential factors of clothing ergonomic function. Moreover, clothing ergonomic functional performance can be evaluated by scientific methods including (a) subjective method (questionnaire survey or image and video analysis), (b) objective method (clothing pressure measurement), and (c) computer simulation. The following research gaps are identified:

a) Limited works have been done to investigate the effects of fit design on clothing ergonomic functional design.

b) Little research about ergonomic functional evaluation of tight-fit running wear has been carried out.

2.4 Clothing Fit Design and Assessment

Studying the effects of clothing fit on apparel ergonomic function is an important way to design high performance sportswear. Liang (2002) provided proper definition of clothing fit. Static fit is "the relationship between garment and body size", and dynamic fit is "whether a garment allows the body to perform usual tasks without interference and resistance". Clothing fit is inextricably linked with the body measurement and movement function. Therefore, to develop high performance running wear, it is important to review the literature about classifications of clothing fit, anthropometric methods, body movement functions, ease design and fit evaluation.

2.4.1 Background of Clothing Fit

Clothing is designed to achieve a desired fit relationship between the body and the garment, and it is a complex activity that may be repeated many times in the life of a garment (Ashdown & Conell, 2006). Therefore, a garment's fit involves interactions among multiple factors, such as garment sizes, proportions, postures of the wearer, and the dimensions and drape of the garment.

Clothing fit usually includes three styles: tight-fitting, just-fitting and loose-fitting. A tight-fitting garment would constrain the body. A just-fitting garment fits smoothly over the chest and slightly loose at the waist. A loosely fitted garment provides greater ease. Usually, the fullness begins above the chest line and falls loosely around the body in the design of loose-fitting clothing.

Ease, line, grain, balance, and set are the five criteria to decide whether the garment conforms to the body in clothing design (Erwin & Kinchen, 1974, Chen, 2007). Ease, including functional ease and styling ease, is the dimensional difference between the garment and the body. Functional ease is considered as the amount of fabric allowed for body movement, and styling ease is defined as the amount of fabric needed to demonstrate the design of the garment. The second criterion of clothing fit is line, which includes different seams in clothing. For a good-fit garment, the basic requirement is that vertical seams are perpendicular to the floor and parallel to the body centre. Furthermore, some special lines need to be designed for creating shapes, especially for women's tight fitting clothing. The relationship among fabric, pattern and wearer is regarded as the third criterion of clothing fit. The basic principle is that the grain lines of the garments should be parallel or perpendicular to the floor. The fourth criterion is balance, which means that apparel with good balance design should evenly hang on the body, so the distance from the right side of the body to the centre is the same as the distance from the left side to the centre, and so forth. The last criterion is set, which refers to the absence of wrinkles on garments.

In order to achieve good clothing fit, a systematic plan should be followed, which was built up from practical experience: The starting point is to obtain the anthropometric data with reference to the clothing style and functional design. The next step is the ease design, which includes wearing ease and design ease. The amount of ease to put in a garment is decided by the body movement function and the style. When the clothing size is defined, the style and functional lines become the third consideration. The design principle of different lines is to ensure the good wearing effect on the figure and to establish the appropriate amount of ease for a particular style. In line design, the position, length and shape of the structural and style lines are decided. As discussed, defining the pattern size and correct figure type are probably the most important decisions for arriving at good fit (Perry, 1977).

2.4.2 Body Measurement and Anthropometric Methods

Body measurement is the most important way to describe body geometric features and to understand how it works (Gerard, 1992). Body measurement is also the foundation for clothing fit design.

Many methods have been developed to measure the body. Linear methods, Multiple Probe methods and Body Form methods are the three major types of method used to measure a human body. The linear methods are regarded as the most traditional and popular methods that describe the three-dimensional human body in lengths and widths. Multiple Probe methods can capture more information about the body contours, posture, and body angle than the linear method. In comparison with standard linear and multiple probe methods, the body form methods are more accurate in measurement taking and it can achieve more precise fit. The application of 3D body scanning technology to the construction of body forms makes the body measurement process much faster and less invasive (Gerard, 1992), as shown in Figure 2-19.

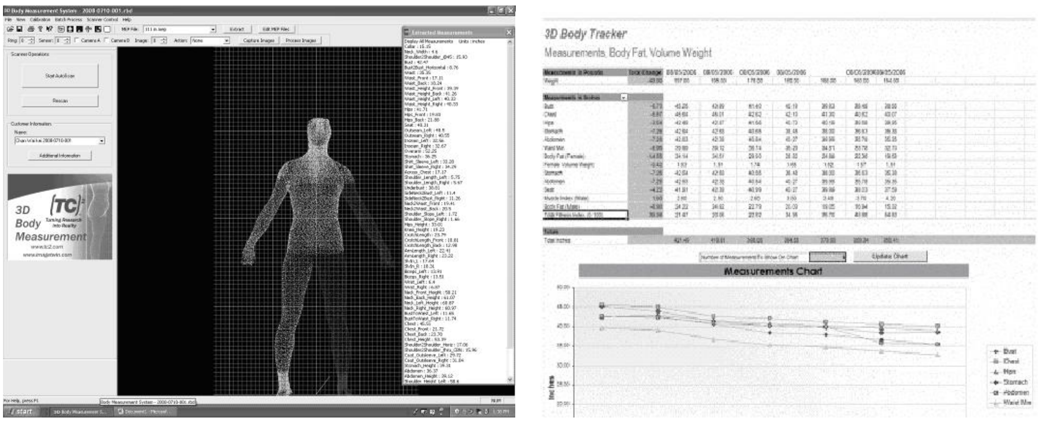


Figure 2-19 The result of 3D body scanner system

The results of body measurement acquired from these anthropometric methods are described as points, lengths, surfaces, shapes or volumes. Each method captures a range of data and a summary is found in Table 2-1. Linear methods describe the distance between two points. Multiple Probe methods describe the body contours and the relationship between lines. Body Form methods relate the body information as surface, shape and volume (Elizabeth et al., 2006).

Table 2-1 Comparison of body measurement methods

	Point	Length	Surface	Shape	Volume
Linear Methods					
Tape Measurement		*			
Direct Measurement		*			
Proportional Measurement		*			
Anthropometer		*			
Calipers		*			
Multiple Probe Mrthods					
Complex Anthropometer	*	*		*	
Somatography	*	*		*	
Minott Method		*		*	
Planar Method	*	*	*		
CIAM	*	*		*	
Photography	*	*		*	
Body Form Methods					
Draping			*	*	
Casting			*	*	*
Body Scan	*	*	*	*	*

Based on body measurements, sizing systems are created for ready-to-wear clothing in many districts (Ashdown, 1998), such as China National Standard for

Size Designation of Clothes (GB1335-2008), US standard clothing sizes and UK standard clothing sizes. The differences among these sizing systems are the definition of landmarks and the classification of body shape. For example, in China National Standard for Size Designation of Clothes (GB1335-2008), the shapes of the body (male and female) are divided into four types (Y, A, B, and C), as shown in Table 2-2. However, in US standard clothing sizes, female are initially divided into five types: Misses, Miss Petite, Junior, Young Junior and women. The sizes in these types depend on the overall height and the relative levels of bust and waistlines, as shown in Table 2-3. In the UK, a derivative of the US standard clothing sizes was developed and applied in the 1980s. UK size is roughly 4 sizes different from the US size. Thus, UK size 4 is equivalent to US Size zero. Because of the differences in clothing sizes, it causes many inconveniences to customers in clothing selection.

Table 2-2 An example of China National Standard for Size Designation of Clothes

Unit: cm

Y														
Dimension	Data													
Height	145		150		155		160		165		170		175	
Bust	72		76		80		84		88		92		96	
Waist	50	52	54	56	58	60	62	64	66	68	70	72	74	76
Hip	77.4	79.2	81	82.8	84.6	86.4	88.2	90	91.8	93.6	95.4	97.2	99	100.8

Table 2-3 Examples of US standard clothing sizes

Unit: inches

Women's size							
5'5"-5'6" tall, average bust, average back							
Dimension/Size	38	40	42	44	46	48	50
Bust	42	44	46	48	50	52	54
Waist	35	37	39	41 1/2	44	461/2	49
Hip	44	46	48	50	52	54	56
Back-waist length	14 1/4	14 3/8	17 1/2	17 5/8	17 3/4	17 7/8	18
Young Junior sizes							
5'1"-5'3" tall, higher bust, shorter back							
Dimension/Size	5/6	7/8	9/10	11/12	13/14	15/16	
Bust	28	29	30 1/2	32	33 1/2	35	
Waist	22	23	24	25	26	27	
Hip	31	32	33 1/2	35	36 1/2	38	
Back-waist length	13 1/2	14	14 1/2	15	15 3/8	15 3/4	

Sizing systems are designed to optimise the fit, using as many variables (body dimensions) as needed to account for variability in the population, and sizing systems are often used for mass-produced products. If clothing is designed for individual person, the data from the sizing systems can only be used as reference and body measurement taking is needed. In addition, the data in all size systems are measurements of body in static state. In everyday life, people have different types of body movement. The movement functions of human body determine the ease design in clothing fit design.

2.4.3 Body Movement and Ease Design

For functional running wear design, it is insufficient to understand only the body shape and measurement in static state. There are significant changes in the body shape and skin surface in body movements, which in turn affects the clothing shape and function, as shown in Figure 2-20. Therefore, understanding the features of body movement is necessary for clothing shape and ease design.

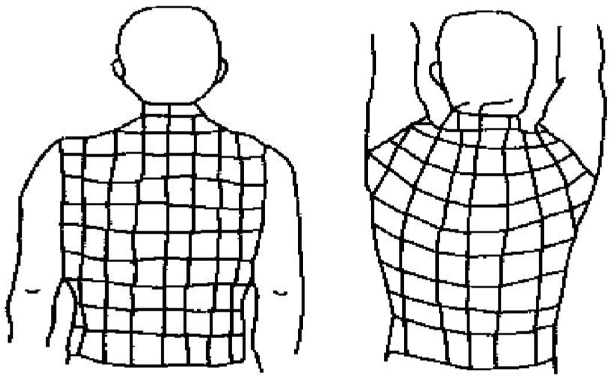


Figure 2-20 The influence of body movement on clothing shape (Liu, 2007)

Running can be decomposed into a number of body postures, in which head, shoulder, arms, torso, hips and legs should maintain correct positions. At the same time, skin surfaces vary in different postures. The head and shoulders should be stable in running state, thus skin surface have little changes in these areas. Although torso and hips should be kept straight (90º to ground) in running state, skin surfaces around the chest change due to breathing. Also, skin surfaces around the hip area change, because of the leg movements. In addition to the head, shoulder, torso and hips, bending and swinging of arms in running cause significant changes in the skin surfaces of the arm, especially around the elbow and shoulder joints. Meanwhile, a slight knee lift, a quick leg turnover and a short stride of runner result in changes of corresponding skin surfaces, especially around the hip and knee joints. Body measurements also change due to the changes of skin surface, and this requires additional ease to be added to the corresponding places of the clothing (Li et al., 2010).

In terms of functionality, three types of ease allowances are defined: (a) comfort ease, which is determined by basic movements, such as breathing and sitting; (b) movement ease, which is determined by extreme postures, such as elbow bending; (c) styling ease, which means that the garment itself needs the extra spacing to conform the required silhouette (Roger et al., 2007).

In fact, deciding the ease standard for different kinds of clothing is very difficult, due to different preferences of individual customers in relation to different age, gender, custom, birthplace, occupation and fashion sense. Moreover, the fashion trend also affects the ease design in clothing. One important rule must follow in ease design is that clothing should not reduce the wearer's mobility or adversely affect the level of protection (Huck & Younghee, 1997). For example, in sportswear design, short sleeve crown are often used in sleeve design to provide enough space for shoulder joint movement. Ease design in clothing must be linked with the requirements of clothing function, and varied amounts of ease should be added to different parts of the clothing.

2.4.4 Evaluation of Clothing Fit

Fit evaluation is a complicated process in which the relationship of the garment to the body is analysed. Researchers have developed different methods for judging apparel fit and these methods are classified as subjective and objective assessments (McConville, 1986). Subjective assessment can either be based on the wearer's response to the look and feel of the garment, or the responses of expert judges to a visual analysis of the garment on the wearer. Wearers assess the garment fit by examining the wearing effect in a mirror. Alternatively, experts make judgements based on visual examination, such as seam placement, the location and orientation of wrinkle. The disadvantages of subjective assessment are the lack of consistency and the large variation between subjects' responses.

Objective assessment is another judging method, which is based on the collection and analysis of the human body and clothing data. On the one hand, the data of clothing and the human body, such as clothing and body sizes, are collected and used to analyse clothing fit. On the other hand, the physiological data of the human body, such as palms, respiration and blood pressure, are also collected for evaluating the clothing fit. Besides, the development of 3D body scanning provides a new way to quantitatively analyse the clothing fit and improve the precision of evaluation.

Clothing fit can be evaluated in all stages of the garment development and assembly process. A typical process may include all, or some, of the following procedures to create appropriate clothing fit for a style: product development, pre-production, production and distribution. In the process of clothing design, three basic steps are involved. The first step is to measure the clothing (pattern) or fit model (wearer). The second step is to evaluate the clothing fit through trial fitting on model or by the customer. Lastly, the clothing (pattern) is modified based on these evaluations (Ashdown & Connell, 2006).

2.4.5 Summary

This section reviewed the related studies of clothing fit, anthropometric method, body movement function, ease design and fit evaluation. Clothing fit can be classified as tight-fit, just-fit and loose-fit. Among which, tight-fit is the most common fit design in sportswear. In clothing fit design, ease allowances must be determined correctly according to the analysis of corresponding body movements and anthropometric data. Linear method, multiple probe and body form methods are the three major types of method used to measure a body. With the development of computer technology, 3D body scanning provides a new tool to measure the body. To evaluate clothing fit, subjective and objective assessments are the major approaches. The following research gaps are identified.

a) The existing anthropometric methods are only suitable for measuring body in static state. Little research about measuring the body in dynamic body movements has been carried out.

b) Scientific method for clothing fit evaluation is absent.

2.5 Clothing Pattern Construction Methods

Once the body measurements and clothing fit (ease design) are decided, the next step of clothing design is patternmaking. It determines the ultimate shape of the clothing, the freedom of body movement and the clothing thermal functional performance. Traditional pattern construction consists of two approaches: flat pattern making where patterns are designed two-dimensionally, and 3D draping where a piece of fabric is manipulated to form a garment on mannequin (Kim & Park, 2007). Each method has its strengths and weaknesses, and the method which is ultimately selected depends predominantly upon the circumstance and cost. In addition to these two methods, new pattern construction methods are being explored recently, and the objectives are to make correct patterns and fulfil the ergonomic functional requirements of the clothing product.

2.5.1 Two-dimensional Pattern Making Methods - Drafting and Block Pattern

In the apparel industry, two-dimensional pattern making is the key approach to create patterns, especially for mass produced garments. The clothing pattern obtained from this approach is a diagrammatic representation of the fabric panels, which should be sewn together to form a garment. Within the two-dimensional pattern making approaches, there are two types of method: direct drafting and block pattern methods (Aldrich, 1994).

The direct drafting method may be defined as a system of drawing patterns on paper with mechanical precision, based on body measurements and ease allowance, as shown in Figure 2-21. In this system, exact body measurements are taken to ensure an accurate pattern and the application of statistical mathematics can simplify the work of pattern drafting (Kidwell, 1979, Gray, 2002). When drafting a pattern, some pattern cutters use a single measurement (such as girth or length measurement) to determine other measurements and the pattern shape by proportion. Other pattern cutters develop the pattern based on the application of many measurements from the body or size chart.

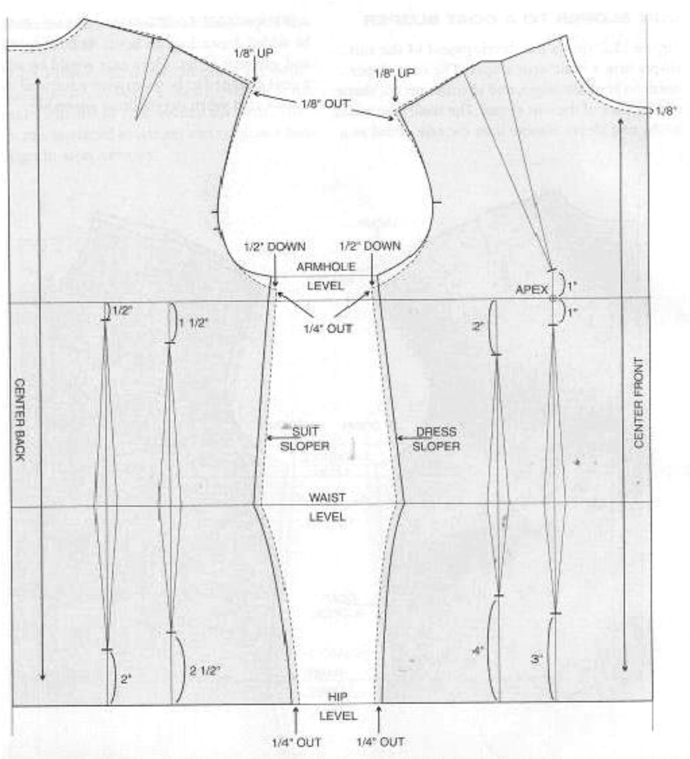


Figure 2-21 The drafting method of pattern making (Rosen, 2004)

In the fashion industry, some patterns developed based on a few standard measurements are often used as templates to create various styles (Rajitha & Geeth, 2005, Cloake, 1998). These patterns are called block or sloper patterns. Block patterns can be obtained from draping and optimised by drafting method. A typical set of basic blocks include front bodice, back bodice, front skirt, back skirt and sleeve for lady's wear, as shown in Figure 2-22. In the industry, each company has its own set of blocks or slopers to coordinate with its line and to conform to her target customers. Each firm has her own size charts and fit models.

When designing from block patterns, the first step is to select one basic pattern and copy it on paper. Next, ease allowance and style line are designed by modifying the measurements and shape of the block, for example, modifying the width or depth of the neckline. Furthermore, important markings are added to the pattern which includes notches, seam allowance and so on. Such markings are necessary to sew the pattern pieces together and fit precisely with each other. Then, a new pattern is created.

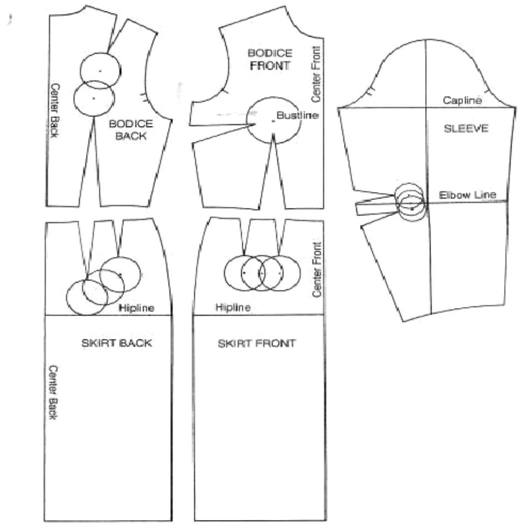


Figure 2-22 Basic block patterns (Noran, 2002)

No matter it is by direct drafting or block pattern method, the two-dimensional pattern making approach has two advantages. The first advantage is that the amount of time and skill required to cut a well fitted garment are comparatively less than the three-dimensional method (Kidwell, 1979). The second advantage is that it can be used to improve the sizing of the ready-to-wear and possibly increase the availability of custom made garments.

However, the two-dimensional approach has its drawbacks. Firstly, this approach cannot provide the designer with a clear picture of fabric drape and overall design effect of the finished garment before the garment pieces are cut and sewn. Secondly, it is not suitable for materials with special properties, such as elastic fabrics and the patterns are only constructed for a common textile, such as woven, no-woven, and knitted fabrics.

2.5.2 Three-dimensional Pattern Making Method – Draping

In the development history of clothing design and production, the original clothing is constructed by draping, which is the oldest method of patternmaking (Noran, 2002, Burns et al., 1997). In the process of draping, a piece of fabric is pinned or sewn by pattern cutters around a mannequin. Furthermore, structure line, ease and seam allowance are correctly designed. After the draping work is finished, the fabric are taken off from the mannequin and modified to make the final pattern. Finally, a three-dimensional garment is created. Figure 2-23 is an example of pattern design by draping.

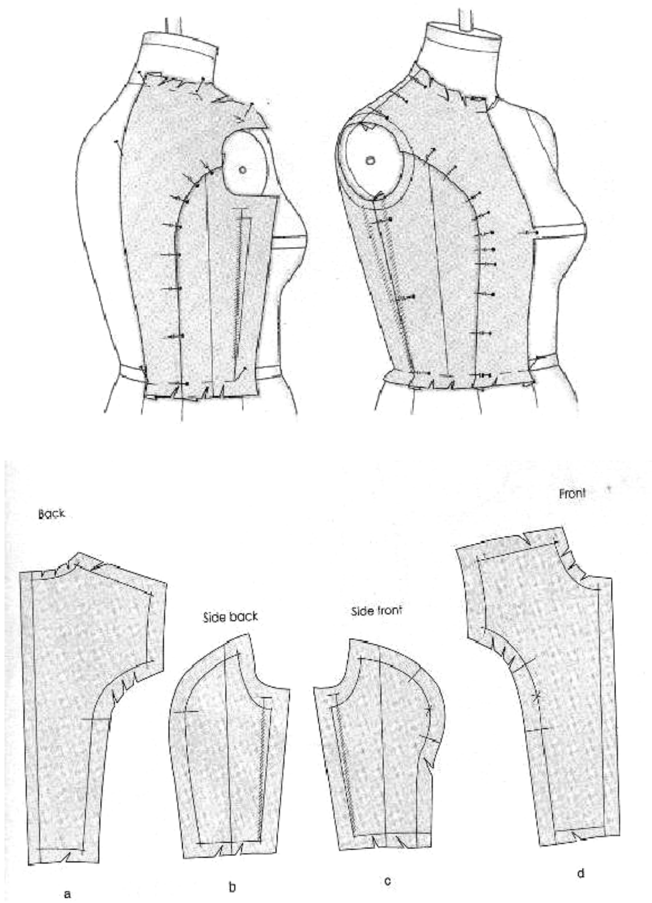


Figure 2-23 Pattern design by draping method (Armstrong, 2000)

As shown in Figure 2-23, fabric, mannequin (or human model) and some tools, such as pin and marker pen, are essential tools for draping. The fabric used in draping is usually inexpensive but dimensionally stable material, such as calico or muslin. Furthermore, the selection of mannequins and human model are very important, which should have consistent measurements representing the target customers and can perform different body postures in clothing functional design.

Comparing with the two-dimensional patternmaking methods, three-dimensional draping method has three advantages: garment made by this approach is guaranteed to fit well and the changes of different body postures have been taken into account. It provides good understanding on the properties of material in garment (Liu, 2007).

Because fabrics are wrapped around a mannequin to create garment, it is convenient for designers to obtain the fit silhouette of the human body and correlate the body measurements. By designing dart and structure line, a well fitted garment can be generated and right sizes are designed during patternmaking. Therefore, the three-dimensional draping method provides an accurate method to produce an individually fitted pattern and widely applied in the haute couture, such as wedding and evening gown.

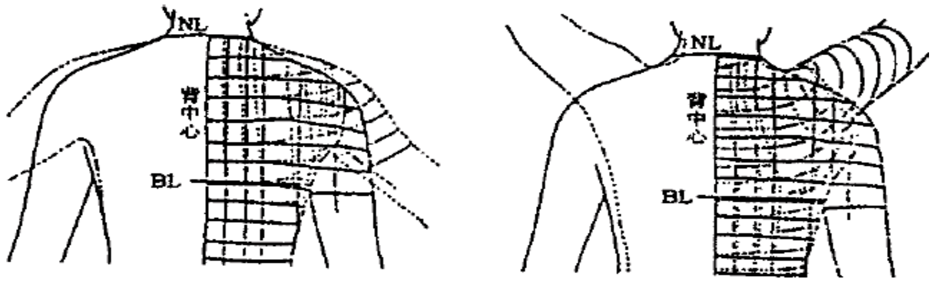
On the other hand, the changes of different body postures are taken into account in the three-dimensional draping method. In the pattern making process, the designer can continually modify the pattern shape or structural lines by examining the wearing effect of different body postures. For example, the length of the armhole curve can be increased or decreased to ensure wearing comfort and sufficient ease for body movement.

The three-dimensional draping method is not only an excellent fit instructor, but also a quick way to understand the fabrics (Bray & Haggar, 1986). Fabrics have different behaviours, which influence the wearing effect of the clothing when it is draped onto the mannequin or the human model. By understanding how the fabric behaves, designers manipulate the fabric to achieve certain effects of line and fit, for example, the drape of the material is emphasized in the hem design of evening gown. All in all, the three-dimensional draping method is the best way for understanding of the material properties and obtaining the desired design.

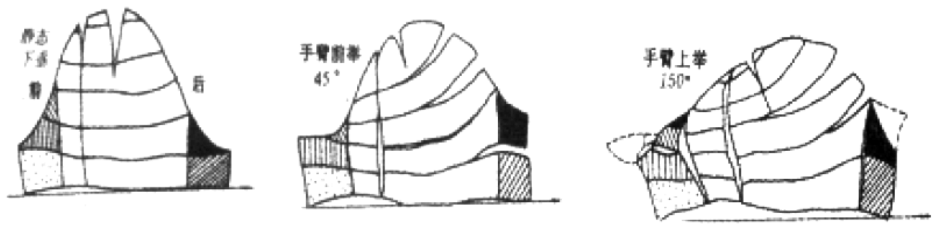
However, the three-dimensional draping method has a few limitations. The most obvious drawback is that the designer must have good experience and ability to predict and evaluate the wearing effect of the garment when draping. This is acquired from practical experience and the course of trial-and-error (Bray & Haggar, 1986). Other limitations include the time-consuming nature of the exercise and expensive in materials used. Moreover, although draping method can create individually fitted patterns, the application of draping in mass production is still limited because of lengthy draping process and the shortage of knowledge on body sizes and the relevant mannequins.

2.5.3 New Pattern Construction Methods for Running Wear

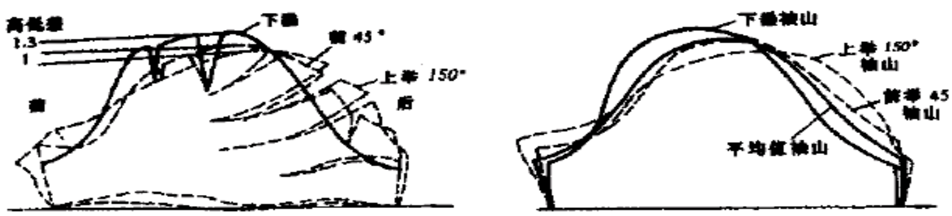
The traditional two-dimensional and three-dimensional patternmaking methods have limited ability to meet body mechanical-physiological requirements in high-performance running wear pattern design. It is firstly because all body measurements used in these two methods are obtained when body is in static state. The corresponding patterns can be regarded as static patterns, which are not optimised for body movements. Secondly, the thermal exchange between body and clothing is not taken into consideration in the pattern construction, which causes poor performance of the thermal-physiological function. In recent years, a number of new pattern construction methods have been proposed.



a)



b)



c)

Figure 2-24 New pattern construction method of sleeve: a) Movements of shoulder and arms; b) skin changing characteristics in different movements; and c) constructed sleeve pattern (Zhou, 2004)

Among the newly proposed methods, some focused on how to design special clothing components by the analysis of body structure and body movement. Wang & Wang (2005) proposed a new method for collar design based on the analysis of neck structure and moving feature. Zhou (2004) proposed a new method to design dynamic sleeve pattern by analysing the structure of torso, arms and the movements, as shown in Figure 2-24.

Yoshihara (1987) studied the movements of body muscles and proposed two pattern development methods. He conducted a systematic study on the changing characteristics of muscle in different body movements. The location of the muscles and the direction of muscle movements (direction of muscular stretching or contraction, or tension) in motion state were analysed and quantified. By analysing the data, changing characteristics of the body shape can be understood, and the portion of clothing being stretched in the body movement can also be determined. In order to allow the apparel to stretch or contract in accordance with the movement of the body, two methods were proposed. In the first method, a stretchable material such as a power net material or a satin net material was used in the corresponding stretching positions of the apparel. In the second method, materials with different stretchabilities may be combined to make a garment.

Kato (2001) invented a pattern construction method for clothing that would not obstruct body movements. In his study, characteristics of the human body in motion were firstly observed. The changes of skin surface in different parts of the body were quantified, see Figure 2-25. Based on the quantified changes, ease allowances were designed and added to the corresponding parts of the static pattern, as shown Figure 2-26.

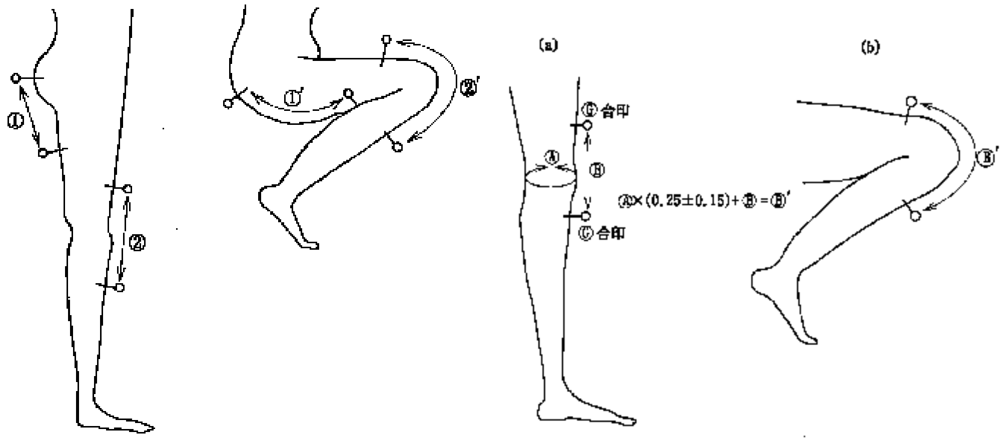


Figure 2-25 Body movement and skin surface changes (Kato, 2001)

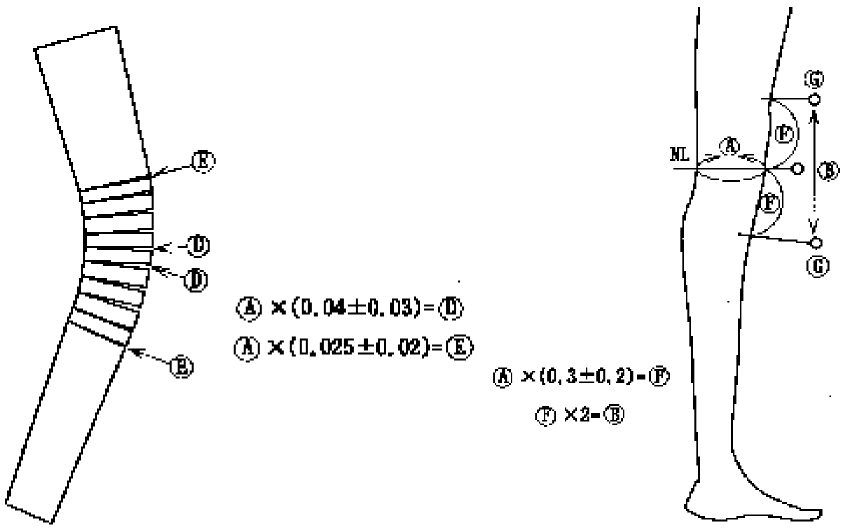


Figure 2-26 Ease design and pattern construction (Kato, 2001)

Nakazawa (2000) proposed the only systematic pattern construction method for high performance sportswear based on body mechanical characteristics in motion state. This method is called 4D pattern construction, which means that pattern is constructed based on body geometric feature in static and motion states. In his work, body structure, body proportion and skin characteristics in static state were first investigated. The relationship between body shape and static patterns were then analysed. The body movements, muscle movements and skin surface characteristics in different body postures were studied, forming the foundation to design dynamic pattern. Based on the analysis results, the pattern construction for clothing components including neck, skirt, sleeve and pant were discussed, refer to Figure 2-27. Nakazawa applied this method to design clothing patterns for sportswear, such as running pant, as shown in Figure 2-28. It has been proven that the 4D pattern making method can provide good mobility for human body in different sport exercises.

However, in Nakazawa's 4D pattern construction method, only the mechanical property of the human body in running state is analysed, but not the physiological property of human body in running state. Clothing made by this method can provide good mobility, but effective thermal function is not guaranteed.

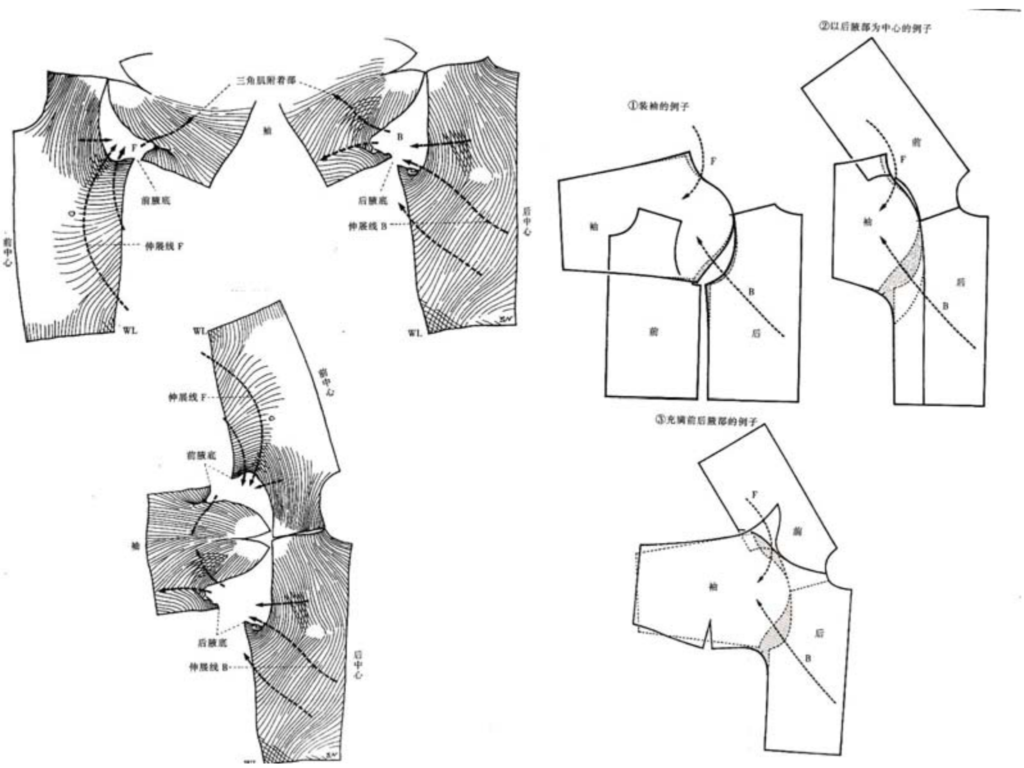


Figure 2-27　Skin surface changes and pattern re-construction (Nakazawa, 2000)

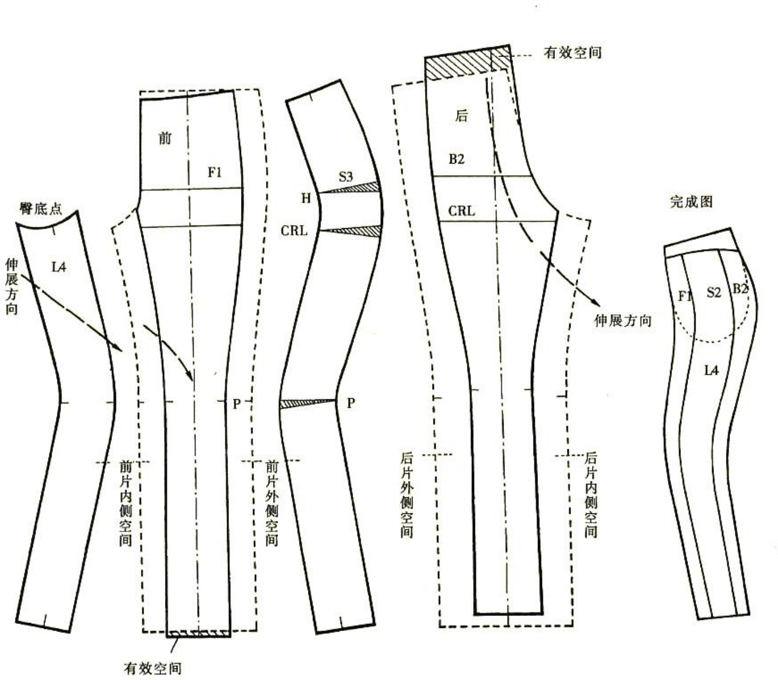


Figure 2-28 Dynamic sports pant pattern construction (Nakazawa, 2000)

2.5.4 Summary

Drafting and block pattern are 2D pattern construction methods and draping is a 3D pattern construction method. In this section, some early works on constructing clothing pattern with improved mobility have been reviewed.

Research gaps are identified. Firstly, patterns generated from the traditional methods are static patterns, because body measurements are static measurements and patternmaking system is designed for body shape in static state. Secondly, patterns constructed from some newly developed methods only took into consideration the body mechanical characteristics in motion state. Therefore, it is necessary to develop one scientific pattern construction method for tight-fit running wear according to the body mechanical, heat and moisture characteristics in running state.

2.6 Summary and Problem Statements

By reviewing the related works, it can be concluded that the research of pattern engineering for functional design of tight-fit running wear requires interdisciplinary knowledge.

2.6.1 Systematic Overview of Running Wear Functional Design

As shown in Figure 2-29, body structure, heat and moisture characteristics in running state demand the running wear to have good ergonomic and thermal functional designs. There are a number of factors to consider in running wear functional design, such as material, style and fit. Clothing fit is one of the most important factors. No matter how well a fabric is engineered to have optimum heat, water or air transmission, the garment made of which cannot be regarded as comfortable if it does not fit properly. A badly fitted garment would restrict cardio-vascular flow, cause skin irritation, and create unpleasant thermal or moisture conditions that manifest to the wearer in the form of discomfort. Moreover, ease and pattern design influences the clothing fit. For instance, ease allowance design determines whether the garment is loose-fit, just-fit, and tight-fit. Patterns influence the shape and structure of the garment. Therefore, it is important to study the fit, ease and pattern design for functional running wear design.

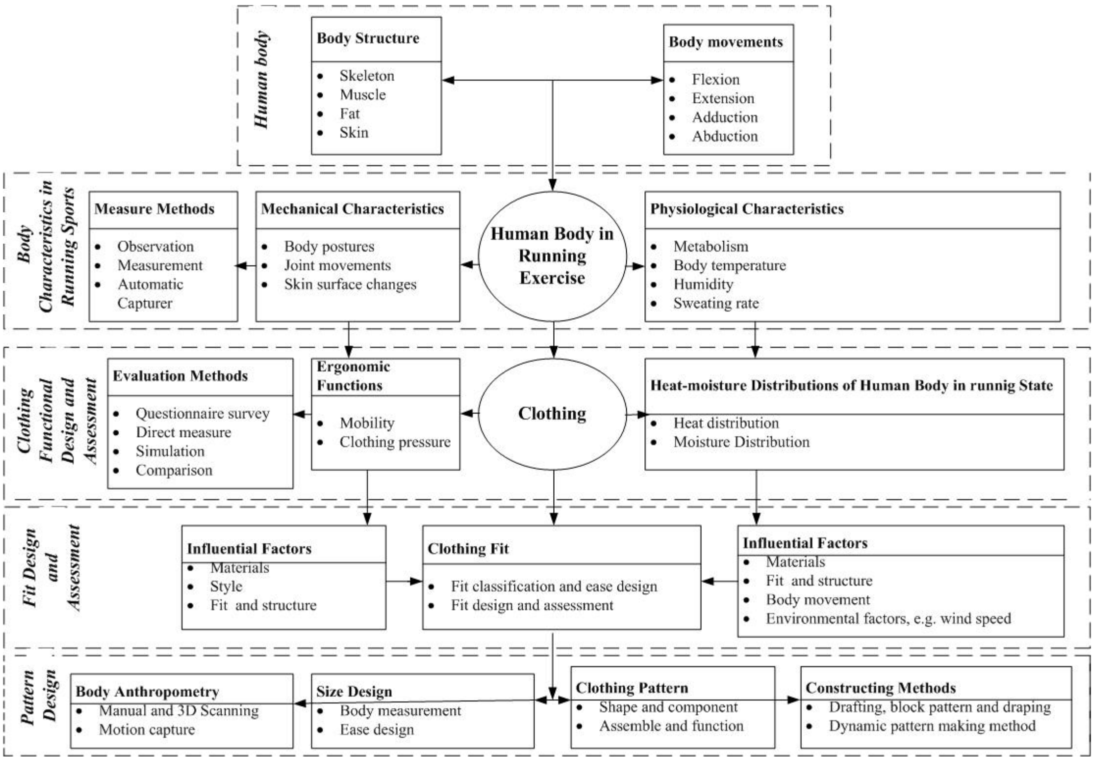


Figure 2-29 Outline of influential factors in running wear pattern design

Based on the literature review above, it is found that

a. Human body has elaborate body structure and great subtlety in movement.

b. Human body has specific mechanical characteristics in running exercise: Human body performs a series of body postures, which can be decomposed into different joint movements. Head, shoulder, arms, torso, hips and legs should keep correct positions in running state. The skin surfaces of the body have significant changes. Four methods can be used to measure skin surface changes: observation of skin stretch or skin strain; measure the change of a grid pattern on an elastic garment in static and motion states; opening and wrinkle observation; and computer scanning.

c. Human body has an effective thermoregulation system. In running exercise, heat is transmitted with conduction, convection, radiation and evaporation through perspiration and sweating. Using different equipment such as thermo detectors and sensors, temperature and humidity of human body can be measured. The distribution of the skin surface temperature and water content vary in different parts of the body.

d. Mechanical characteristics of human body in running state determine the ergonomic wearing comfort. Subjective and objective evaluation methods can be used to evaluate clothing ergonomic wearing comfort.

e. Clothing fit can be classified as tight-fit, just-fit and loose-fit. Ease design influence clothing fit, and ease is added into clothing pattern. Subjective and objective assessments are the major methods to evaluate clothing fit.

f. Body anthropometry is the foundation of ease design. Manual and 3D body scanning are mainly used to collect body measurements in static state.

g. Drafting, block pattern and draping are the traditional pattern construction methods, yet not suitable for high-performance sportswear pattern design. The new pattern construction methods only consider body mechanical characteristics partially.

2.6.2 Problem Statements

The review of the related literature provides a good foundation for the current study. Some research problems are identified:

a. Although a lot of methods have been proposed and used in pattern construction, all were developed either based on body geometric features in static state or body mechanical characteristics in motion state. For high performance running wear, it is still absent of a systematic pattern construction method that takes into consideration of (1) body mechanical characteristics in running state, (2) clothing material properties and (3) clothing fit design.

b. Body anthropometry in motion state is very important for clothing fit and running wear pattern design. However, all current measurement methods are designed for human body in static state. There is no body measurement method for people in motion state.

c. Both subjective and objective assessments have disadvantages in clothing fit evaluation. Among the existing objective evaluation methods, there is none integrating 3D body scanning and reverse engineering technique.

d. The influences of body skin surface changes and thermal-moisture distribution during running exercise on pattern structure design has not been analysed

e. The theory of traditional pattern construction is generated according to body characteristics and measurements in static state. There is no theory on dynamic pattern design.

All gaps listed above are important areas to tackle in the development of high-performance sportswear.

CHAPTER 3 CONSTRUCTION OF STATIC BLOCK PATTERNS WITH JUST-FIT DESIGN

3.1 Introduction

The block pattern method is one of the most important methods for clothing pattern construction and has been widely adopted in the apparel industry. Block patterns are two-dimensional basic patterns, which produces the body contours and fit to the body figure (Poole, 1936). According to the requirements of clothing function and style, pattern makers add sufficient tolerance (ease allowance) and design different structural lines on the basic blocks (Cloake, 1998). Later, seam allowances and markings including notches are drawn on block patterns, so that the pattern pieces can fit precisely and be sewn together. Finally, clothing patterns for standard or individual measurements are produced (Rajitha & Geetha, 2005, Glock & Kunz, 1995).

The wide industrial acceptance of block pattern has led to many years of extensive research in the area, and three approaches have been developed to construct block patterns. One of them is the Haute Couture approach (Bray and Hagger, 1986). In which, papers or fabrics are pinned on the dummy that has the same body shape and measurements as the target consumers. And then, darts, or other forms of suppression, are used to fit the body shape based on the relationship between the bust, the waist and the hips. When all the shaping works are finished, the papers or fabrics are taken off from the dummy, and patterns are flattened to give blocks. The second method involves the application of plaster, which is regarded as the most accurate method of obtaining anatomical measurements (Liu, 2007). In this method, the subject is required to perform specific postures, and then plaster or gypsum is applied on the body skin surface. The plaster remains on the skin surface until it is dried, then it is cut, peeled and flattened to form block patterns. The third approach is by direct drafting, where formulae are derived by experiences, and trial-and-errors are used to calculate the pattern size (Kunick, 1984, 三吉满智子, 2006). In this method, wearing ease allowances are added in these formulae.

In all the three block construction methods, body measurements and geometric features are the foundations for the development of block patterns. Body measurements determine the final size of block patterns and geometric features establish the structure lines. It is important to note that the block patterns obtained from these three methods are static patterns, because body measurements and geometric features in static state are used.

Although these methods can be used to make common block patterns, they are not the right candidates for the construction of static block pattern with just-fit design. Static block patterns with just-fit design are special patterns without ease allowances added, which have excellent fit performance. They are the starting points for developing dynamic patterns of sportswear. In the direct drafting method, wearing ease allowances are incorporated in the formulae, therefore the method is not suitable for the development of just-fit block pattern. In Haute Couture and plaster methods, complicated experimenters are involved, in which extensive skills are required to carry out the experiments. The experiment itself is time consuming and expensive. Therefore, a simple, efficient and accurate method should be developed to generate static block patterns with just-fit design.

In this chapter, body measurements are acquired by 3D body scanning. Then, the relationship between body shape, measurements and pattern structures are analysed. Based on the measurements and analysis results, static block patterns are constructed.

3.2 Refection Method and Its Application in Clothing Pattern Making

Reflection method has been applied in psychology, computer, entertainment, mathematics, and cartography. Different definitions and applications are found in different fields. In cartography, reflection means there is one-to-one mapping relationship between product and the acquired image. With the use of landmarks, key points on an image can be determined. Measurements and lines (shape) can be made on the image (Blinn & Newell, 1976, Buckalew & Fussell, 1989).

The skin surface of the human body can be regarded as a kind of perfect, seamless clothing with high elasticity, called the body clothing (Renbourn, 1972). Static block pattern with just-fit design cover body just like skin surface in static (standing) state. Therefore, it is appealing to construct static block patterns with just-fit design by the reflection method.

3.3 Research Methodology

The construction method of static block pattern with just-fit design is developed by experiment, which includes three steps: 1) body measurements in static state; 2) analysing the relationship among anatomical points, lines, body measurements and pattern structures; and 3) constructing static block pattern with just-fit design by the reflection method.

3.3.1 Body Measurements in Static State

3.3.1.1 Subjects

In this research, male's static block patterns are studied. A total of 5 Chinese male subjects with ages 20-24 were recruited from The Hong Kong Polytechnic University as volunteers in this experiment. To avoid variations caused by different body size and build, all recruited subjects are in one size group with natural body shape, body height between 170-175 cm, and of BMI (Body Mass Index) value between 21-23. Before the experiment, all subjects were introduced about the objectives and the experiment procedures, and their consensuses were obtained.

3.3.1.2 Measurement taking

According to ISO 8559-1989 standard, 50 measurements were measured for each subject, including

a. 15 girth measurements: neck base girth, chest girth, armscye girth, waist girth, hip girth, upper arm girth, elbow girth, forearm girth, wrist girth, Max-thigh girth, Mid-thigh girth, knee girth, calf girth, mini leg girth and ankle girth.

b. 19 height measurements: front neck base height, side neck height, back neck height, long shoulder height, armscye height, across back height, across front height, chest height, Chest point height, waist height, hip height, crotch height, Max-thigh height, Mid-thigh height, knee height, calf height, minimum leg height, ankle height, and crown height.

c. 11 depth and length measurements: front neck depth, back neck depth, back waist length, front waist length, outside leg length, under arm length, Arm length, back neck to elbow, total crotch length, shoulder length and shoulder slope.

d. 5 width measurements: shoulder width, across back width, across front width, chest point to chest point width, neck width

3.3.1.3 Experiment instrument and environment

Figure 3-1 TC² 3D body scanning system

In the experiment, all body scanning were carried out in 3D body scanning lab of The Hong Kong Polytechnic University. 3D body scanning is a non-contact measuring method, which is a quicker and less invasive way to take static state body measurements (Kang and Kim, 2000). Figure 3-1 shows the 3D body scanning system (Style: TC² NX-16) used in this study, where Table 3-1 is the specification. The system scans the whole body in a few seconds and produces a true scale 3D body model. The scanning system consists of two parts: hardware and software. The hardware includes scanner, lighter, scanning box, computer, and output device such as printer. The software includes automatic body measurement software (V 3.0), which can extract over 400 measurements.

Table 3-1 The specification of TC^2 3D body scanning system

Items	Descriptions
Dimensions	4 feet × 5 feet
Power	15 amp
Technology	White-light, non-moving scan heads
Operation systems supported	Window XP, Vista

3.3.1.4 Body scanning procedure

In the experiment, each subject wore only white tight-fit under pant. Thirty-four anatomical points involved in the 50 body measurements were determined according to the definitions given in ISO 8559-1989, as shown later in Table 3-7 to Table 3-9. Black colour round stickers of diameter 0.5 cm were stuck onto the body skin and garment surfaces to indicate the anatomical points. Black colour sticker would not reflect light, thus all defined anatomical points will be shown as holes on the scanned surfaces. When anatomical points were marked, the subject was required to stand on the footprints indicated on the ground of the scanning room and look straight ahead with hands holding the handles (see Figures 3-2 and 3-3). In the scanning process, subject was required to keep a steady posture. When scanning was over, 3D point data were automatically generated and saved in three file formats: obj, rbd and wrl. Apart from 3D data, body skin surface images captured during the scanning process were recorded, which include images of front view, back view, and two side views.

Figure 3-2 Footprint on the ground of the scanning room

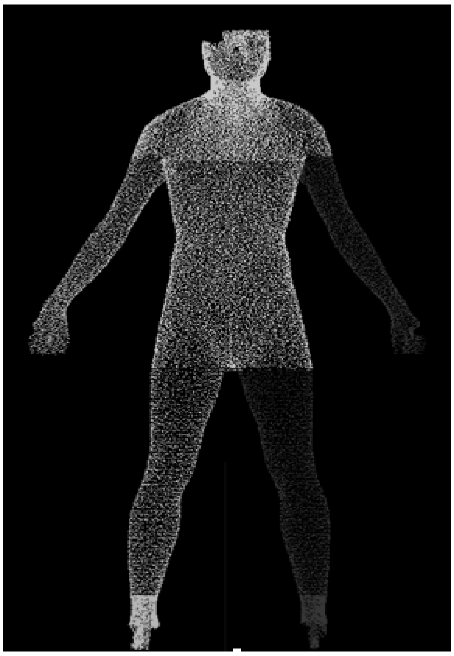


Figure 3-3 Standing posture of human body in scanning process

3.3.1.5 Extraction of body measurements

TC² 3D body scanning system uses the ISO 8559-1989 standard to extract body measurements from scanning. Body measurements were extracted automatically and can be exported as excel file.

3.3.2 Relationships among Anatomical Points, Structure Lines, Body Measurements and Static Block Patterns

The reflection method discussed in section 3.2 can be used to mirror and construct 2D images. By the reflection method, anatomical points, body structure lines and body measurements from 3D scan can construct 2D clothing patterns. Landmarks refer to the anatomical points of the human body. Body structure lines are routes passing two or more landmarks on the skin surface. Based on these landmarks and structure lines, corresponding body measurements can be acquired, which determine the sizes in clothing pattern.

2D block pattern consists of points and lines. These points and lines can be corresponded to those points and lines on the skin surface. For these reasons, analysing landmarks, feature lines on body surface and body measurements are essential steps to construct clothing patterns, especially in pattern making for static block patterns with just-fit design. In this study, landmarks can be determined in 3D body scanning as discussed in section 3.3.1.4, which define the lines to extract body measurements. According to these points, lines and body measurements of the human body, the location of feature points, the shape of style lines and the size of the pattern can be determined by the reflection method. The resulted pattern is called static block pattern with just-fit design, which is clothing pattern without the incorporation of garment ease, and from which functional clothing pattern are developed.

3.3.3 Construction of Static Block Patterns with Just-fit Design

In this study, drafting method is developed to construct pattern framework and structures: Anatomical points and body structure lines are applied to determine frameworks of static block patterns with just-fit design, which include shirt, sleeve and trouser block patterns. When the frameworks are determined, final pattern structure lines are drafted based on acquired body measurements.

3.4 Body Measurement Results

Tables 3-2 to 3-6 are the results of the 5 subjects' body measurements in static state. The selected 5 subjects are Chinese males. Table 3-2 shows that the 5 subjects have a mean stature of 173.2 cm, and the BMI mean value of 22.14 indicates that their body figures belong to the normal type (BMI range between 18-25) (Kagawa, et al., 2006). Tables 3-3, 3-4, 3-5 and 3-6 list the detailed body measurements and mean values of the 5 subjects. According to the China National Standard for Size Designation of Clothes-Men GB1335-1997, the 5 subjects belong to the same size group of 170/ 84/72A.

Table 3-2 Results of stature, weight and BMI of the five subjects

Items	Subject					Means	Std. Dev.
	1	2	3	4	5		
Stature (cm)	170.00	172.00	175.00	174.00	175.00	173.20	2.17
Weight (Kg)	65.00	65.00	65.00	69.00	68.00	66.40	1.95
BMI	22.49	21.97	21.22	22.79	22.20	22.14	0.60

Table 3-3 Results of girth measurement of the five subjects

Measurements (cm)	Subject					Means	St. Deviation
	1	2	3	4	5		
Neck Base Girth	40.17	39.32	40.01	40.35	39.78	39.93	0.40
Chest Girth	97.67	93.96	96.82	95.95	97.98	96.48	1.62
Armscye Girth	38.91	39.68	42.76	42.01	44.15	41.51	2.17
Waist Girth	77.65	79.96	78.63	81.68	78.47	79.18	1.54
Hip Girth	93.65	94.36	98.85	98.66	94.22	95.95	2.58
Upper Arm Girth	24.97	27.24	28.49	27.98	26.67	27.07	1.36
Elbow Girth	24.55	24.81	24.61	24.52	24.82	24.66	0.14
Forearm Girth	24.47	25.48	25.46	24.64	24.56	24.92	0.50
Wrist Girth	15.80	16.58	16.39	16.14	15.79	16.14	0.35
Max-Thigh Girth	55.87	52.87	57.67	56.58	52.60	55.12	2.27
Mid-Thigh Girth	43.98	46.74	45.13	49.66	45.37	46.18	2.18
Knee Girth	36.36	38.28	36.03	38.77	36.16	37.12	1.30
Calf Girth	36.72	39.03	35.34	38.12	36.28	37.09	1.47
Minimum Leg Girth	21.55	23.46	21.13	22.63	21.77	22.11	0.93
Ankle Girth	24.56	26.93	24.26	25.31	25.01	25.22	1.04

Table 3-4 Results of height measurement of the five subjects

Items (cm)	Subject					Means	St. Dev.
	1	2	3	4	5		
Front Neck Base Height	140.89	140.02	141.31	140.11	143.07	141.08	1.24
Side Neck Height	144.14	144.02	147.31	146.11	147.07	145.73	1.57
Back Neck Height	143.39	143.77	146.81	145.86	146.32	145.23	1.55
Long Shoulder Height	138.14	139.14	140.81	139.74	141.82	139.93	1.43
Armscye Height	128.93	129.22	130.99	129.92	130.87	129.99	0.93
Across Back Height	132.03	132.05	132.70	132.44	133.55	132.55	0.63
Across Front Height	134.63	134.22	135.49	134.82	135.77	134.98	0.64
Chest Height	128.39	129.02	130.31	129.86	130.82	129.68	0.98
Chest Point Height	122.89	123.52	126.56	125.86	126.82	125.13	1.81
Waist Height	96.89	97.02	102.56	98.36	102.32	99.43	2.81
Hip Height	82.89	83.52	87.56	84.36	86.32	84.93	1.96
Crotch Height	77.39	77.52	82.56	78.36	82.32	79.63	2.60
Max-Thigh Height	77.09	71.32	82.66	78.46	82.02	78.31	4.56
Mid-Thigh Height	63.89	60.27	61.31	60.86	60.33	61.33	1.49
Knee Height	45.39	46.02	48.06	47.36	46.33	46.63	1.07
Calf Height	31.39	32.52	33.06	32.86	33.83	32.73	0.89
Minimum Leg Height	11.63	12.63	12.00	12.50	12.75	12.30	0.47
Ankle Height Outside	7.13	8.25	7.25	8.00	7.63	7.65	0.48
Crown Height	10.57	10.71	10.98	10.83	12.63	11.14	0.84

Table 3-5 Results of depth and length measurement of the five subjects

Measurements (cm)	Subject					Means	St. Dev.
	1	2	3	4	5		
Front Neck Depth	6.25	6.00	5.75	6.00	6.75	6.15	0.38
Back Neck Depth	1.25	1.25	1.50	1.75	1.25	1.40	0.22
Back Waist Length	49.04	49.90	49.70	50.86	50.35	49.96	0.69
Front Waist Length	44.77	44.86	45.58	46.19	46.10	45.50	0.67
Outside Leg Length	101.56	102.41	103.61	103.05	102.60	102.65	0.76
Under Arm Length	45.10	45.02	46.29	45.02	44.07	45.10	0.79
Arm Length	53.74	55.08	56.27	55.12	53.69	54.78	1.08
Back Neck To Elbow	56.59	52.20	54.82	53.71	53.71	54.20	1.63
Total Crotch Length	58.17	61.66	72.65	64.17	68.83	65.10	5.73
Shoulder Length	12.81	12.61	13.32	12.93	12.16	12.77	0.43
Shoulder Slope	5.17	4.52	5.58	5.29	4.97	5.11	0.39

Table 3-6 Results of width measurement of the five subjects

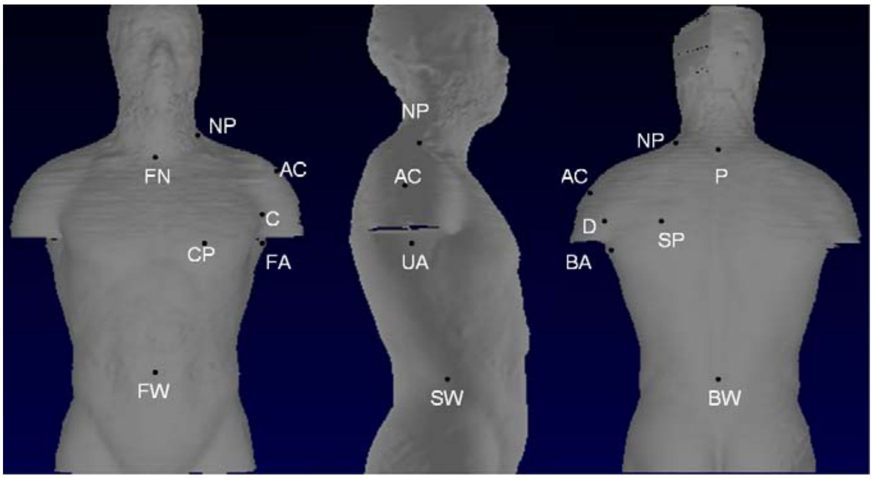
Measurements (cm)	Subject					Means	St. Dev.
	1	2	3	4	5		
Across shoulder Width	39.09	40.59	40.55	40.08	40.94	40.25	0.72
Across Back Width	38.04	39.45	39.38	39.22	39.43	39.11	0.60
Across Front Width	37.16	38.80	38.33	38.41	38.87	38.31	0.69
Chest Point to Chest Point Width	19.73	17.23	22.62	20.51	14.95	19.01	2.98
Neck Width	11.84	12.12	12.50	12.65	13.01	12.42	0.46

3.5 Analysis Results of the Relationships among Antinational Points, Lines and Static Block Patterns with Just-fit Design

3D body scanning system can construct skin surface models. In these 3D skin surface models, small holes were found, indicating the position of the black colour dot stickers on the body skin. With these holes, anatomical points on the 3D model can be determined. Upon defining the anatomical points, the relationships among points, lines, and body measurements can be analysed for pattern making.

3.5.1 Upper Torso

3.5.1.1 Anatomical points and body measurements



a) front view b) side view c) back view

Figure 3-4 Anatomical points of upper torso

Table 3-7 Definitions of upper torso anatomical points

Points	Definitions
FN	The medial superior borders of the left and right clavicles
NP	The neck shoulder point
P	The base of the 7^{th} cervical vertebra
AC	Point of the acromion extremity
C	Point of half-way between the front upper and lower scye levels
D	Point of half-way between the back upper and lower scye levels
FA	Front point of armscye depth
BA	Back Point of armscye depth
UA	Under Point of armscye
CP	Point of chest point
SP	Point of scapulae

FW	Point of front waist
BW	Point of back waist
SW	Point of SW waist

Figure 3-4 is the skin surface model of the upper torso constructed by the TC^2 3D body scanning system, and 14 anatomical points are marked on the skin surface. The definitions of 14 anatomical points are listed in Table 3-7. Based on these points and definitions, the following body measurements used in static shirt block pattern construction can be determined.

1) Points of left and right NP are reference points of neck width measurement;
2) Points FN and NP are reference points of front neck depth measurement;
3) Points FN and P are reference points of back neck depth measurement;
4) Points FN, NP (left and right) and P are reference points of neck base girth measurement;
5) Points of left right AC are reference points of shoulder width measurement;
6) Points NP and AC are reference points of shoulder length measurement;
7) Points AC, C, UA and D are reference points of armscye girth measurement;
8) Points of left and right C are reference points of across front width measurement;

9) Points of left and right D are reference points of across back width measurement;

10) Points FA, UA and BA are reference points of chest girth measurement;

11) Points FW, SW and BW are reference points of waist girth measurement;

12) Points NP and CP are reference points of front waist length measurement;

13) Points NP and SP are reference points of back waist length measurement;

14) Points of left and right CP are reference points of chest point to chest point width measurements.

15) All points are reference points of corresponding height measurements listed in section 3.3.1.2.

3.5.1.2 Anatomical points and body structure lines

As discussed in the introduction, anatomical points are reference points for determining the body structure lines. In Figure 3-5, the relationship between anatomical points and body structure lines are shown:

a. Front neck base line is determined by feature points of FN and NP;
b. Shoulder length line is determined by feature point of NP and AC;
c. Armscye line is determined by feature points of AC, C, FA, BA and D;
d. Across front width line is determined by feature points of left and right C;
e. Chest girth line is determined by feature points of FA and BA at left and right sides of the body;

f. Front waist length line is determined by feature points of NP and CP;

g. Waist girth line is determined by feature points of FW, SW and BW;

h. Front centre line is determined by feature points of FN and FW;

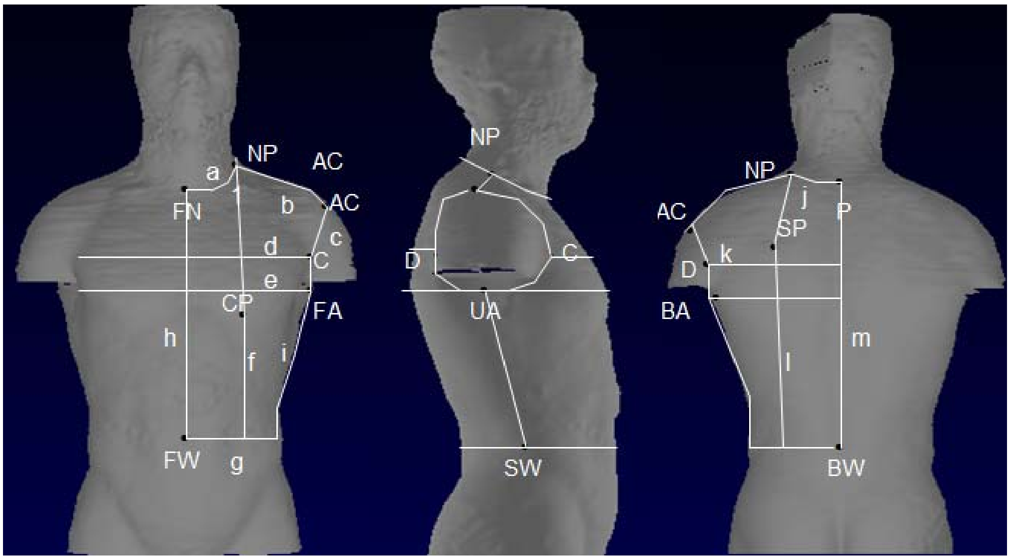
i. Side length line is determined by feature points of UA and SW;

j. Back neck base line is determined by feature points of NP and P;

k. Across back width line is determined by feature point D on the left and right sides of the body;

l. Back waist length line is determined by feature points of NP and SP;

m. Back centre line is determined by feature points of P and BW.



a) front view b) side view c) back view

Figure 3-5 Anatomical points and body structure lines

3.5.1.3 Anatomical points and body structure lines in static block pattern of shirt

Upon defining the anatomical points and body structure lines, the skin surface of the upper torso can itself be regarded as the static block pattern of shirt with just-fit design. It is shown in Figure 3-6 that anatomical points are key landmarks for constructing the pattern shape. Meanwhile, body structure lines are good references to define the framework of the static block pattern of shirt.

Anatomical points FN, NP, C, UA, SW and FW are the key landmarks of the front pattern. Points P, NP, AC, D, UA, SW and BW are the key landmarks of the back pattern. Lines d, e, f, k and l form the framework, and lines a, b, c, g, h, i, j and m are the final pattern structure lines.

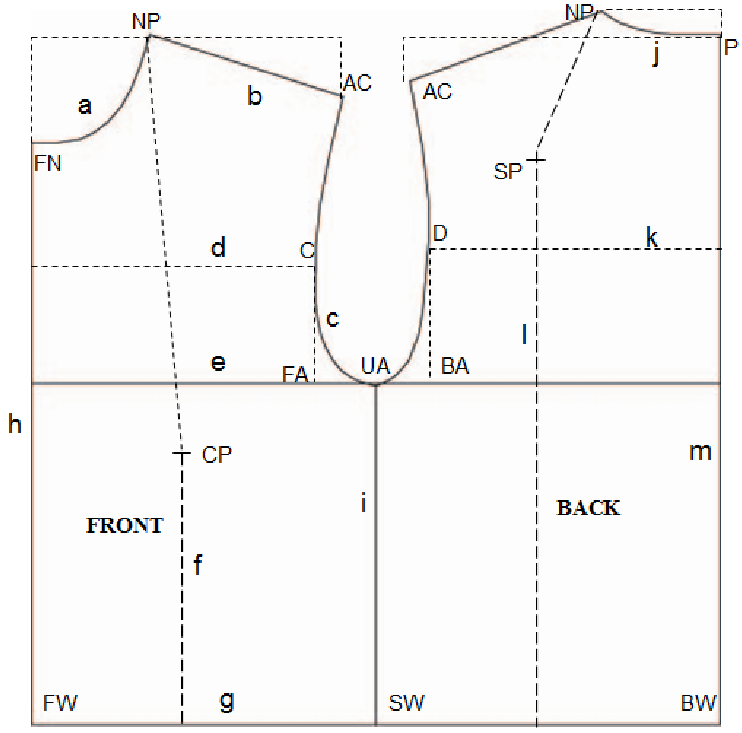
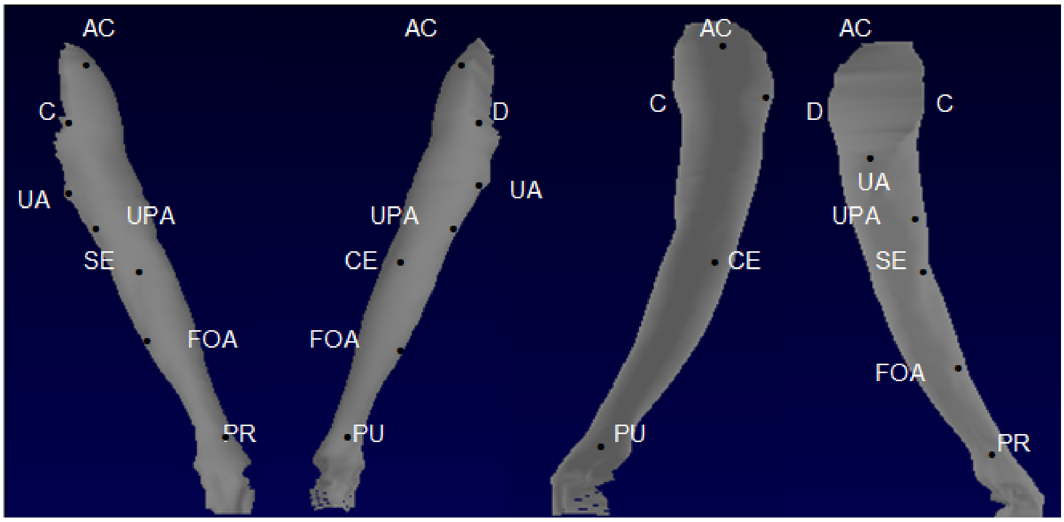


Figure 3-6 Anatomical points and body structure lines in static shirt block pattern

3.5.2 Arms

3.5.2.1 Anatomical points and body measurements



a) front view b) back view c) outer side view d) inner side view

Figure 3-7 Anatomical points of arms

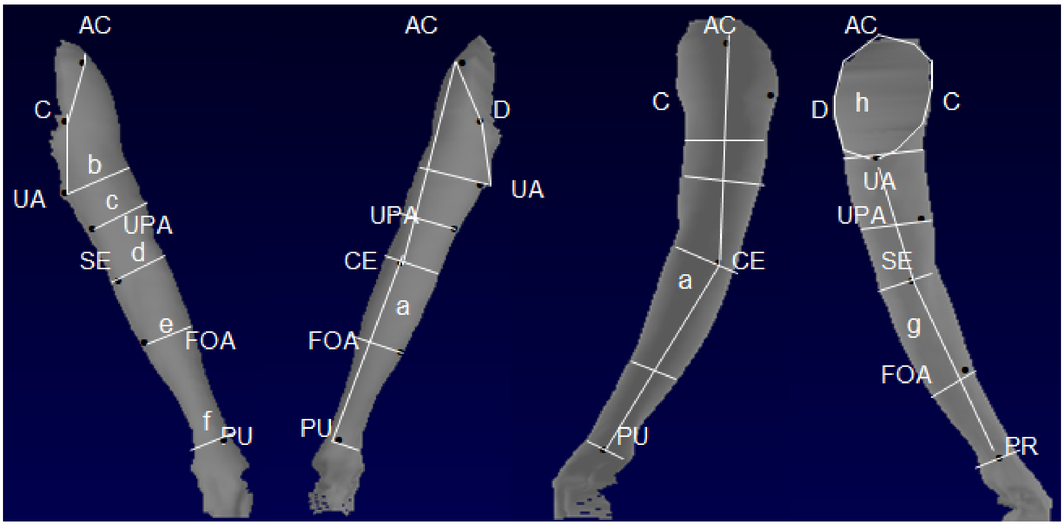
Figure 3-7 shows the front view, back view, outer side view and inner side view of the skin surface model of the arm. Ten anatomical points are shown as holes in the images and the definition of these anatomical points is listed in Table 3-8. Upon defining the anatomical points, body measurements used in static block pattern construction for sleeve can be determined:

1) Points AC, CE and PU are reference points of arm length measurement;
2) Points UA, SE and PR are reference points of underarm length;
3) Points AC, C, UA and D are reference points of sleeve crown length measurement (Armscye girth measurement);
4) Point UPA is the reference point of upper arm girth measurement;
5) Points CE and SE are reference points of elbow girth measurement;
6) Point FOA is the reference point of forearm girth measurement;
7) Points PR and PU are reference points of wrist girth measurement;
8) Points P, D and CE are reference points of back neck to elbow length measurement.

Table 3-8 Definitions of arm anatomical points

Points	Definitions
UPA	Point of maximum girth of the upper arm at lowest scye level
CE	Point of elbow centre
SE	Point of elbow side
FOA	Point of maximum girth of the forearm
PU	Outside point of carpal
PR	Inside point of carpal

3.5.2.2 Anatomical points and body structure lines



a) front view b) back view c) outer side view d) inner side view

Figure 3-8 Anatomical points and body structure lines

The anatomical points are reference points for determining the body structure lines. Figure 3-8 shows the relationship between anatomical points and body structure lines:

a. Centre line of static sleeve block pattern is determined by feature points AC, CE and PU;

b. Crown width line of static sleeve block pattern is determined by feature point UA;

c. Upper arm girth line of static sleeve block pattern is determined by feature point UPA;

d. Elbow girth line of static sleeve block pattern is determined by feature points SE and CE;

e. Forearm girth line of static sleeve block pattern is determined by feature point FOA;

f. Cuff line of static sleeve block pattern is determined by feature points PU and PR

g. Inner side line of static sleeve block pattern is determined by feature points UA and PU;

h. Crown line length of static sleeve block pattern is determined by feature points AC, C, D and UA.

3.5.2.3 Anatomical points and body structure lines in static block pattern of sleeve

Upon defining the anatomical points and body structure lines, static block pattern of the sleeve can be designed using the reflection method. In Figure 3-9, anatomical points and body structure lines are shown on the static block pattern of the sleeve with just-fit design. Similar to the case of the shirt block pattern, all anatomical points AC, S, D, UA, SE, PR and PU are key landmarks, and structure lines form the framework of static block pattern of the sleeve. Except line h, all the rest body structure lines are developed as framework lines of the sleeve pattern.

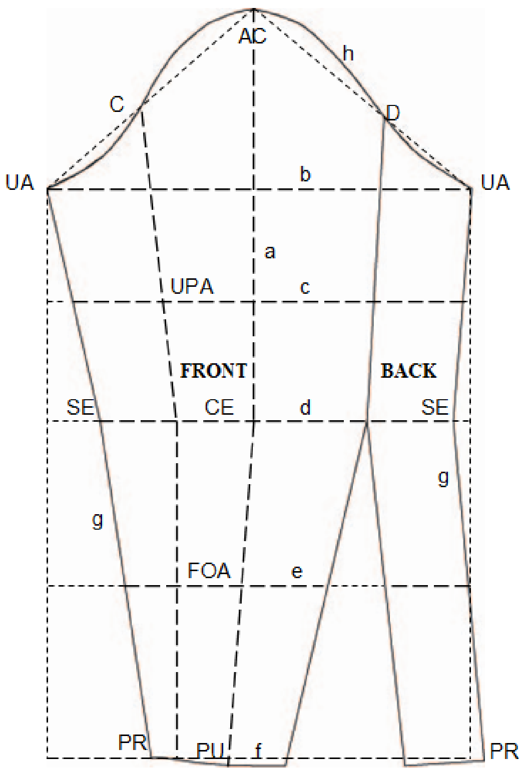


Figure 3-9 Anatomical points and body structure lines in static block pattern of sleeve

3.5.3 Lower Torso and Legs

3.5.3.1 Anatomical points and body measurements

Figure 3-10 shows the front view, back view, outer side view and inner side view of skin surface model of the lower torso and legs. Fifteen anatomical points are shown as holes on the skin surface model, where the definitions of the 15 anatomical points are listed in Table 3-9. Upon defining anatomical points, body measurements used in static block pattern construction for trousers can be determined:

1) Points FW, SW and BW are reference points of waist girth measurement;
2) Points FH, SH and BH are reference points of hip girth measurement;

3) Points FW, FH, CR and BW are reference points of total crotch length measurement;

4) Points CR and SF are reference points of maximum thigh girth measurement;

5) Points FT and BT are reference points of mid-thigh girth measurement;

6) Points FK, SK and BK are reference points of knee girth measurement;

7) Points FC and BC are reference points of calf girth measurement;

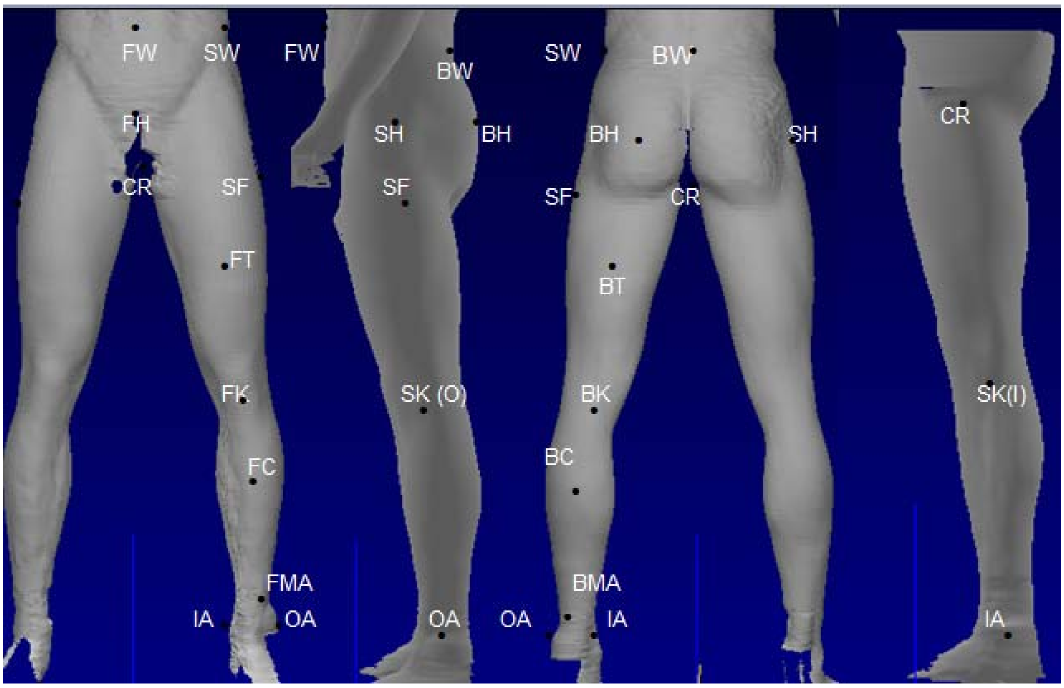
8) Points FMA and BMA are reference points of minimum leg girth measurement;

9) Points OA and IA are reference points of ankle girth measurement;

10) Points SW, SF and OA are reference points of outside leg length measurement;

11) Points CR, SK(I) and IA are reference points of inside leg length measurement;

12) All points are reference points of the corresponding height measurements listed in section 3.3.1.



a) front view　b) side view　c) back view　d) side view

Figure 3-10　Anatomical points of lower torso and legs

Table 3-9　Definitions of lower torso and leg anatomical points

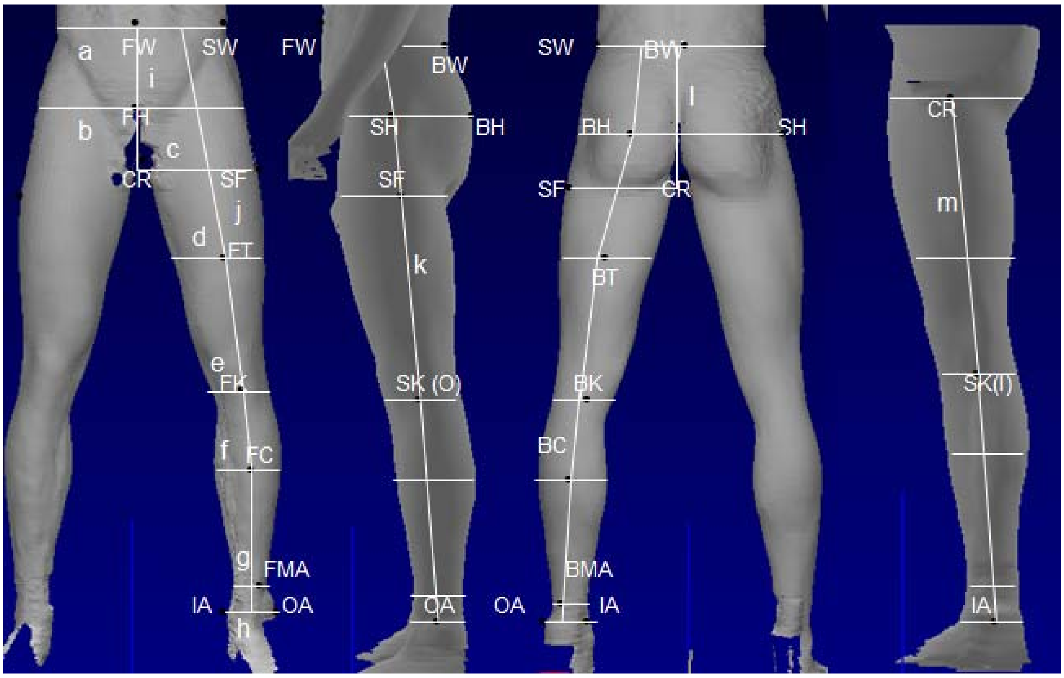
Points	Definitions
FH	Point of front and centre horizontal hip circumference
SH	Point of the greatest lateral trochanteric projection
BH	Point of the greatest buttock projection
CR	Under point of crotch
SF	Side point of horizontal crotch circumference
FT	Front point of thigh
BT	Back point of thigh (the greatest projection of thigh muscle)
FK	Front point of knee（knee-bone projection）
SK(O)	Outside point of knee
SK(I)	Inside point of knee
BK	Back point of knee

FC	Front point of calf
BC	Back point of calf (the greatest projection of calf muscle)
IA	Point of ankle inside projection
OA	Point of ankle outside projection

3.5.3.2 Anatomical points and body structure lines

In addition, structure lines of the static block pattern of trousers can be determined based on these anatomical points.

a. Waist line is determined by feature points FW, SW and BW;
b. Hip girth line is determined by feature points FH, SH and BH;
c. Thigh girth line is determined by feature points CR and SF;
d. Mid-thigh girth line is determined by feature points FT and BT;
e. Knee girth line is determined by feature points FK, SK(O), BK and SK(I);
f. Calf girth line is determined by feature points FC and BC;
g. Minimum leg girth line is determined by feature points FMA and BMA;
h. Cuff line is determined by feature points OA and IA.
i. Front crotch line is determined by feature points FW, FH and CR;
j. Front centre line is determined by feature points FT,FK and FC;
k. Outer side line is determined by feature points SW, SH, SK(O) and OA;
l. Back crotch line is determined by feature points BW and CR;
m. Inner side line is determined by feature points CR, SK(I) and IA;



a) front view b) side view c) back view d) side view

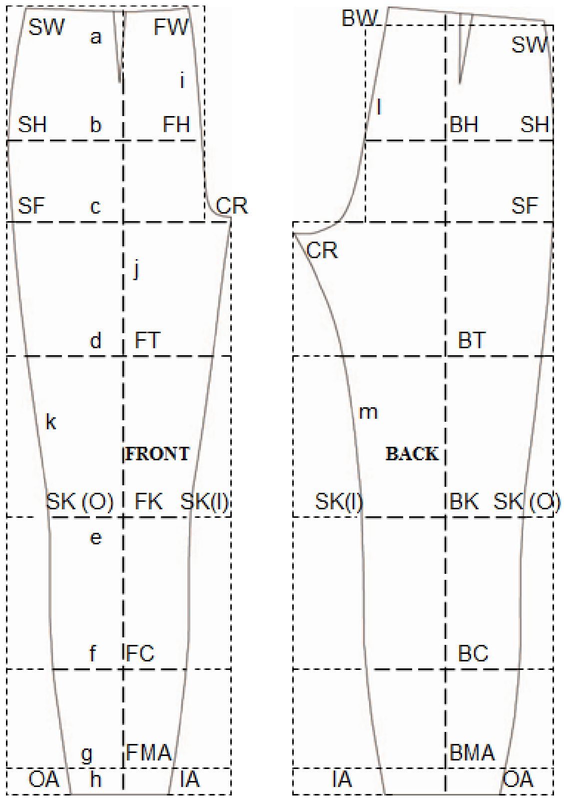
Figure 3-11 Anatomical points and body structure lines

3.5.3.3 Anatomical points and body structure lines in static block pattern of trousers

The relationship among anatomical points, body structure lines and static trousers block patterns are shown in Figure 3-12. All anatomical points are landmarks for determining body structure lines and sizes. At the same time, body structure lines are used as reference to design framework and structure lines.

Points FW, SW, FH, SH, CR, SF, SK (I), IA and OA are the key landmarks in static block pattern of the front trouser panel. Points BW, SW, SH, SF, CR, SK (O), IA and OA are the key landmarks in static block pattern of the back trouser panel.

Among all body structure lines, lines a, i, m, h and k are structure lines of the front pattern, and lines a, l, m, h and k are that of the back panel. Lines b, c, d, e, f and g are framework lines.



a) front b) back

Figure 3-12 Anatomical points and body structure lines in static trouser block patterns

3.6 Construction of Static Block Patterns with Just-fit Design

3.6.1 Size Design for Static Block Patterns

In this research, body measurements of subject 2 were used as pattern size to construct static block pattern with just-fit design. The body measurements shown in Table 3-3 to Table 3-6 can be used to design the size for static block pattern. All measurements are naked body measurements and no ease is added in static block pattern with just-fit design.

3.6.2 Procedure of Static Block Pattern Construction

By the reflection method, static block pattern of the human body can be constructed if anatomical points, body structure lines and body measurements are determined. Three types of static block patterns are developed: shirt, sleeve and trouser. The construction procedure of static block pattern includes two steps: 1) framework line construction and 2) pattern structure line construction. Based on anatomical points and body structure lines, framework lines are constructed. With the framework lines and body measurements, final pattern structure lines are added.

3.6.3 Construction of Static Block Pattern of Shirt with Just-fit Design

3.6.3.1 Construction of framework lines

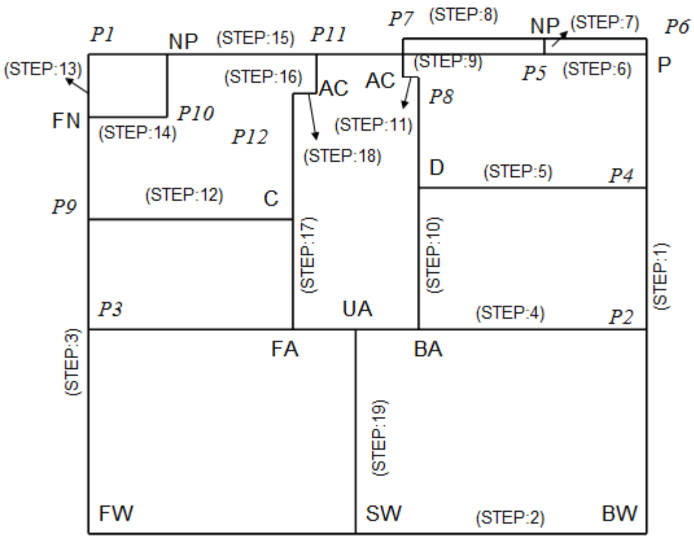


Figure 3-13 Framework lines of static block pattern of shirt with just-fit design

As shown in Figure 3-13, the framework lines of static block pattern of shirt can be constructed according to the following steps:

Step 1: Determine point P position. Draw a line between points P and BW based on the difference between the back neck height and the waist height.

Step 2: Square out a line from BW to FW, with the length equal to the chest girth measurement. Draw a parallel line from P to P1.

Step 3: Connect points P1 and FW with a line completing a rectangle.

Step 4: Mark P2, where the distance from P to P2 is the difference between back neck height and chest height. Draw a line parallel to the line P-P1, intersecting line P1-FW at point P3.

Step 5: Mark P4, where the distance from P to P4 is the difference between across back height and back neck height. From P4, draw a line parallel to line P2-P3 to a point D, where its length is 1/2 across back width measurement.

Step 6: From P, mark a point P5 with 1/2 neck width measurement.

Step 7: Determine a point NP above P5 by back neck depth measurement, connect P5 to NP. Draw a parallel line from P to P6, connect P6 to NP.

Step 8: Connect P6 to NP, extend the line to point P7, where distance from P6 to P7 is 1/2 shoulder width measurement.

Step 9: From P7 square down and determine AC point by the shoulder slope angle, connect AC and P7.

Step 10: Draw a line from point D parallel to line P-BW, intersecting line P2-P3 at point BA.

Step 11: From AC, draw a line parallel to line P-P1, intersecting the line developed in step 10 at point P8.

Step 12: Mark a point P9 along line P1-FW, where the distance from P1 to P9 is the difference between back neck height and across front height., From P9, draw a line parallel to line P1-P to point C, where its length is 1/2 front width measurement.

Step 13: Mark FN below P1 by the front neck depth measurement.

Step 14: From FN square out to P10 of neck width measurement, square up from P10 and intersect line P1-P at point NP.

Step 15: Mark point P11 away from NP at shoulder with measurement, square down to determine AC by shoulder slope angle.

Step 16: Draw a line parallel to line P1-FW from point C, intersecting line P3-P2 at point FA.

Step 17: From AC, draw a line parallel to line P1-P, intersecting with the line developed in step 16 at point P12.

Step 18: Mark a point UA as the midpoint of line P2-P3, square down from UA intersecting line FW-BW at point SW.

3.6.3.2 Construction of pattern structure lines

After constructing the framework lines, pattern structure lines are drawn to develop the static block pattern of shirt with just-fit design. In Figure 3-15, structure lines are marked with the corresponding drawing steps below.

Step 1: Connect point P to NP with a curve line of 1/2 back neck base girth;

Step 2: Connect point NP to AC on the back piece, which is shoulder length measurement.

Step 3: Connect point FN to NP with a curve line of 1/2 front neck base girth measurement.

Step 4: Connect point NP and AC on the front piece, which is shoulder length measurement.

Step 5: Draw a smooth curve connecting point AC (front), C, UA, D and AC (back) with the armscye girth measurement.

Before drawing the darts on the block patterns (as shown in Figure 3-15 Step 6 to Step 11), reference lines for dart position design in shirt block pattern should be determined. Traditionally, 12 vertical lines parallel to the frontal and sagittal planes, which divide skin surfaces into 12 parts, and these vertical lines are the reference lines for the design of waist dart position (中保淑子, et al, 1995). As shown in Figure 3-14, the waist is divided into 12 parts by centre front line, centre back line, two side lines, and other eight lines passing through anatomical points CP1, CP2, FA1, FA2, BA1, BA2, SP1 and SP2. The centre front line is the opening of a shirt, thus usually not an option for the placement of dart in pattern design. The rest of the 11 positions are possible waist dart positions. In Figure 3-15, centre front line, centre back line and the two side lines are first drawn, and four reference lines are drawn afterwards: The first line is from NP, CP to R1 on the front pattern; the second line is from NP, SP to R2 on the back pattern; the third line is drawn by extending from P8 to BA and R4; and the fourth line is drawn by extending from P12 to FA and R5.

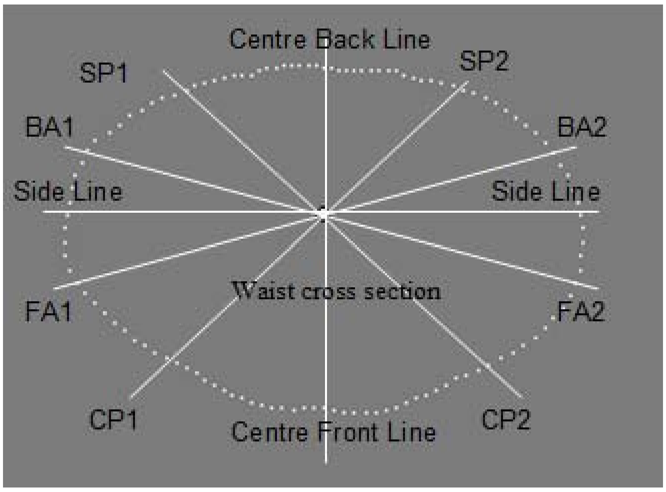


Figure 3-14 The vertical dividing lines of human body

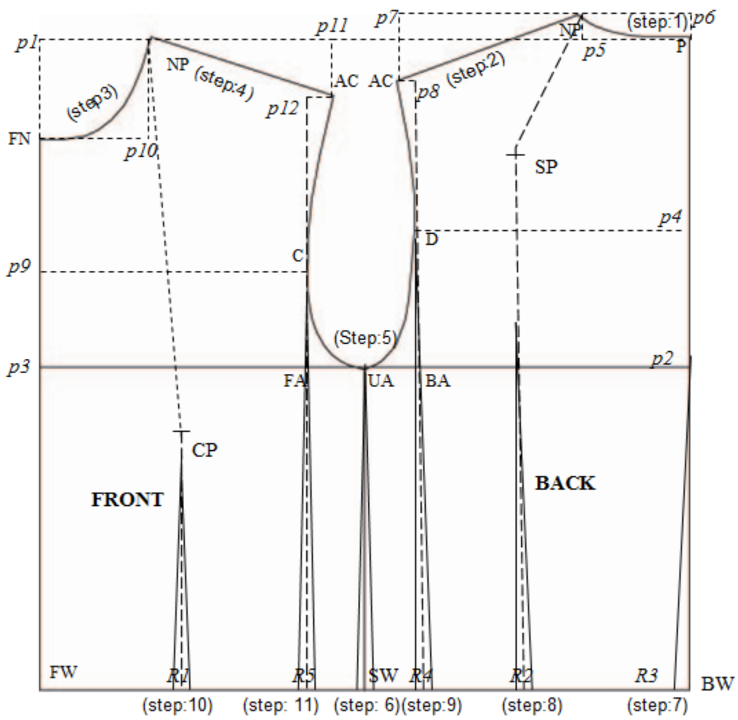


Figure 3-15 Construction of static shirt block pattern with just-fit design

In addition to the dart position design, the size of to the darts should be determined too. First of all, the difference between chest girth and waist girth measurements is calculated by the following equation.

$$\Delta G = G_{chest} - G_{waist} \qquad (3\text{-}1)$$

where G_{chest} is measurement of chest girth and G_{waist} is waist girth measurement.

The static block pattern of shirt covers half of the torso, the total size of the darts in front and back patterns is half of the difference (ΔG) obtained by equation (3-1). Preferred size of waist darts can be calculated as follows: dart 1 = 7%×ΔG, dart 2 = 7.5%×ΔG, dart 3=5.5%×ΔG, dart 4 = 17.5%×ΔG, dart 5 = 9%×ΔG, and dart 6 = 3.5%×ΔG (中保淑子, et al, 1995, 三吉满智子, 2006). Then, step 6 to step 10 is finished and darts are drawn on the static block pattern accordingly.

3.6.4 Construction of Static Block Pattern of Sleeve with Just-fit Design

3.6.4.1 Construction of framework lines

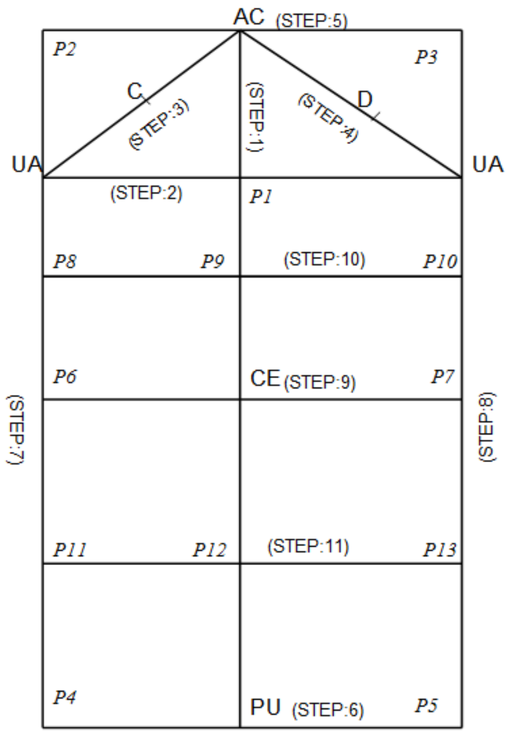


Figure 3-16 Framework lines of static block pattern of sleeve with just-fit design

As shown in Figure 3-16, framework lines of the sleeve pattern are drawn according to anatomical points and structure lines of arm. The detailed steps are as follows:

Step 1: Determine point AC position. Draw a line from point AC to PU with the distance equal to the measurement of arm length.

Step 2: Mark point P1 below AC at a distance, which is the difference between long shoulder height and armscye height. Square out a line from P1.

Step 3: On the line developed in step 2, mark a point UA so that the distance from AC to US is the front armscye length measurement.

Step 4: On the line developed in step 2, mark another point UA for the back sleeve, so that the distance from AC to UA is the back armscye length measurement.

Step 5: Draw a line P2-P3 parallel to the line developed in step 2.

Step 6: Draw a line P4-P5 parallel to the line developed in step 2.

Step 7: Connect P2 to P4.

Step 8: Connect P3 to P5.

Step 9: Mark point CE at a position that the distance between AC and CE is the length measurement from back neck to elbow. Draw a line passing through point CE parallel to line P2-P3, joining lines P2-P4 and P3-P5 at points P6 and P7.

Step 10: Mark point P9 as the midpoint from P1 to CE. Draw a line passing through P9 parallel to line P2-P3, joining lines P2-P4 and P3-P5 at points P8 and P10.

Step 11: Mark point P12 as the midpoint from CE to PU. Draw a line passing through P12 parallel to line P2-P3, joining lines P2-P4 and P3-P5 at points P11 and P13.

3.6.4.2 Construction of pattern structure lines

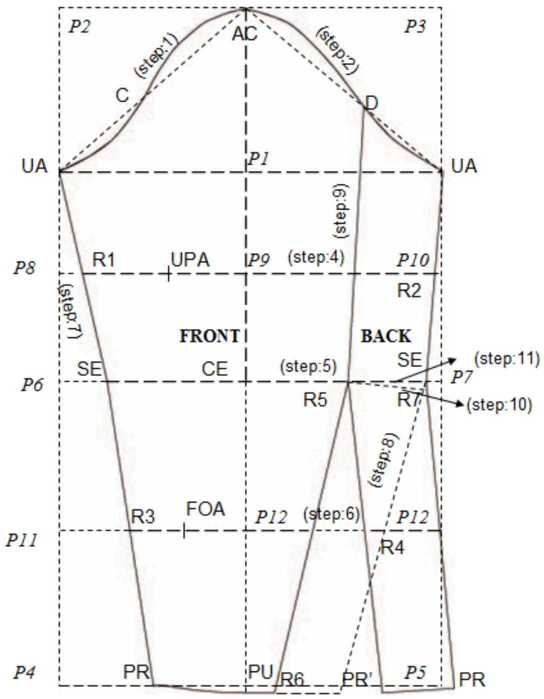


Figure 3-17 Construction of static sleeve block pattern with just-fit design

According to the body measurements and the defined framework lines, the structure lines of static block pattern of sleeve with just-fit design are drawn, as shown in Figure 3-17. The detailed drafting procedure is as follows:

Step 1: According to front armscye length and shape of body structure line, make a curve line of front sleeve crown passing through points AC, C and UA.

Step2: According to back armscye length and shape of body structure line, make a curve line of back sleeve crown passing through points AC, D and UA. The total length of two curves acquired in Steps 1 and 2 is the same as armscye length measurement.

Step 3: Before drawing the cuff structure line, measure the distance from P4 to P5 (W_{p4-p5}), then the difference between W_{p4-p5} and wrist girth measurement is acquired. Determine the positions of points PR and PR’ on the front and back pieces which have the same distances (1/2 difference between W_{p4-p5} and wrist girth measurement) to points P4 and P5. With point PR on the front piece and point PR’ on the back piece, design a curve line, forming the cuff structure line.

Step 4: Use the same method as described in Step 3 to determine upper arm girth line and its end points are R1 and R2.

Step 5: Use the same method as described in Step 3 to determine elbow girth line and its end points are SE on the front piece and SE on the back piece.

Step 6: Use the same method as described in Step 3 to determine forearm girth line and its end points are R3 and R4.

Step 7: By connecting points UA, R1, R3, SE and PR on front piece, draw the front side line of the sleeve pattern which has the same measurement as underarm length.

Step 8: By connecting points UA, R2, R4, SE and PR’ on the back piece, draw the back side line of the sleeve pattern.

Step 9: From point D, draw a line parallel to the back side line intersecting with elbow line at point R5 and cuff line at point R6.

Step 10: Make a dart based on the difference between lengths of the front side line and the back side line: One dart leg is elbow line from R5 to SE and another dart leg is from R5 to R7.

Step 11: Cut three lines: line from R5 to R6, line from R5 to SE and line from R5 to R7. By combining line from R5 to SE and line from R5 to R7, transfer the dart in back side line to the cuff line. Finally, new sleeve pattern structure lines are designed.

3.6.5 Construction of Static Block Pattern of Trousers with Just-fit Design

3.6.5.1 Construction of framework lines

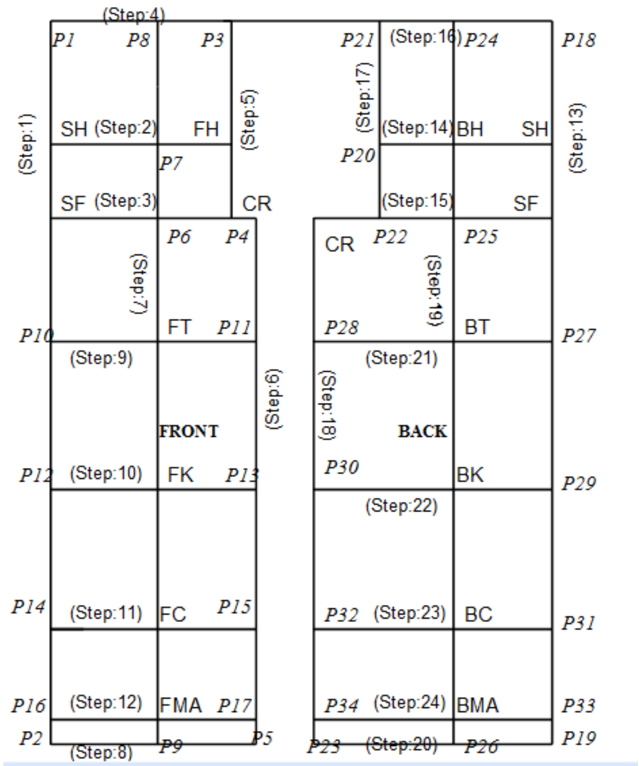


Figure 3-18 Framework lines of static block pattern of trousers with just-fit design

Similar to the shirt and sleeve block patterns, framework lines of the static block pattern of trousers can be drawn based on anatomical points and body structure lines of lower torso and legs. With reference to Figure 3-18, the detailed drafting steps are described as follows:

Step 1: Determine point P1. Draw a vertical line from P1 to P2 with the measurement of out leg length.

Step 2: According to the difference between waist height and hip height, draw a horizontal line called hip line (front) and its size is 1/4 hip girth measurement. The hip line connects with line defined in Step 1 at points SH and FH.

Step 3: According to the difference between waist height and crotch height, draw a crotch line (front) parallel to hip line. The crotch line connects with line defined in Step 1 at points SF and CR.

Step 4: Draw a line parallel to hip line from point P1 to Point P3.

Step 5: Draw a vertical line from point P3 to point FH, extend it and reach crotch line at point P4.

Step 6: From Point CR, draw a line parallel to the line defined in Step 1 at point P5.

Step7: Determine point P6, which is the point of 1/2 length of crotch line. From point P6, draw a vertical line, called front centre line, which ends at points P8 and P9.

Step 8: Draw a horizontal line, call front cuff line, which is determined by points P2, P9 and P5.

Step 9: According to the difference of crotch height and mid-thigh height, draw mid-thigh girth line which ends at points P10 and P11. The mid-thigh girth line connects with front centre line at point FT.

Step 10: According to the difference of crotch height and knee height, draw knee girth line which ends at points P12 and P13. The knee girth line connects with front centre line point at FK.

Step 11: According to the difference of crotch height and calf height, draw calf girth line which ends at points P14 and P15. The calf girth line connects with front centre line at point FC.

Step 12: According to the difference of crotch height and the minimum leg height, draw the minimum leg girth line which ends at points P16 and P17. The minimum leg girth line connects with front centre line at point FMA.

When these 12 steps are finished, the framework lines of front trouser block pattern are completed. The similar steps are used to draft the framework lines of back trouser block pattern as follows.

Step 13: Determine point P18. Draw a vertical line from point P18 to P19 which has the same size as the out leg length.

Step 14: According to the difference between waist height and hip height, draw a horizontal line, called hip line (back), and its size is 1/4 hip girth measurement. The hip line connects with line defined in Step 13 at points SH and P20.

Step 15: According to the difference between waist height and crotch height, draw a crotch line (back) which is parallel to the hip line. The crotch line connects with line defined in Step 13 at points SF and CR.

Step 16: Draw a line parallel to hip line from point P18 to point P21.

Step 17: Draw a vertical line from point P21 to point P20, extend it to reach crotch line at point P22.

Step 18: From Point CR, draw a vertical line to point P23, which is parallel to line defined in Step 13.

Step 19: From point P22, determine a point P24 at the crotch line. The width from P22 to P24 is same as the width from P7 to FH. From P24, draw a vertical line, called back centre line, to point P26, which connects the line defined in Step 16 at point P25.

Step 20: Draw back cuff line, which is determined by points P19, P23 and P26.

Step 21: According to the difference of crotch height and mid-thigh height, draw mid-thigh girth line (back), which ends at points P27 and P28. The mid-thigh girth line connects with back centre line at point FC.

Step 22: According to the difference of crotch height and knee height, draw knee girth line (back) which ends at points P29 and P30. The knee girth line connects with back centre line at point BK.

Step 23: According to the difference of crotch height and calf height, draw calf girth line (back) which ends at points P31 and P32. The calf girth line connects with back centre line at point BC.

Step 23: According to the difference of crotch height and the minimum leg height, draw the minimum leg girth line (back) which ends at points P33 and P34. The minimum leg girth line connects with back centre line at point BMA.

3.6.5.2 Construction of pattern structure lines

Based on the defined framework lines and body measurements, structure lines of static block pattern of trousers with just-fit design are then drawn. With reference to Figure 3-19, the static block pattern of trousers is constructed as follows:

Step 1: Based on points FW, FH and CR, draw one curve which has the same size of front crotch length. The distance between FW and P3 is 1.0 cm.

Step 2: Calculate the difference between 1/4 waist girth and the width of line FW-P1. Draw a dart of size 1.0 cm at waist. Draw a curve from FW to SW, and its size is the sum of 1/4 waist girth and 1.0 cm.

Step 3: According to the difference between the width of line P10-P11 and 1/2 mid-thigh girth, determine points R1 and R2 which have the same horizontal distances from points P10 and P11. The horizontal distances are equal to 1/2 difference between the width of P10-P11 and 1/2 mid-thigh girth.

Step 4: According to the difference between the width of line P12-P13 and 1/2 knee girth, determine points SK(O) and SK(I) which have the same horizontal distances from points P12 and P13. The horizontal distances are equal to 1/2 difference between the width of P12-P13 and 1/2 knee girth.

Step 5: According to the difference between the width of line P14-P15 and 1/2 calf girth, determine points R3 and R4 which have the same horizontal distances from points P14 and P15. The horizontal distances are equal to 1/2 difference between the width of P14-P15 and 1/2 calf girth.

Step 6: According to the difference between the width of line P16-P17 and 1/2 of the minimum leg girth, determine points R5 and R6 which have the same horizontal distances from points P16 and P17. The horizontal distances are equal to 1/2 difference between the width of P16-P17 and 1/2 of the minimum leg girth.

Step 7: According to the difference between the width of line P2-P5 and 1/2 ankle girth, determine points OA and IA which have the same horizontal distances from points P2 and P5. The horizontal distances are equal to 1/2 difference between the width of P2-P5 and 1/2 ankle girth.

Step 8: According to points SW, SH, SF, R1, SK(O), R3, R5 and OA, draw outside structure line of the front trouser pattern which has the same size of out leg length.

Step 9: According to points CR, R2, SK(I), R4, R6 and IA, draw inside structure line of the front trouser pattern which has the same size of inner leg length.

Step 10: At the midpoint of curve line from FW to SW, mark the position for a dart. The length of the dart is 7 cm, and the size is 1.0 cm.

By finishing these 10 steps, structure lines of the front piece are completed. Steps 11 to 20 are the detailed constructing processes of the back piece.

Step 11: Determine point R7, at a distance of 2.5 cm from point P20. Lower point CR’ by 1.0 cm and define the new CR point. Draw a curve line and extend it upward. Determine the length of line extension as the back crotch length, and mark the end point as BW.

Step 12: From point BW, draw a line with length equal to 1/4 waist girth plus 1.0 cm, which connects with line P18-P21 at point SW.

Step 13: According to the difference between the width of line P27-P28 and 1/2 mid-thigh girth, determine points R8 and R9 which have the same horizontal distances from points P27 and P28. The horizontal distances are equal to 1/2 difference between the width P27-P28 and 1/2 mid-thigh girth.

Step 14: According to the difference between the width of line P29-P30 and 1/2 knee girth, determine points SK(O) and SK(I) which have the same horizontal distances from points P29 and P30. The horizontal distances are equal to 1/2 difference between the width P29-P30 and 1/2 knee girth.

Step 15: According to the difference between the width of line P31-P32 and 1/2 calf girth, determine points R10 and R11 which have the same horizontal distances from points P31 and P32. The horizontal distances are equal to 1/2 difference between the width P31-P32 and 1/2 calf girth.

Step 16: According to the difference between width of line P33-P34 and 1/2 of the minimum leg girth, determine points R12 and R13 which have the same horizontal distances from points P33 and P34. The horizontal distances are equal to 1/2 difference between the width P33-P34 and 1/2 of the minimum leg girth.

Step 17: According to the difference between the width of line P19-P23 and 1/2 ankle girth, determine points OA and IA which have the same horizontal distances from points P19 and P23. The horizontal distances are equal to 1/2 difference between width P19- P23 and 1/2 ankle girth.

Step 18: According to points SW, SH, SF, R9, SK(O), R11, R13 and OA, draw outside structure line of back trouser pattern which has the same size of out leg length.

Step 19: According to points CR, R8, SK(I), R10, R12 and IA, draw inside structure line of back trouser pattern which has the same size of inner leg length.

Step 20: At the mid-point of curve line from BW to SW, mark the position for a dart. The length of the dart is 8 cm, and the size is 1.0 cm.

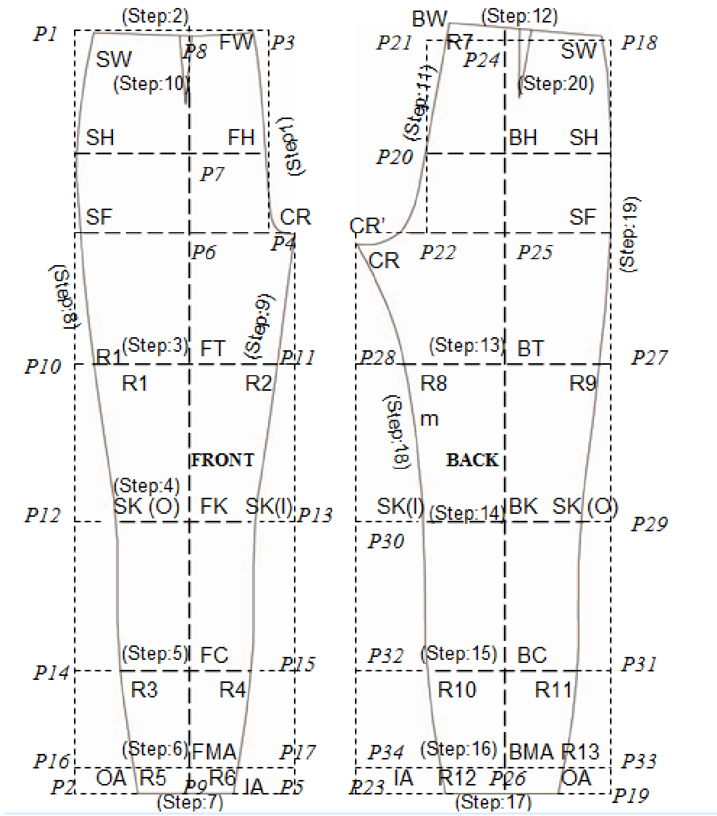


Figure 3-19　Construction of static block pattern of trousers with just-fit design

3.7　Discussions

Figure 3-20 shows the construction process of static block pattern with just-fit design. It is shown that anatomical points, body structure lines and body measurements are important inputs to the reflection method.

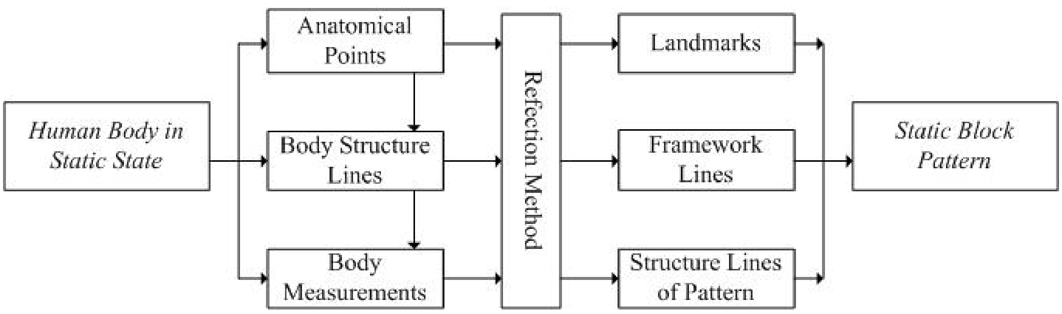


Figure 3-20　Static block pattern construction system by reflection method

Comparing with traditional methods for block pattern construction, the reflection method has a number of advantages. First of all, it is a simple and direct method. With the use of 3D body scanning, anatomical points, body structure lines and body measurements can be acquired easily, which provides one simple mean to obtain the framework and structure lines of block pattern. Secondly, the method is suitable to construct block pattern with just-fit design, because naked body measurements acquired from 3D body scanning give the corresponding size of the pattern structure. In traditional method, ease allowances are usually added to certain body measurements, and the resulted block pattern is not truly a just-fit block pattern.

On the other hand, the reflection method has a few drawbacks. Firstly, the reflection method is suitable only for block patterns with just-fit design, but not for loose-fit design. Secondly, marking anatomical points on the subject's skin surface before scanning is a very important step, which largely influences the final measurement results. Thirdly, the accurate definition of anatomical points and body structure lines is necessary for the construction of static block patterns. Therefore, the anthropometric method and instruments used in the experiment must be carefully chosen. In order to reduce the errors caused by measurer and instruments used, static block patterns developed by the reflection method must be verified by objective evaluation, which will be discussed in Chapter 4.

3.8 Conclusions

In this chapter, the reflection method has been used to construct static block pattern with just-fit design. By analysing the relationship among anatomical points, body structure lines, body measurements and pattern structure, the drafting procedures are described for the construction of shirt, sleeve and trousers block patterns.

The reflection method is shown to be a simple and direct method for static block pattern construction. Anatomical points, body structure lines and body measurements are important inputs in this method. Anatomical points of the human body determine body structure lines and the corresponding body measurements. Upon defining these features, framework lines are first constructed. Next, the structure lines of block pattern are drafted. No special formula or approximation is involved in the process.

The reflection method is found to be easily influenced by factors like measurer's skills or the correct use of instrument. Incorrect definition of anatomical points on the body skin surface would lead to poor fit block pattern. Thus, there are high demands on the measurement instruments and method used in the experiment. All in all, the static block pattern developed by the reflection method should be evaluated, so as to improve the static block patterns.

CHAPTER 4 OBJECTIVE FIT EVALUATION OF STATIC BLOCK PATTERNS WITH JUST-FIT DESIGN

4.1 Introduction

The reflection method has been developed to construct static block patterns with just-fit design in Chapter 3. In this chapter, the clothing fit of the sample garments made from the fitted static block patterns is evaluated. The block patterns can be further improved based on the result of the fit evaluation.

Clothing fit is the relationship between garment and body size. Many research papers have proved that fit performance influences clothing functions and wearing comfort (Alexander et al., 2005). Chen et al. (2006) reported that garment fit affects clothing thermal insulation and moisture vapour resistance, and tight-fit garments are preferred in keeping the body warm in windy conditions. Yiu and Zhang (2000) studied the relationship between tight-fit design and subjective pressure evaluation, and found that the gap values between the clothing and the body can predict clothing pressure. Huck et al. (1997) indicated that 17cm is a desirable amount of ease to use in the designing of the pant’s crotch, otherwise the wearer’s mobility would be reduced. All in all, clothing fit design is of paramount importance in clothing product development.

Many methods have been developed by researchers to assess the fit of garment. These methods can be classified into two categories: objective evaluation and subjective perception. Subjective perception is the perceived fit of wearer’s self-assessment or expert’s evaluation in terms of visual and comfort performance (McConville, 1986). In subjective evaluation of clothing fit, ease, line, grain balance, and set are the five key criteria (Chen, 2004). The wearer is required to try on the garment and stand in front of a mirror, and the wearer decides the garment fit and records the fitting evaluation, usually by a rating scale in the form of a questionnaire. Meanwhile, photos are taken for further analysis, and experts also evaluate on the clothing fit. The objective analysis of clothing fit includes two approaches. The first one is by collecting and analysing data between the body and the garment. Two sets of measurements are collected, one set is when the garment is put on and the other set is without putting on the garment. Each set of measurements include the circumference and area at different cross sections of the body. By analysing the difference between the two sets of measurements, garment fit can be assessed (Ashdown, 2000, 2005, 2004). The second approach of objective fit evaluation is by clothing pressure analysis: the amounts of clothing pressure placed on the body at different locations are collected and analysed (Toyonoti, 1998).

Comparatively, subjective methods are simple to apply, but they only provide limited information about the wearer's body shape and proportion. The methods do not provide precise data: for instance, even the same wearer may have different perceptions of clothing fit at different times; different experts may have varied views on fit of the same clothing design (Ashdown and Delong, 1995). In objective methods, as discussed early, the differences between the clothing and the body's circumference and area together with clothing pressures are important data to assess the clothing fit. The numeric data can help designers determine whether the product is a fitted design or not, and also how loose or tight it is at different areas. The clothing pressure data can be used to determine the level of tightness at various locations of the body. With numeric data, the relationship between the body and the clothing can be quantified, from which correct conclusion on garment fit can be drawn. To conclude, objective evaluation provides more precise data on clothing fit.

Although traditional methods of objective fit evaluation can analyse the relationship between the clothing and the body, there are still some shortcomings. Firstly, the methods cannot provide designers with detailed information about fit, such as the length and area changes at different parts of the body with and without the clothing on. This information is essential to evaluate the clothing balance, namely clothing levels of the front, back, left side and right side of the body at different cross sections. Secondly, traditional methods cannot provide the gap values between the clothing and the body, which is necessary for understanding the fitting at different locations as well as the overall fit. In this regard, a new method for scientific objective evaluation of clothing fit is proposed in this chapter, which makes use of 3D body scanning and reverse engineering techniques. By this proposed method, the fitted static block patterns are improved.

4.2 Overview of a New Objective Fit Evaluation Method

An effective method for scientific fit evaluation of clothing must provide the following functions: 1) it determines whether the clothing is loose, fit or tight in different parts of the body; 2) it helps designers to assess the clothing balance, which means the detail levels of drape (front and back, left and right) at different cross sections; and 3) it helps designers to understand the overall distributions and detail gap values at different locations.

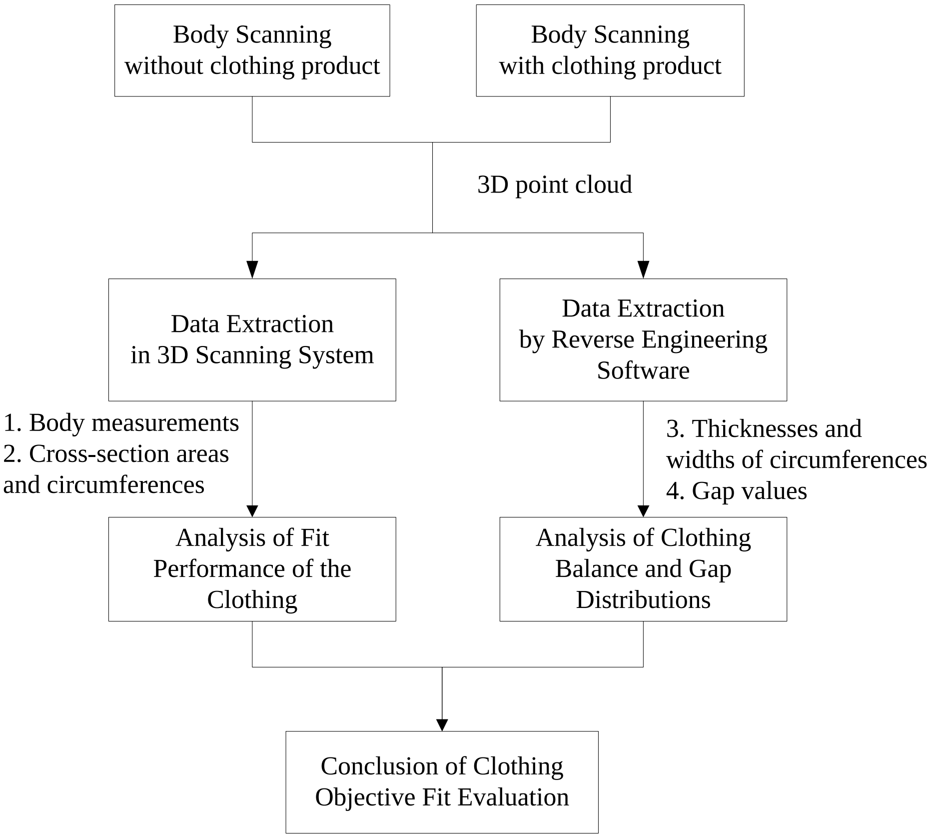


Figure 4-1 A new technique for clothing objective fit evaluation

In order to perform the above functions, a set of numeric data about the body and the clothing product must be collected and analysed. Figure 4-1 shows the workflow of the proposed fit evaluation technique, which includes body scanning with and without clothing, data extraction and analysis, and fit evaluation.

4.3 Methodology

According to the proposed workflow of the new technique, an experiment was designed including the following tasks: a) Body scanning; b) Data extraction from 3D point cloud data; c) Clothing sample fit evaluation; and d) Improvement of the static block pattern based on fit evaluation results.

4.3.1 Experiment Details

4.3.1.1 Subjects

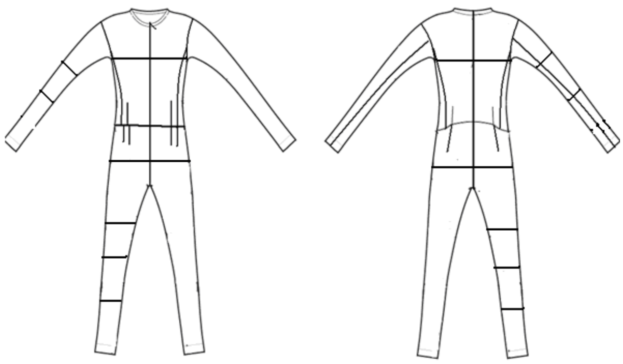
The same subjects in the research works of Chapter 3 are recruited to take part in this new study. All subjects are 170-175cm tall with BMI (Body Mass Index) figures of 21-23. According to the body measurement definitions given in ISO 8559-1989 standard, 23 measurements were measured for each subject using TC^2 body scanner. The measurement results are listed in Table 4-1. Before the experiment, the objectives and procedure of the study were introduced to all subjects and their approvals were obtained.

Table 4-1 Body measurements of the five subjects

Body measurements (cm)		Subjects				
		1	2	3	4	5
Girth	Neck base	40.17	39.32	40.01	40.35	39.78
	Chest girth	97.67	93.96	96.82	95.95	97.98
	Armscye girth	38.91	39.68	42.76	42.01	44.15
	Waist girth	77.65	79.49	78.63	81.68	78.47
	Hip girth	93.65	94.36	98.85	98.66	94.22
	Upper arm girth	24.97	27.24	28.49	27.98	26.67
	Elbow girth	24.55	24.81	24.61	24.52	24.82
	Wrist girth	15.80	16.58	16.39	16.14	15.79
	Mid-thigh girth	43.98	46.74	45.13	49.66	45.37
	Knee girth	36.36	38.28	36.03	38.77	36.16
	Calf girth	36.72	39.03	35.34	38.12	36.28
	Ankle girth	24.56	26.93	24.26	25.31	25.01
Width	Across shoulder width	39.09	40.59	40.55	40.08	40.94

	Across back width	38.04	39.45	39.38	39.22	39.43
	Across chest width	37.16	38.80	38.33	38.41	38.87
Length	7th-cervical to waist length	48.00	51.30	46.55	44.25	47.50
	Back waist length	49.04	49.90	49.70	50.86	50.35
	Front waist length	44.77	44.86	45.58	46.19	46.10
	Shoulder length	12.81	12.61	13.32	12.93	12.16
	Total crotch length	58.17	61.66	72.65	64.17	68.83
	Crotch depth	19.60	19.50	20.00	20.00	20.00
	Outside leg length	101.56	102.41	103.61	103.05	102.60
	Central arm length	53.74	55.08	56.27	55.12	53.69

4.3.1.2 Garment samples



a) front b) back

Figure 4-2 Style of garment sample used in the experiment

Five sample garments with one-piece just-fit design, as shown in Figure 4-2, were produced using a selected elastic knit fabric for this experiment. The properties of fabric are shown in Table 4-2. The body measurements in Table 4-1 were used as garment size, in which no additional ease was added to the static block of the just-fit design of the knitwear. As shown in Figure 4-3, the just-fit knitwear has a zip opening at the front for easy wearing, and reference lines are marked on the garment surface to facilitate fit evaluation. Matching the marked lines on the clothing with the anatomical lines on the body ensures that the body measurements can be properly collected.

Table 4-2 Properties of knitted fabric used in the sample

Content	Nylon: 92% Spandex: 8%	Construction	Plain
Thickness (mm)	0.71	Weight (g/cm²)	212.70
Resistance to air penetration (KPa. S/M)	0.84	Thickness, (mm, $T_o$at 50gf)	1.02
Surface thickness, (mm, ST)	1.49	Thickness (mm, T_m at 50gf)	0.82
Tensile resilience (%, RT)	56.49	Extensibility (%, EMT)	68.61
Shear stiffness (gf/cm, G)	0.65	Shear hysteresis (gf/cm, 2HG)	2.15
Shear hysteresis (gf/cm, 2HG5)	2.32	Bending rigidity (gf, cm/cm, B)	0.02
Bending rigidity (gf, cm/cm, 2HB)	0.07	Coefficient of friction (MIU)	0.47
Mean deviation of MIU	0.02	Geometric roughness, SMD	3.09

Figure 4-3 Opening design and anatomical lines in clothing sample

4.3.1.3 Experiment instruments and environment

TC² 3D body scanner was used to collect the subjects' measurements. All scanning processes were conducted in the 3D body scanning lab of The Hong Kong Polytechnic University, where the temperature and the relative humidity were controlled at 23± 0.5 C° and 65±5%, respectively. The air velocity was kept under 0.1m/s to reduce the influence of wind speed on body scanning.

4.3.1.4 Experiment procedure

All subjects were scanned twice: the first scan was for subjects with only underwear on and the second scan was for subjects having put on the just-fit knitwear. In order to allow the two scans to be accurately matched in reverse engineering software, markers were fixed on the following positions before the scanning procedure: 1) elbow joint, 2) outer points of wrist joint, 3) chest point, 4) navel, 5) knee joint, and 6) outer points of ankle joint. In the scanning process, each subject was required to stand on the footprints marked on the floor and look straight ahead with arms hanging naturally, as shown in Figure 4-4. 3D point cloud data were generated and saved for each scan.

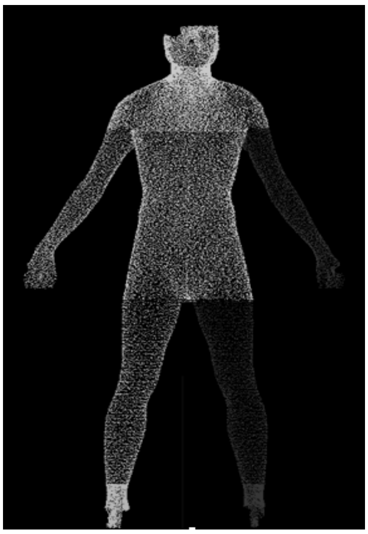


Figure 4-4 Posture in body scanning process

4.3.2 Data Extraction from 3D Point Cloud Data

With the obtained 3D point clouds, valuable information can be extracted by both the 3D scanning software system and reverse engineering software for the analysis of clothing fit. TC^2 software system can develop 3D human models (i.e., surface models) from the scanned point cloud, from which critical anthropometric measurements can be extracted according to body measurement standards. The extracted data contains a vast array of measurements, such as chest and waist girth measurements, areas of different body cross sections, and so forth.

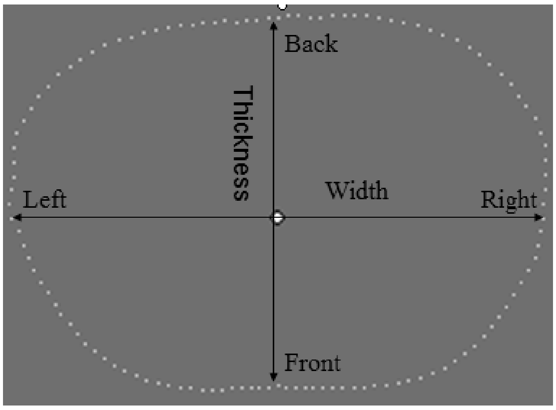


Figure 4-5 Thickness and width of body cross section

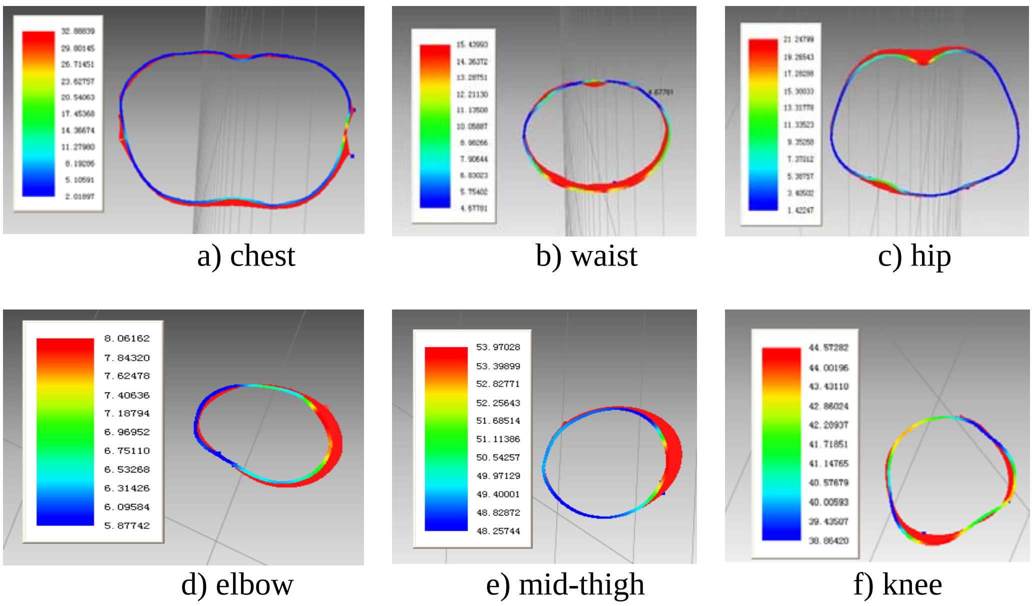
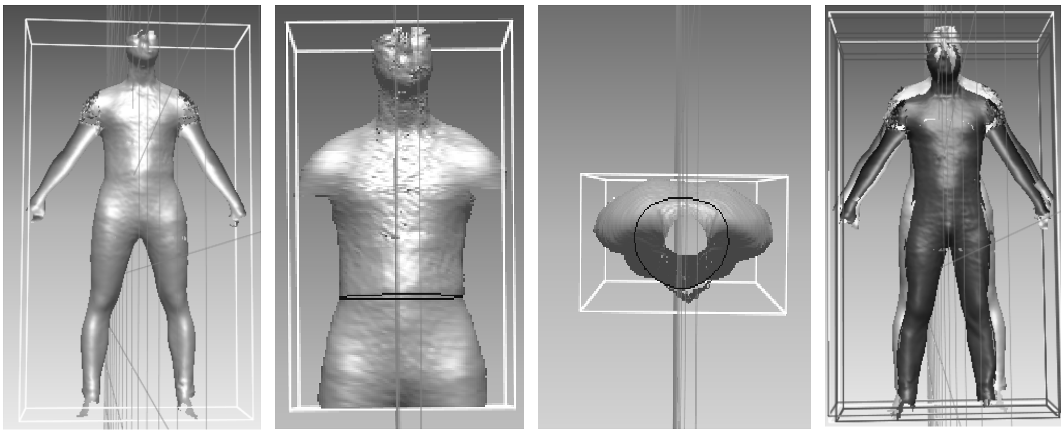


Figure 4-6 Examples of gap value between body and clothing in different locations

Apart from this, reverse engineering software can help designers to understand the relationship between the body and the clothing, because the software can readily superimpose different 3D models. For example, 3D human models are developed from the two-state scans. In this research, a reverse engineering software, RapidForm (Lee, 2004), was used to extract the thicknesses and widths of the body cross section at different locations, and also the gap values of the cross section. The thickness is the distance between the front and the back on a body cross section, and the width is the distance between the left and the right sides on the cross section, as shown in Figure 4-5. The gap value means the space between the body and the clothing, as shown in Figure 4-6.



a) Step 1 b) step 2 c) step 2 d) step 3

Figure 4-7 Procedure of data extraction using Rapidform 2006 software

As shown in Figure 4-7, the data extraction process using the reverse engineering software consists of three steps. The first step involves the re-building of the human model. In this research, models of the human body with or without clothing sample were re-built by inputting the acquired two-state body scan data. The second step is extracting cross sections at different locations of the rebuilt models, for example, along the chest line, waist line and hip line. The thickness and width of each cross section are also measured using the software in the second step. The third step is superimposing the two re-built models and calculating the gap values at key locations. Meanwhile, overall gap distributions can also be obtained by the reverse engineering software.

4.3.3 Data Analysis and Fit Evaluation

An in-depth analysis of clothing fit can be carried out using the extracted fit analysis data. The cross sectional circumferences and the areas of the body help designers determine the preliminary fit performance of the clothing, namely whether the clothing is too loose, just fit or too tight to the wearer.

In addition, the detail relationship between the body and the clothing are analysed using the data extracted from the reverse engineering software. On the one hand, the thicknesses and widths of cross sections in two-state scans can be used to assess the loose, fit or tight levels at different locations of the body. The differences between the front and the back, the left and the right are important information to assess the clothing balance. On the other hand, the acquired gap values at key locations illustrate the detailed relationship, while the gap distribution projects the overall relationship between the clothing and the body. An objective conclusion on clothing fit can be drawn with all these numerical data.

4.3.4 Application of Fit Evaluation Results to Pattern Improvement

The fit evaluation results pin point the locations where clothing sample has excess or insufficient wearing ease. The numeric data also help to determine the exact surplus or shortage values of the wearing ease. Therefore, the corresponding modifications on clothing pattern are discussed to improve the fit performance of the clothing pattern.

4.4 Data Extraction Results

4.4.1 Data Extracted by 3D Body Scanning System

In the experiment, 23 body measurements were extracted using the body scanning software system. Among the 23 measurements, 11 circumferential measurements are used for objective fit evaluation, including the chest, waist, hip, neck base, upper arm, elbow, wrist, mid-thigh, knee, calf, and ankle girths. Meanwhile, photographs were taken of the subject wearing the sample garment.

Table 4-3 Differences of the 11 body circumferences

Girths (cm)	Subjects					Mean	SD
	1	2	3	4	5		
Chest	2.88	3.77	3.36	2.70	1.30	2.80	0.94
Waist	2.60	1.19	1.29	2.67	2.08	1.96	0.70
Hips	0.53	0.27	0.10	0.01	2.05	0.59	0.84
Neck Base	-2.12	-0.01	-0.45	-0.70	-0.15	-0.69	0.85
Upper Arm	1.03	1.21	3.66	0.39	0.52	0.95	1.72
Elbow	0.74	0.88	1.50	1.05	0.68	0.97	0.33
Wrist	1.53	2.08	1.40	1.50	1.70	1.64	0.27
Mid Thigh	0.64	1.32	0.82	0.02	0.46	0.65	0.48
Knee	0.92	1.73	0.91	0.93	0.99	1.09	0.36
Calf	1.50	0.55	0.46	0.65	0.74	0.78	0.42
Ankle	1.03	2.09	2.57	1.25	2.26	1.84	0.67

The measurement differences between the two-state body scans are listed in Table 4-3. The circumference measurements for the subject's body with only underwear were subtracted from the same measurements for subject wearing the clothing sample. All circumferential differences are positive values except the neck base measurement. Positive differences imply that there are gaps between the clothing and the body in the corresponding locations. Negative difference in neck base reveals that the neck opening is a tight-fit design.

Among all positive differences, chest circumference has the largest mean value. The second largest is the waist and the third is the ankle. Moreover, the wrist, knee, and elbow also have large positive differences. The hip has the smallest positive difference between the two states.

Table 4-4 Differences of the cross-sectional areas

Cross-sectional	Subjects						
area (cm^2)	1	2	3	4	5	Means	SD
Chest	37.87	37.19	37.06	38.25	38.35	37.75	0.60
Waist	36.26	35.70	36.63	35.76	36.78	36.23	0.49
Hips	28.35	29.69	28.79	31.31	26.79	28.97	0.49
Neck Base	-4.66	-5.96	-5.40	-5.51	-5.02	-5.31	0.50
Upper Arm	4.59	4.77	3.39	3.88	3.37	3.99	0.66
Elbow	5.01	5.54	5.54	4.27	5.11	5.09	0.52
Wrist	3.52	3.55	4.23	4.24	3.84	3.87	0.35
Mid Thigh	12.03	13.60	13.77	14.83	12.29	13.31	1.15
Knee	7.70	7.14	7.41	7.59	7.46	7.46	0.21
Calf	3.41	3.87	3.98	3.62	3.94	3.76	0.24
Ankle	16.82	16.17	16.57	17.32	15.55	16.49	0.67

In addition to extracting girth measurements, TC^2 software system was also used to acquire and extract the areas of different cross sections, which are shown in Table 4-4. Again, except for the neck base, the cross section areas of all the other 10 locations increased after the subjects put on the sample garments. Among these area data, the chest has the maximum increase, and the waist and hip ranked the second and the third, respectively. The calf area has the smallest increase.

4.4.2 Data Extraction by Reverse Engineering Software

Two digital human models can be re-built from the two-state scans in reserve engineering software. Necessary data cleaning and hole-filling steps were performed. After which, the 11 cross sections were extracted by the software tool, and the detail coordinates of all data points along the circumference of the cross section were obtained. Therefore, the thickness and width of each cross section can be calculated based on the data point coordinates. The differences of the two-state measurements were calculated and shown in Table 4-5.

There is a negative circumferential difference in the neck base area because the sample garment has a tight-fit design. For the rest of the 10 measurements, positive differences in thickness and width are obtained. The waist and the hip measurements have the biggest and second biggest increases in thickness, and the knee has the smallest increase in thickness. In terms of width, the chest has the biggest increase, and the calf has the smallest increase. Among the 10 measurements, seven measurements have larger increases in the width than in the thickness, except the waist, the hip and the calf.

Table 4-5 Differences in thicknesses and widths of cross-sections

Unit: cm	1		2		3		4		5		Mean		Std. Dev	
	T*	W*	T	W	T	W	T	W	T	W	T	W	T	W
Chest	0.31	1.68	0.62	3.09	0.14	1.99	0.26	2.88	0.02	2.09	0.27	2.35	0.23	0.61
Waist	1.41	0.14	1.10	0.38	1.78	0.99	0.96	0.10	1.52	0.04	1.35	0.33	0.33	0.39
Hips	0.99	0.87	0.85	0.18	0.73	0.45	0.22	0.05	0.59	0.48	0.68	0.41	0.29	0.32
Neck Base	-0.04	-0.35	-0.08	-0.42	-0.10	-0.38	-0.15	-0.24	-0.14	-0.07	-0.10	-0.29	0.05	0.14
Upper Arm	0.28	0.89	0.22	0.8	0.49	-0.02	-0.02	1.06	0.20	0.28	0.23	0.60	0.18	0.45
Elbow	0.13	0.97	0.34	0.33	0.56	0.21	-0.02	0.09	0.44	0.51	0.29	0.42	0.23	0.34
Wrist	0.501	1.29	0.54	0.67	0.57	0.46	-0.07	-0.44	0.41	0.42	0.39	0.48	0.27	0.62
Mid Thigh	-0.02	0.41	0.32	0.63	0.22	0.68	0.24	0.59	0.50	0.09	0.25	0.48	0.19	0.24
Knee	-0.02	0.34	0.32	0.39	0.27	0.61	0.15	0.38	0.26	0.38	0.19	0.42	0.14	0.11
Calf	0.35	0.30	0.25	0.12	0.35	0.24	0.31	0.19	0.34	0.33	0.32	0.24	0.42	0.09
Ankle	0.35	0.91	0.46	0.81	0.15	0.33	-0.76	-0.06	0.46	0.98	0.27	0.45	0.22	0.75

Subjects: 1–5

* T=thickness, W=width

Table 4-6 Gap values between the clothing and the body in 11 body circumferences (front and back)

	Subjects													
Unit: cm	1		2		3		4		5		Mean		Std. Dev	
	F*	B*	F	B	F	B	F	B	F	B	F	B	F	B
Chest	0.15	0.58	0.22	0.70	0.28	0.54	0.19	0.50	0.18	0.24	0.20	0.51	0.05	0.17
Waist	0.42	1.71	0.47	1.45	0.70	1.15	0.65	1.85	0.61	1.34	0.57	1.50	0.12	0.28
Hips	0.41	0.40	0.60	0.65	0.47	0.41	0.47	0.57	0.21	0.70	0.43	0.55	0.14	0.14
Neck Base	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Upper Arm	0.00	0.33	0.17	0.00	0.14	0.40	0.23	0.47	0.23	0.16	0.15	0.27	0.09	0.19
Elbow	0.00	0.27	0.19	0.25	0.49	0.13	0.22	0.22	0.52	0.10	0.28	0.19	0.22	0.08
Wrist	0.84	0.86	0.32	0.89	0.74	0.90	0.86	0.55	0.31	0.51	0.61	0.74	0.28	0.19
Mid Thigh	0.18	0.13	0.00	0.00	0.27	0.21	0.17	0.20	0.22	0.39	0.17	0.19	0.10	0.14
Knee	0.35	0.33	0.00	0.39	0.23	0.36	0.20	0.49	0.37	0.49	0.23	0.41	0.15	0.07
Calf	0.37	0.38	0.49	0.28	0.15	0.38	0.33	0.59	0.41	0.53	0.35	0.43	0.13	0.13
Ankle	0.16	0.52	0.36	0.55	0.28	0.52	0.33	0.51	0.34	0.55	0.29	0.53	0.08	0.02

* F=front, B=back

As discussed, the reverse engineering software allows the superimposition of the two human models, so that the gaps between the two models can be extracted. In the proposed method, the models obtained from the two-state scans are superimposed along the central axle. Once the two models are matched properly, all gap values at the 11 locations are extracted, which include the front (F), back (B), left side (L) and right side (R) values. The extracted gap values are listed in Table 4-6 and Table 4-7, respectively.

As shown in Table 4-6, all cross sections have positive front and back gap values between the clothing and the body, except for the neck base circumference (values are 0.00). The waist has the maximum mean value of gap, and large gaps are found in the back waist. The second largest gap is found in the wrist circumference. The mid-thigh circumference has the smallest gap value. It is found that all body circumferences have larger gap values in the back than in the front, except for the elbow.

Table 4-7 displays the gap values of the left and right sides, and it is found that the chest circumference has the biggest gap. The wrist and the ankle rank the second and the third, respectively. The waist circumference has the smallest gap value.

By comparing Tables 4-6 and 4-7, it is found that the waist, the hip and the calf circumference have larger gap values in the front and the back than on the left and the right sides. The rest of the 7 body circumferences have larger gaps on the left and the right sides than in the front and the back. The gap value results are consistent with the results of the thickness and width at each cross section.

Table 4-7 Gap values between the clothing and the body in 11 body circumferences (right and left side)

	Subjects													
Unit: cm	1		2		3		4		5		Mean		Std. Dev.	
	R*	L*	R	L	R	L	R	L	R	L	R	L	R	L
Chest	0.91	0.70	0.95	0.98	0.75	0.81	0.55	0.68	1.01	0.66	0.83	0.77	0.19	0.13
Waist	0.27	0.33	0.10	0.00	0.14	0.46	0.31	0.25	0.00	0.10	0.16	0.23	0.13	0.18
Hips	0.23	0.25	0.31	0.27	0.25	0.19	0.44	0.59	0.36	0.39	0.32	0.34	0.09	0.19
Neck Base	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Upper Arm	0.33	0.36	0.45	0.51	0.47	0.50	0.22	0.47	0.49	0.25	0.39	0.42	0.11	0.11
Elbow	0.37	0.35	0.55	0.58	0.43	0.53	0.38	0.57	0.48	0.27	0.44	0.46	0.07	0.14
Wrist	0.85	0.95	0.86	0.96	0.95	0.98	0.96	0.95	0.50	0.57	0.82	0.88	0.19	0.17
Mid Thigh	0.11	0.13	0.00	0.00	0.45	0.42	0.41	0.20	0.28	0.27	0.25	0.20	0.19	0.16
Knee	0.60	0.68	0.45	0.40	0.59	0.61	0.66	0.75	0.59	0.56	0.58	0.60	0.08	0.13
Calf	0.27	0.32	0.30	0.32	0.37	0.31	0.35	0.30	0.30	0.35	0.32	0.32	0.02	0.02
Ankle	0.65	0.55	0.58	0.55	0.74	0.82	0.75	0.65	0.80	0.78	0.70	0.69	0.09	0.11

* R= right side, L=left side

4.5 Clothing Objective Fit Evaluation

4.5.1 Fit Analysis Based on Cross-sectional Girth and Area Measurements

In order to preciously evaluate the clothing fit, the influence of fabric thickness on body girth measurement should be analysed. Usually, the torso, arm and leg of a human body can be approximated as cylinder shapes, and each body girth measurement can be viewed as the circumference of the approximating cylindrical cross section. The girth measurement of the body without the clothing sample is first calculated by the following formula:

Naked body girth measurement = cross section circumference of approximating cylinder

$$= 2\pi r \tag{4-1}$$

where r is the radius of the approximating cylinder.

When the subject puts on a clothing sample, a new circumference can be calculated:

$$\text{Girth measurement for body with garment} = 2\pi(r + T_{fabric}) \tag{4-2}$$

where r is the radius of the approximating cylinder and T_{fabric} is the thickness of the fabric.

According to formula (4-1) and (4-2), the net measurement gained from fabric thickness is calculated as $2\pi T_{fabric}$. As shown in Table 4-2, the thickness of the fabric used in this experiment is 0.071 cm, so the extra length gained from fabric thickness should be 0.45 cm.

The experimental results of the two-state measurement differences are shown in Figure 4-8. As illustrated in the figure, when the measurement gained from the fabric thickness is subtracted from the two-state measurement difference, it is found that only the chest, the waist, the ankle and the wrist have over 1.00 cm increase in net circumference measurements, and the rest of the measurements have very small net increases. The results indicate that the clothing samples have just-fit design in all areas, except the chest, the waist, the neck base, the wrist and the ankle.

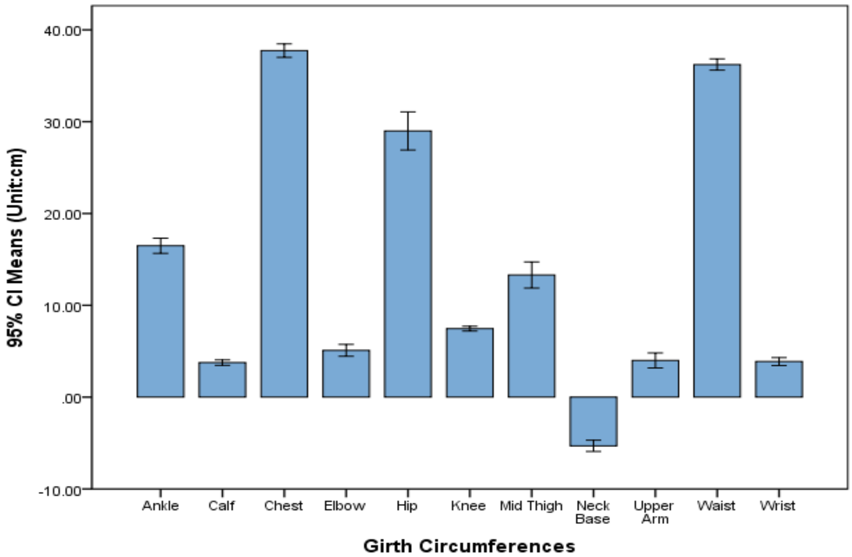


Figure 4-8 Differences between body circumference measurements with and without clothing sample

Similar to the net measurement gain, the cross sectional area gain due to fabric thickness can also be calculated and the results are shown in Figure 4-9. The area gain analysis provides additional information for clothing fit evaluation.

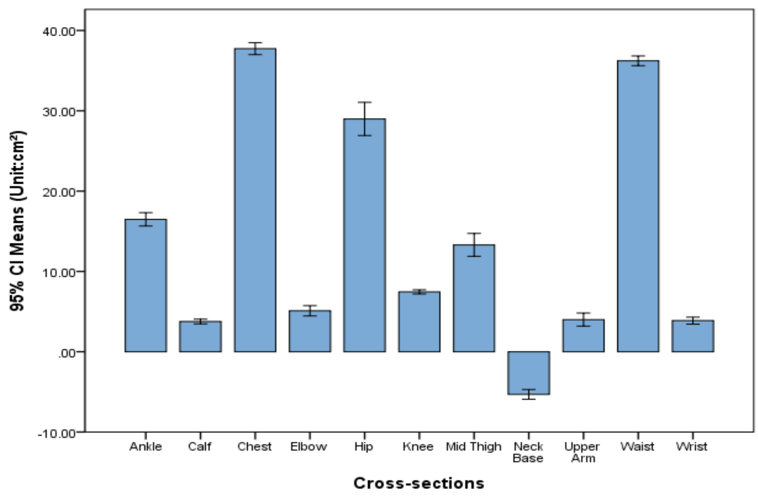


Figure 4-9 Area differences between cross sections with and without clothing sample

Although clothing fit can be evaluated based on the cross sectional circumference and area measurements, the analysis is still preliminary: Detailed data is absent to explain the relationship between the clothing and the body. Designers have no idea about the gap value at different parts of the clothing and also the overall gap distribution. Because of this limitation, reverse engineering software is used further to analyse the clothing fit.

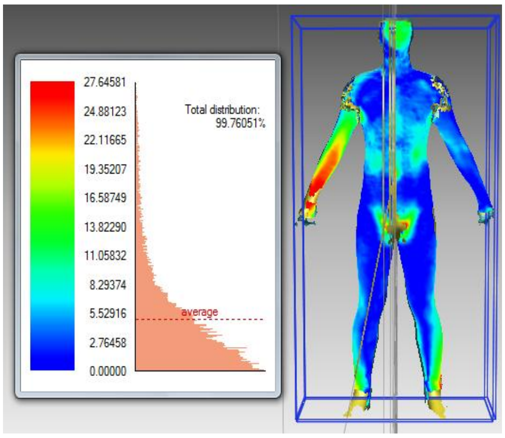
4.5.2 Fit Analysis Based on Thickness and Width of Body Cross Sections

The early analysis results indicated that the sample clothing have less satisfactory fit at the chest, the waist, the ankle and the wrist. The detailed relationship between the body and the clothing in these places were further analysed using data extracted by the reverse engineering software. As shown in Table 4-5, it is found that the waist cross section has larger gap value in the thickness than in the width. The detail thickness analysis of Table 4-6 indicated a larger gap value at the back (B) than that at the front (F), which means that the clothing at the back waist is looser than that of the front waist. This can be explained by the geometric feature of the human's vertebra, which forms a hollow shape at the back waist. Moreover, Table 4-5 also indicated that the other three not-so-fit areas (the chest, the wrist and the ankle) have larger width gap values compared with the thickness. Among the three cross sections, the chest has the largest width gap values.

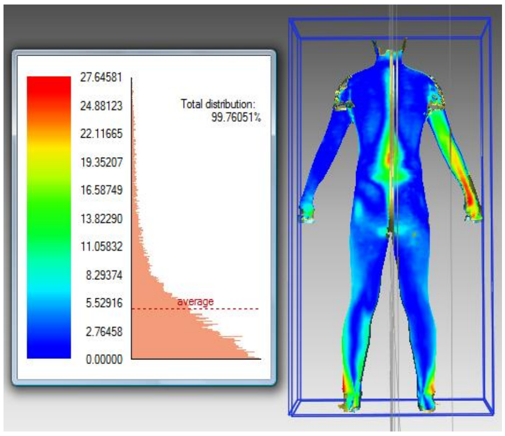
4.5.3 Fit Analysis Based on Gap Values between Clothing and Body

In addition to the width and the thickness, the gap values of the front, the back, the left side and the right side, as shown in Tables 4-6 and 4-7, provide more numeric data for designers to understand the detailed relationship between the clothing and the body in specific areas. The chest has the maximum gap value on the right side (0.83 cm) and the minimum gap value in the front (0.20 cm). In the waist area, the maximum gap value is at the back (1.50 cm) and the minimum is on the right side (0.16 cm). In the ankle area, the maximum gap value is on the right side (0.70 cm) and the minimum is in the front (0. 29 cm). In the wrist area, the maximum gap value is found on the left side (0.88 cm) and the minimum is found in the front (0.61 cm). The four numeric gap values provide designers with detailed information on which area of the clothing is loose and how loose it is. For example, it is found that the back waist is the loosest area of the sample garment. Another example is that a larger gap value at the wrist than at the ankle means that the fit of the wrist is looser than that of the ankle.

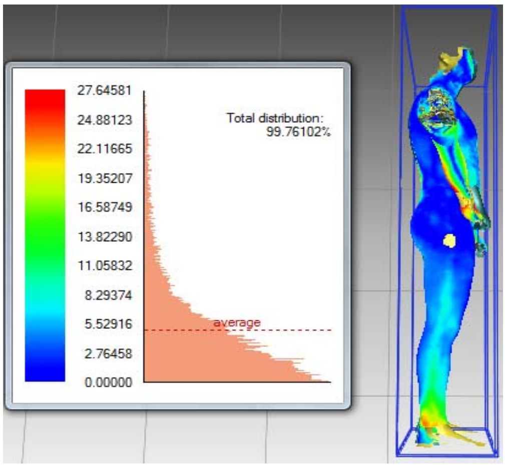
Moreover, the reserve engineering software can visually display the gap distribution in addition to the numeric data on fit, as shown in Figure 4-10. In the gap distribution map, different colours represent different fitting conditions. Blue colour represents a just-fit condition with the gap value close to 0.00 cm. Red colour represents a loose-fit condition, where the gap value is about 3.00 cm (about 27mm) in the example. The colour map of Figure 4-10 shows that the chest, the waist, the ankle and the wrist are in loose-fit condition, and there is a large gap in the back waist area. The remaining parts of the body are shown in blue colour, implying a just-fit condition in these areas.



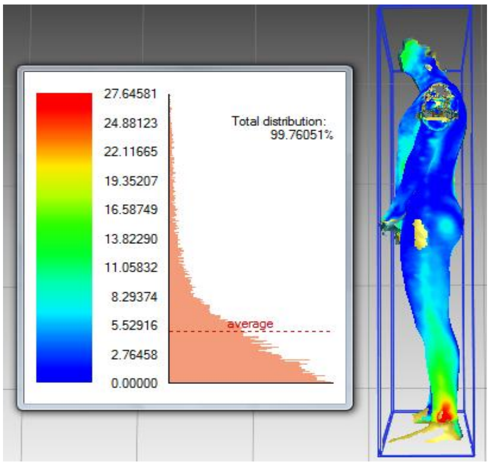
a) Front view



b) back view



c) right side view



d) left side view

Figure 4-10 Distribution of gaps between the clothing and the body

Based on the data extracted from the 3D body scanning system and the reverse engineering software, the clothing fit of the sample garments can be objectively evaluated, and the findings are summarised as follows. The neck base design is tight fit, and the garment has just-fit design in most areas except for the chest, the waist, the ankle and the wrist, in which loose-fit designs are found. In these loose-fit areas, bigger gaps are found in the front and back waist areas (the thickness of the waist) than the left and right sides of the waist (the width of the waist). On the contrary, bigger gaps are found in the left and right sides (the widths) than at the front and back (the thicknesses) of the chest, the ankle and the wrist cross sections.

4.6 Applications of Fit Evaluation Results to Pattern Improvement

It is clear from the objective fit evaluation that some parts of the sample garment are too tight, such as the neck base area, and some parts are too loose, like the chest, ankle and wrist areas. The static block patterns, from which the sample garments were developed, should be carefully modified to improve the overall clothing fit.

In the neck base cross section, the thickness, width and gap values indicate that wearing ease is not sufficient in both the front and the back, and also in the left and the right sides. To increase the wearing ease of the neck opening, both the width and the depth of the neck should be extended. The differences of the thickness and width of the neck base girth in Table 4-5 determine that the neck width and depth should be extended by 0.3cm and 0.1cm, respectively (see Figure 4-11).

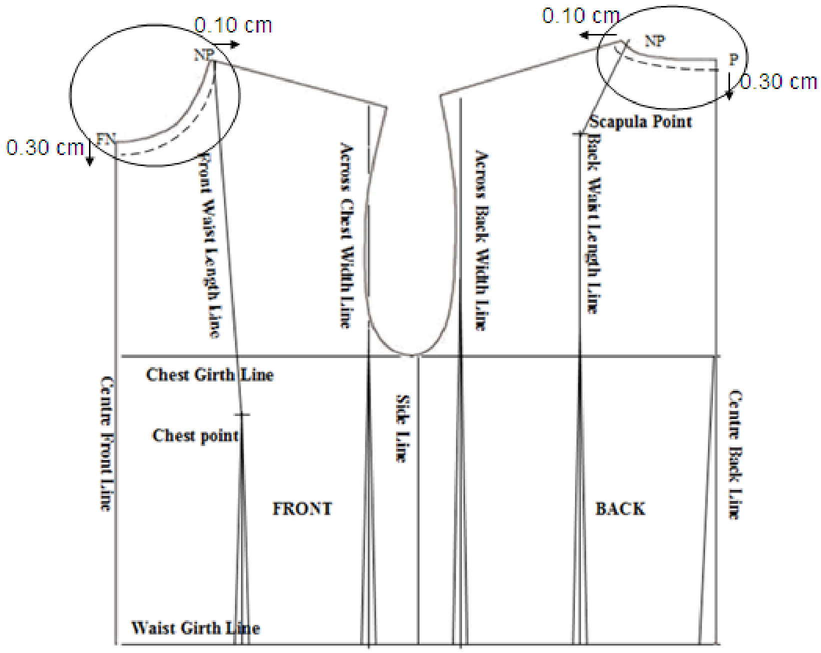


Figure 4-11 Modifications in neck base girth

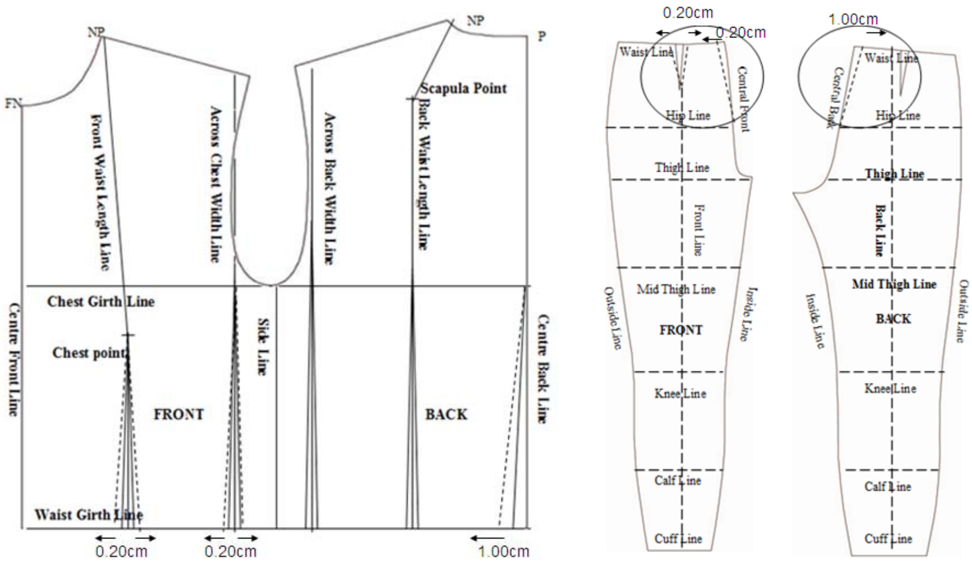


Figure 4-12 Modifications in waist girth

On the waist cross section, a larger gap is found in the thickness (front and back) than that in the width (left and right sides). The wearing ease at the back waist is in excess. This extra ease can be removed by introducing a dart at the waist along the centre back line, and the size of the dart is determined by the difference of the front and back gap value (Table 4-6), which is 1.00 cm in this experiment. Meanwhile, darts with value of 0.40 cm are added in front piece, as shown in Figure 4-12.

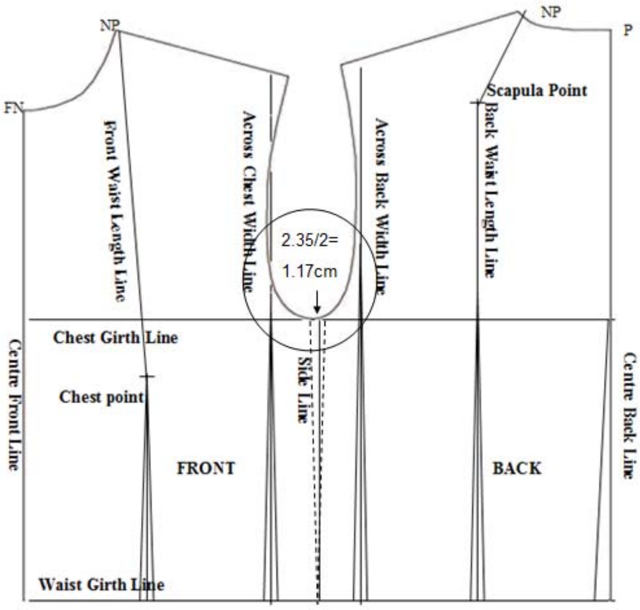


Figure 4-13　Modifications in chest girth

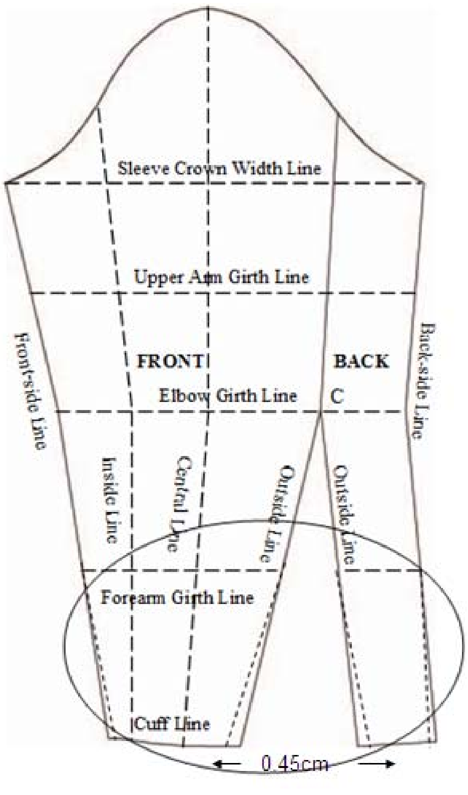


Figure 4-14　Modifications in wrist girth

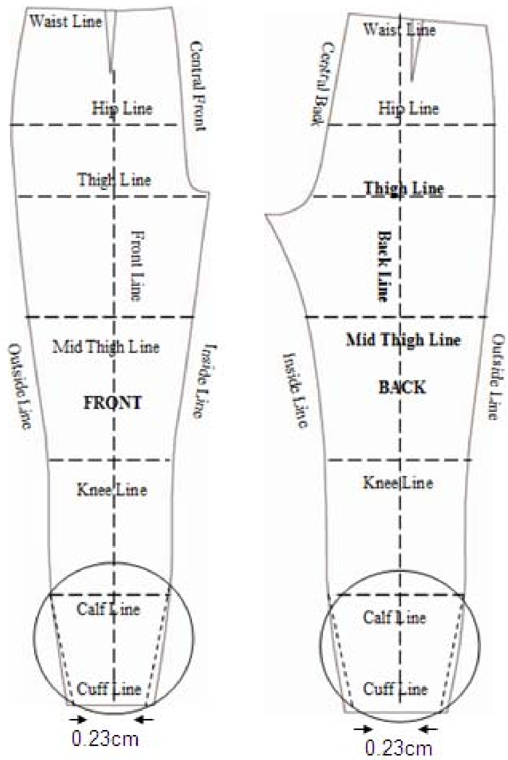


Figure 4-15 Modifications in ankle girth

For the chest, ankle and wrist cross sections, the differences in width are larger than that in thickness, meaning bigger gap values (excess eases) are found in the left and right sides of these cross sections. To improve the clothing fit, the pattern pieces should be modified by adjusting the connecting lines of the front and back pieces, reducing wear eases at both sides, as shown in Figures 4-13, 4-14 and 4-15. The amounts of ease to reduce in the three girth measurements are 2.35 cm, 0.45 cm and 0.45 cm, respectively.

By introducing the described modifications, the static block patterns with just-fit design are improved. The resulted block patterns became the foundation to construct dynamic block pattern, which will be discussed in Chapters 5 and 6.

4.7 Conclusions

In this chapter, a new method has been proposed to integrate 3D body scanning and reverse engineering techniques for objective fit evaluation. The circumference and area measurements can be obtained from body scans with and without putting on the sample garment. The measurement differences of two-state scans are used for initial fit analysis. In addition, six parameters including the thickness and the width of each cross section, the front, the back, the left and the right gap values can be extracted using reverse engineering software for detailed fit evaluation. These data are useful for understanding the detailed relationship between the clothing and the body. By superimposing the two-state scan models, the gap distribution map can visually display the clothing fit. The experimental and analysis results have shown that the proposed method is effective for objective clothing fit evaluation.

The fit performance of clothing sample made from the static block patterns with just-fit design developed in Chapter 3 has been evaluated by the proposed method. It is found that the neck base design is tight fit, and other areas are just-fit, except for the chest, the waist, the ankle and the wrist, which have loose-fit design. Detail fit analysis has been carried out in the tight-fit and loose-fit areas. Modifications to the static block patterns with just-fit design have been proposed based on the fit evaluation results.

CHAPTER 5 BODY MEASUREMENTS IN DYNAMIC POSTURES

5.1 Introduction

In Chapters 3 and 4, one effective method has been provided to develop static block patterns with just-fit design. This static block pattern is not the final product pattern and new dynamic block pattern must be constructed by adding necessary ease values in static block pattern. In order to construct dynamic block pattern and fulfil the requirements of clothing freedom, the changes of body measurement in static state and during dynamic movement should be studied.

Clothing freedom is an important function because garment size must be properly designed to provide the wearer with sufficient room for body movement. Clothing freedom is controlled by many factors, among which the design of clothing ease is the most crucial one. Generally speaking, clothing ease is defined as the difference between human body measurement and garment size (Huck et al., 1997), and it includes two kinds of ease: wearing ease and design ease. Wearing ease is the amount of ease that ensures physiological comfort and mobility; while the design ease is the additional amount of ease for special style design (Adriana and Susan, 2008). In these two kinds of ease, wearing ease determines the overall clothing freedom. A proper design of wearing ease can provide sufficient space between the body and garments, thus improving wearers' mobility and comfort. In contrast, improper design of wearing ease hampers body movement and constrains the performance of clothing functions. Certain designs of sleeve, for example, with deep and narrow sleeve crown, can be an attractive shape to wearers, but is not suitable for active clothing because such sleeve design prevents wearers from lifting their arms above their heads (Liu, 2007). In short, defining appropriate wearing ease in garment patterns is fundamentally important for clothing product development.

In clothing manufacturing, experienced patternmakers decide the amount of wearing ease to use in different parts of the pattern. For example, a small amount of wearing ease, such as 0-2cm, is usually recommended for waist circumference, while much larger ease is needed for the hip area in the patternmaking of trousers. These recommended wearing ease values are determined by subjective judgments, which patternmakers acquire through trial and error and years of practice (Bray and Haggar, 1986). Patternmakers usually determine the appropriate wearing ease values for different types of clothing and body figure, and apply those in the process of patternmaking. It is important to note that subjective judgment is a common practice in the apparel industry to decide wearing ease values. However, subjective judgment has an obvious drawback of inconsistency: different patternmakers use different wearing ease values even for the same garment style. Subjective judgment on wearing ease is therefore not accurate or precise enough for high performance clothing, such as sportswear or protective garments. On the other hand, objective methods have also been used to analyse the skin surface expansion and contraction of the body during body movements, from which desired wearing ease values are defined. One approach is to measure the human body in both the static state and dynamic postures using traditional manual methods and 3D body scanning. The measurement differences between the two states are calculated and regarded as the minimum wearing ease for patternmaking. Another approach is to draw grid lines on the body skin surface of a subject, and then measure the dimensional changes of these grid lines when the subject moves. The circumferential, horizontal and vertical changes of grid lines can be used to determine the location and the amount of wearing ease in girth, width and length.

Over the years, many anthropometric experiments have been carried out to study the changes of body measurement in static and dynamic states. Kirk and Ibrahim (1996) studied the relationship between the stretching of the body skin and clothing fit using elastic fabrics. In their study, both horizontal and vertical skin stretches at the buttocks, crotch, back, elbow and knee were measured in three dynamic postures: bending, stretching and sitting. Koblyakova (1980) measured the body circumferences of above chest, at chest, and at waist in two states: relaxed state and a state of taking a deep breath. Based on the differences between the two states, the necessary minimum ease values for upper-body garment were calculated as a percentage of the circumference value to the value in the relaxed state. Huck et al. (1997) studied the crotch (vertical circumference) ease and evaluated the clothing fit. They suggested a crotch ease of 17cm (6.7 inch) by analysing different body postures, such as bending and crouching. They found that the fitting was too loose if more than 17cm crotch ease was used; in contrast it was too tight with less than 17cm ease.

In all these investigations, the changes of body measurements in the static state and in dynamic postures were calculated as the corresponding wearing ease values to use in patternmaking. However, these studies have some drawbacks. On the one hand, only a small number of body measurements and dynamic postures were studied, and the relationships between dynamic postures and changes of body measurement have not been systematically analysed. On the other hand, no patternmaking method has ever been proposed to integrate the obtained wearing ease to fulfil the requirements of clothing freedom. Therefore, the study in this chapter aims to propose a method for the collection and analysis of body measurements in different postures, and their relationship to body movements. Based on the research results, the optimal wearing ease values are determined, and they are the foundation to construct dynamic block pattern.

5.2 Research Methodology

To develop a dynamic block pattern with ensured wearing comfort and fit, anthropometric data of subjects in static and dynamic states are collected and analysed. The optimal wearing ease values are determined as the maximum increases of body measurement between the two states.

5.2.1 Acquisition of Body Anthropometric Data in Static State and Dynamic Postures

The same subjects conducted experiments in Chapters 3 and 4 were recruited to take part in this new study.

Traditional manual tape measurement is the most common method for the collection of anthropometric data. Apart from the traditional tape measurement, 3D body scanning is another measuring method, which can obtain body measurements without any body contact, in a quicker and less invasive way (Liu and Kennon, 2006). However, 3D body scanning is not suitable for the measurement of the body in dynamic postures because some areas are difficult to scan such as the armhole areas (Zheng et al., 2007), which in turn affects the overall accuracy of the measurements. Therefore, traditional manual tape measurement method was used in this study.

In order to collect accurate anthropometric data during static state and dynamic postures, 74 anatomical landmarks were identified based on ISO 8559-1989 for each subject. As shown in Figure 5-1, these 74 landmarks are put on the neck (4 markers), chest (16 markers), waist (8 markers), hip (8 markers), shoulders (2 markers), arms (16 markers), as well as legs (20 markers). With these landmarks, 30 body measurements were obtained for each subject, which include (a) 14 girth measurements: neck base, chest, waist, hip, armscye, upper arm, elbow, forearm, wrist, thigh, mid thigh, knee, calf, and ankle; (b) 13 length measurements: front waist, back waist, 7th-cervical to waist, underarm to waist , total crotch, crotch depth, arm (central, outside and inside), and leg (outside, inside, front and back); and (c) 3 width measurements: across shoulder, across chest and across back.

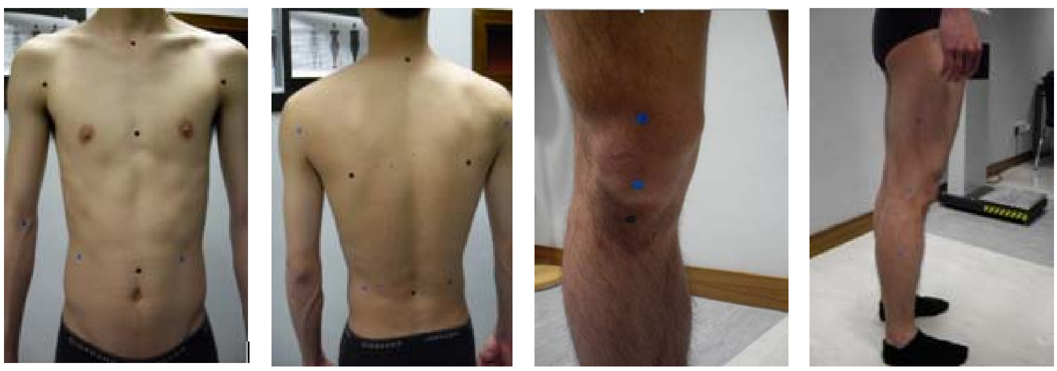
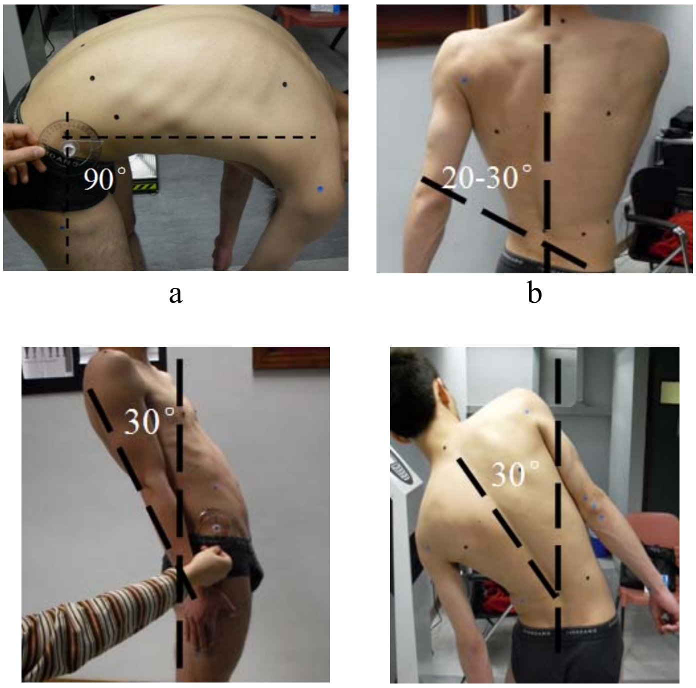


Figure 5-1 Anatomical landmarks for taking body measurements

It is also important to understand how people complete different body movements, which is necessary for the analysis of the change in human skin surface during body movement. The movements of the body are accomplished by a chain of complex reactions of nerve cells and muscle fibres (Watkin, 1995). All body movements can be decomposed into a series of dynamic postures, which are the results of different joint movements. Dynamic postures of the human body have been studied in sport science and clothing pattern construction. Yesis (2000) studied the body postures in running. Liu (2005a) described the geometric characteristics of common dynamic postures of the human body in terms of direction and angle. With reference to the comprehensive study of human body motion (Hamilton et al., 2008) together with the review of related literature on body running postures (Tozeren, 2000; Galloway, 2002)given in Sections 2.2.1 and 2.2.2, 17 dynamic postures, due to waist, elbow, shoulder, hip and knee joint movements, can explain most of the human body movements including running exercise. These 17 dynamic postures are investigated in this paper, and Figures 5-2 to 5-4 illustrate the 17 postures.



a b

c d

Figure 5-2 Dynamic postures of waist movements (a, b, c and d)

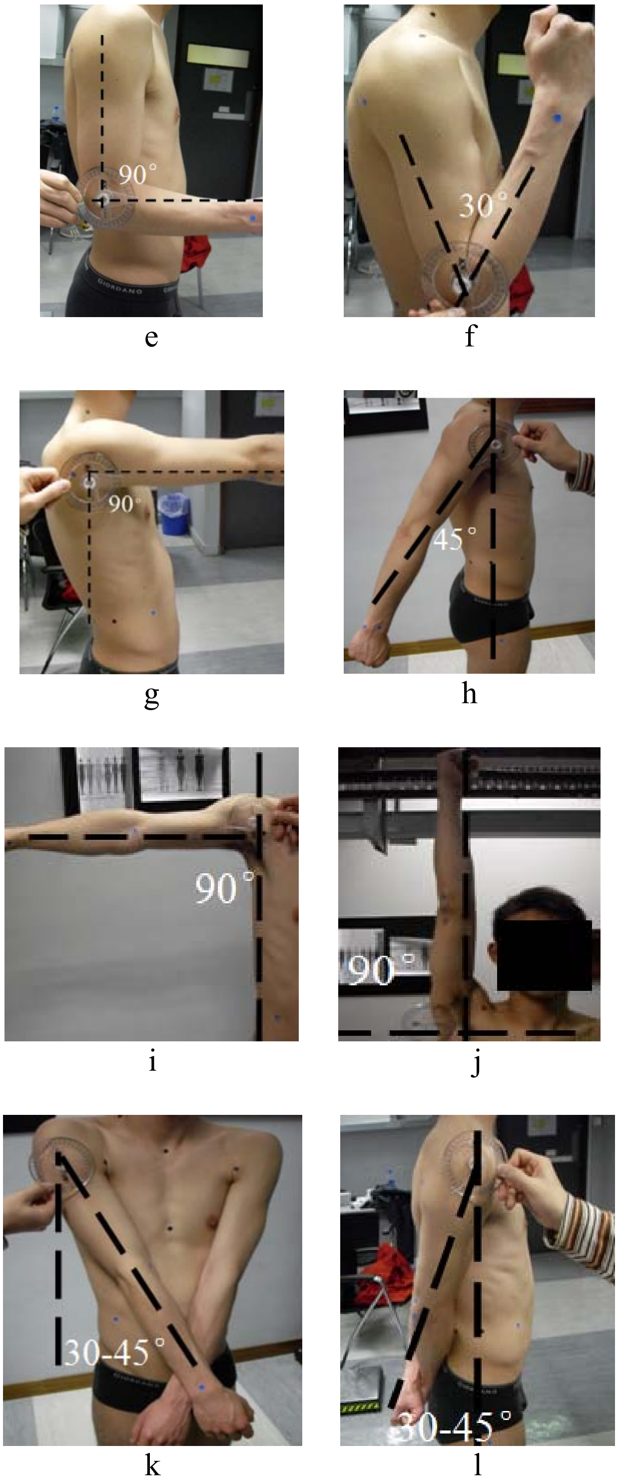
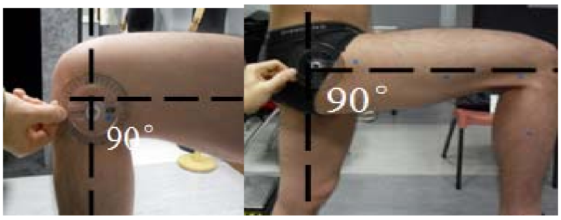
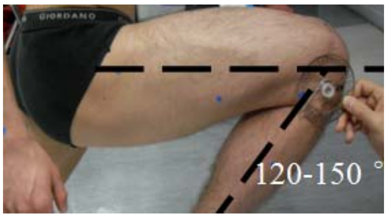


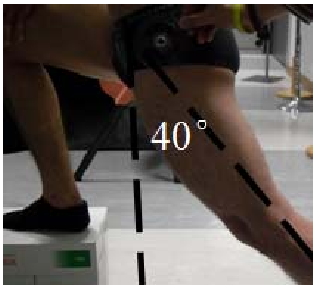
Figure 5-3 Dynamic postures of elbow and shoulder joint movements (e, f, g, h, i, j, k and l)



m

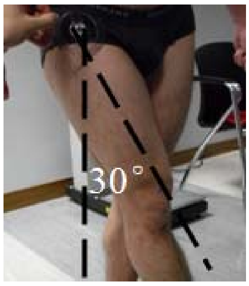


n



o

p



q

Figure 5-4 Dynamic postures of hip and knee joint movements (m, n, o, p and q)

In this study, 30 body measurements were taken manually. A plastic measuring tape was used to obtain all measurements except for the weight and the height. A goniometer was used to help subjects to keep correct postures when taking measurements (Zheng, 2007; Huck, 1991). The 30 measurements were collected in two states: static state and dynamic postures. In the static state, each subject wearing tight-fit underpant was required to take a normal standing posture with the feet slightly apart, standing up straight, arms hanging naturally and looking straight ahead (ISO 8559:1989). Then, each subject was asked to perform the 17 dynamic postures (Figures 5-2 to 5-4), and the same 30 measurements were collected in every posture. Each measurement was repeated three times to calculate the mean value to ensure accuracy.

5.2.2 Data Analyses

In this study, the differences between the body measurements in the static state and in the dynamic postures were calculated. Three statistical methods including descriptive statistics, factor analysis and one-way analysis of variance (abbreviated: one-way ANOVA) were used.

Descriptive statistics describes the characteristics of the data, and important numerical descriptive statistics include the mean, standard deviation, standard error, and minimum and maximum values. In this study, descriptive statistics was used to describe body measurements in the static state, the differences between body measurements in the static state and in dynamic postures, and suggested wearing eases. Factor analysis was used to identify important body measurements, called key measurements, among the 30 body measurements examined. One-way ANOVA was used to analyse the impacts on key measurements due to the human body dynamic movements.

5.2.3 Determination of Wearing Ease Values Used in Dynamic Block Patterns

In the apparel industry, static block pattern with just-fit design is a clothing pattern constructed based on the body measurements of the static state. Clothing made from this block pattern is not ready to wear, because the necessary wearing ease has not yet been incorporated in the pattern. Dynamic block pattern should be constructed with optimal wearing eases incorporated in the static fitted block patterns to provide the required clothing freedom and comfort. For this reason, determining the wearing ease values is a very important step of running wear pattern development and in this study they are acquired based on analysis results on the differences of body measurements in static state and dynamic postures, and the determination of key measurement.

5.3 Results and Discussion

5.3.1 Measuring Results of Subjects in the Static State

Tables 5-1 and 5-2 are the measuring results of the 5 subjects in the static state. Table 1 shows that the 5 subjects have a mean stature of 173.2 cm, and the BMI values of all subjects (Maximum: 22.79/ Minimum 21.22) indicate that their body figures belong to the normal type (BMI of 18-25) (Kagawa et al., 2006). Table 5-2 lists the maximum, minimum and mean values of 30 body measurements for the 5 subjects. The selected 5 subjects are Chinese males. According to the China National Standard for Size Designation of Clothes-Men GB1335-1997, the subjects belong to the same size group of 170/ 84/72A.

Table 5-1 Results of stature, weight and BMI of the subjects

Items	Min.	Max.	Mean	Std. Dev
Stature (cm)	170.00	175.00	173.20	2.17
Weight (kg)	65.00	69.00	66.40	1.95
BMI	21.22	22.79	22.14	0.60

Table 5-2 Body measurements of the subjects in static state

Body measurements		Min. (cm)	Max. (cm)	Mean (cm)	Std. Dev
Girth	Neck base	39.50	40.50	40.10	0.42
	Chest	95.00	98.00	96.40	1.29
	Waist	77.00	81.00	78.80	1.48
	Hip	93.00	99.00	95.50	2.78
	Armscye	38.00	44.00	41.20	2.46
	Upper arm	25.50	29.00	27.40	1.43
	Elbow	24.00	25.00	24.60	0.54
	Forearm	25.00	26.00	25.40	0.42
	Wrist	16.00	17.00	16.20	0.45
	Thigh	52.00	58.00	55.1 0	2.51
	Mid-thigh	44.00	49.50	45.99	2.27
	Knee	36.00	39.00	37.21	1.30
	Calf	35.00	3900	37.11	1.53
	Ankle	24.00	27.00	25.20	1.15
Width	Across shoulder	39.00	41.00	40.40	0.89
	Across chest	37.00	39.00	38.60	0.89
	Across back	38.00	40.00	39.20	0.84
Length	Front waist	45.00	46.00	45.60	0.55
	Back waist	49.00	51.00	50.00	0.79

7^{th}-cervical to waist	44.00	48.00	46.10	1.75
Underarm to waist	28.50	33.00	30.90	2.01
Total crotch	59.00	73.00	71.70	1.49
Crotch Depth	20.00	20.00	20.00	0.00
Central arm	54.00	56.00	54.90	0.89
Inside arm	50.00	52.50	51.50	1.00
Outside arm	52.00	55.00	53.60	1.14
Inside leg	71.17	75.09	72.73	1.62
Outside leg	102.00	104.00	102.60	0.87
Front leg	90.78	95.62	93.27	1.79
Back leg	97.50	101.06	99.19	1.63

5.3.2 Differences between Body Measurements in Static State and in Dynamic Postures

The differences between body measurements in the static state and in dynamic postures are calculated and shown in Table 5-3. These are presented as the mean values of the three measured values and the percentage of differences compared to the static state measurements.

Among all torso measurements listed in Table 5-3 (marked with 'UB' and 'LB'), hip girth has the most significant changes, in which the skin extends the most, by 5.60 cm (5.86%) when knee joints make the maximum forward bend (posture: n). The chest girth extension ranks second, namely 3.00 cm (3.11%) when the waist is bent forward by 90° (posture: a). In terms of the width and length measurements, the extension of across back is the biggest, 5.00cm

(12.76%), when arms make the maximum crossing over the body (posture: k). The length of the 7^{th}-cervical to waist, underarm to waist, front and back waist have similar extensions, i.e., 4.20cm, 4.40cm, 4.40cm, and 4.60cm respectively. In terms of the percentage change, the skin extension along the anatomical line of underarm to waist is the most significant (14.24%) and the second is armscye girth (10.92%). On the other hand, the neck base girth measurements do not change at all during dynamic movements.

For arm measurements (A) in Table 5-3, elbow girth and central arm length have the maximum extensions in girth and length of 7.40cm (30.08%) and 5.40 cm (9.84%) respectively. Among all arm measurements, the wrist girth measurements do not change during dynamic movements.

For leg measurements (L) in Table 5-3, knee girth has the maximum extension of 5.60cm (15.05%) when knee joints make the maximum bending backward (posture: n). In terms of length, back leg length extends the most by 5.50cm (5.55%) when the body bends forward by 90° (posture: a). The ankle girth measurements do not change during dynamic movements.

Table 5-3 Differences between body measurements in static state and dynamic postures acquired by manual method

Body measurements			Postures of waist joint movement				Postures of elbow and shoulder joint movement								Postures of hip and knee joint movement				
			a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q
Girth	Neck base (UB)	Mean (cm)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		[percentage:%]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
	Chest (UB)	Mean (cm)	**3.00**	0.20	0.20	-0.20	-0.50	0.60	1.40	-0.80	-0.60	-1.00	1.60	-0.80	0.00	0.00	0.00	0.00	0.00
		[percentage:%]	**[3.11]**	[0.21]	[0.21]	[-0.21]	[-0.52]	[-0.62]	[1.45]	[-0.83]	[-0.62]	[-1.04]	[1.66]	[-0.83]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
	Waist (UB/LB)	Mean (cm)	**2.00**	1.20	0.40	0.40	0.00	0.00	0.80	0.40	0.40	-0.80	0.20	0.20	0.60	0.80	0.80	0.60	0.60
		[percentage:%]	**[2.54]**	[1.53]	[0.51]	[0.51]	[0.00]	[0.00]	[1.02]	[0.51]	[0.51]	[-1.02]	[O.26]	[0.26]	[0.78]	[1.02]	[1.02]	[0.78]	[0.78]
	Hip (LB)	Mean (cm)	1.60	-0.60	0.60	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00	**5.60**	5.50	1.80	-0.60
		[percentage:%]	[1.68]	[-0.63]	[0.63]	[0.63]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[3.15]	**[5.86]**	[5.76]	[1.88]	[-0.63]
	Armscye (UB/A)	Mean (cm)	-3.00	4.40	2.00	0.20	3.20	**4.50**	-2.60	4.60	-4.20	-3.00	1.80	4.40	0.00	0.00	0.00	0.00	0.00
		[percentage:%]	[-7.28]	[10.68]	[4.85]	[0.49]	[7.77]	**[10.92]**	[-6.31]	[11.17]	[-10.19]	[-7.28]	[4.37]	[10.68]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
	Upper arm (A)	Mean cm)	-0.50	0.60	0.40	0.20	1.10	**3.10**	-0.20	1.40	-1.10	-1.30	0.70	1.10	0.00	0.00	0.00	0.00	0.00
		[percentage:%]	[-1.82]	[2.19]	[1.46]	[0.73]	[4.02]	**[11.31]**	[-0.73]	[5.11]	[-4.02]	[-4.74]	[2.55]	[4.02]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
	Elbow (A)	Mean (cm)	-0.40	0.60	0.60	0.40	2.00	**7.40**	-0.60	0.50	-0.70	-0.70	0.20	0.50	0.00	0.00	0.00	0.00	0.00
		[percentage:%]	[-1.63]	[2.44]	[2.44]	[1.62]	[8.13]	**[30.08]**	[-2.44]	[2.05]	[-2.85]	[-2.85]	[0.81]	[2.05]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
	Forearm (A)	Mean (cm)	-0.50	0.50	0.70	0.60	0.20	0.50	0.30	**1.10**	0.70	-0.70	0.50	0.30	0.00	0.00	0.00	0.00	0.00
		[percentage:%]	[-1.96]	[1.96]	[2.76]	[2.36]	[0.78]	[1.96]	[1.18]	**[4.33]**	[2.76]	[-2.76]	[1.96]	[1.18]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
	Wrist (A)	Mean (cm)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		[percentage:%]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]

	Thigh (L)	Mean (cm)	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	2.10	**2.80**	-1.00	1.80
		[percentage:%]	[0.73]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[3.63]	[3.81]	**[5.08]**	[-1.81]	[3.27]
	Mid thigh (L)	Mean (cm)	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.40	**1.80**	-0.80	0.80
		[percentage:%]	[0.43]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[3.04]	**[3.91]**	[-1.74]	[1.74]
	Knee (L)	Mean (cm)	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.60	**5.60**	-0.80	-1.00	1.60
		[percentage:%]	[2.15]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[6.99]	**[15.05]**	[-2.15]	[-2.68]	[4.30]
	Calf (L)	Mean (cm)	-0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**1.40**	1.20	-1.00	-0.40	-0.20
		[percentage:%]	[-0.01]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	**[3.77]**	[3.23]	[-2.69]	[-0.01]	[-0.01]
	Ankle (L)	Mean (cm)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		[percentage:%]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
Width	Across shoulder (UB)	Mean (cm)	-13.80	-2.80	1.20	0.20	1.00	0.60	-3.60	-4.30	-9.80	-17.40	**2.80**	-4.60	0.00	0.00	0.00	0.00	0.00
		[percentage:%]	[-34.16]	[-6.93]	[2.97]	[0.49]	[2.48]	[1.49]	[-8.91]	[-10.64]	[-24.26]	[-43.07]	**[6.93]**	[-11.39]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
	Across front (UB)	Mean (cm)	-9.20	2.80	1.20	0.80	1.10	1.60	-5.80	3.40	0.80	-8.00	-7.20	**4.00**	0.00	0.00	0.00	0.00	0.00
		[percentage:%]	[-23.83]	[7.25]	[3.11]	[2.07]	[2.85]	[4.15]	[-15.03]	[8.81]	[2.07]	[-20.73]	[-18.65]	**[10.36]**	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
	Across back (UB)	Mean (cm)	4.00	-3.60	1.60	0.60	1.00	-1.40	4.50	-5.20	-4.00	-2.80	**5.00**	-10.20	0.00	0.00	0.00	0.00	0.00
		[percentage:%]	[10.21]	[9.18]	[4.08]	[1.53]	[2.55]	[3.57]	[11.48]	[-13.27]	[-10.21]	[7.14]	**[12.76]**	[-26.02]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
Length	Front waist (UB)	Mean (cm)	-3.80	2.20	**4.40**	0.80	0.60	0.80	0.80	1.50	2.10	1.60	-2.00	2.40	0.00	0.00	0.00	0.00	0.00
		[percentage:%]	[-8.33]	[4.82]	**[9.65]**	[1.75]	[1.32]	[1.75]	[1.75]	[3.29]	[4.61]	[3.51]	[-4.39]	[5.26]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
	Back waist (UB)	Mean (cm)	0.80	-0.80	4.40	1.00	1.00	0.60	0.80	-0.60	1.40	**4.60**	0.80	-1.60	0.00	0.00	0.00	0.00	0.00
		[percentage:%]	[1.60]	[-1.60]	[8.80]	[2.00]	[2.00]	[1.20]	[1.60]	[-1.20]	[2.80]	**[9.20]**	[1.60]	[-3.20]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
	7^{th}-cervical to waist (UB)	Mean (cm)	4.40	-1.40	**4.20**	0.90	0.00	0.00	0.00	-1.00	0.20	0.60	0.40	-0.20	0.00	0.00	0.00	0.00	0.00
		[percentage:%]	[9.54]	[3.04]	**[9.11]**	[1.95]	[0.00]	[0.00]	[0.00]	[-2.17]	[0.43]	[1.30]	[0.86]	[-0.43]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]

Underarm to waist	Mean (cm)	4.00	2.60	3.60	1.40	0.00	0.40	2.20	2.00	3.90	**4.40**	0.60	0.60	0.00	0.00	0.00	0.00	0.00
(UB)	[percentage:%]	[12.95]	[8.41]	[11.65]	[4.53]	[0.00]	[1.23]	[7.12]	[6.47]	[12.52]	**[14.24]**	[1.94]	[1.94]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
Total crotch (LB)	Mean (cm)	0.80	1.00	0.60	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.40	**1.70**	1.50	0.80	1.30
	[percentage:%]	[1.22]	[1.52]	[0.92]	[0.92]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[2.13]	**[2.58]**	[2.28]	[1.23]	[1.98]
Crotch Depth (LB)	Mean (cm)	0.70	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.80	0.90	**1.10**	0.80
	[percentage:%]	[3.50]	[3.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[2.00]	[4.00]	[4.50]	**[5.50]**	[4.00]
Central arm (A)	Mean (cm)	2.00	-4.80	0.80	0.60	3.10	**5.40**	3.20	-2.40	-2.00	2.40	2.80	-1.60	0.00	0.00	0.00	0.00	0.00
	[percentage:%]	[3.64]	[-8.74]	[1.46]	[1.09]	[5.65]	**[9.84]**	[5.83]	[-4.37]	[-3.64]	[4.37]	[5.10]	[-2.91	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
Inside arm (A)	Mean (cm)	2.00	3.20	1.80	2.20	-6.00	-9.20	-2.60	**3.50**	1.60	1.60	-1.60	1.40	0.00	0.00	0.00	0.00	0.00
	[percentage:%]	[3.88]	[6.21]	[03.50]	[4.27]	[-11.65]	[-17.86]	[-5.05]	**[6.80]**	[3.11]	[3.11]	[-3.11]	[-2.71]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
Outside arm (A)	Mean (cm)	-2.40	-3.00	2.00	0.40	3.30	**3.50**	-4.00	-3.60	-4.40	-3.80	1.40	1.60	0.00	0.00	0.00	0.00	0.00
	[percentage:%]	[-4.48]	[-5.60]	[3.73]	[3.11]	[6.15]	**[6.53]**	[-7.46]	[-6.72]	[-8.21]	[-7.09]	[2.61]	[2.99]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
Inside leg (L)	Mean (cm)	0.40	0.40	**1.00**	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-1.40	-1.00	0.70	0.90	-1.00
	[percentage:%]	[0.55]	[0.55]	**[1.38]**	[0.82]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[-1.92]	[-1.38]	[0.96]	[1.24]	[-1.38]
Outside leg (L)	Mean (cm)	0.20	0.60	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.70	**2.80**	2.20	-3.20	1.80
	[percentage:%]	[0.19]	[0.57]	[0.97]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[2.63]	**[2.72]**	[2.14]	[-3.12]	[1.75]
Front leg (L)	Mean (cm)	-9.40	1.20	0.40	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-8.40	-6.80	**2.20**	1.20	-1.40
	[percentage:%]	[-10.08]	[1.28]	[0.43]	[0.43]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[-9.01]	[-7.29]	**[2.36]**	[1.29]	[-1.50]
Back leg (L)	Mean (cm)	4.80	-4.40	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.80	**5.50**	-2.60	1.80	4.00
	[percentage:%]	[4.84]	[-4.44]	[0.21]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[4.84]	**[5.55]**	[-2.62]	[1.81]	[4.03]

Remark: (UB) = upper body; (LB) = lower body; (A) = arm; (L) = leg; "+" =extension; "-"= contraction

5.3.4 Key Measurements of the Human Body

Although anthropometric studies help people to understand better the geometric characteristics of the human body and form the foundation of clothing pattern construction, it is time consuming to collect a large number of measurements. In practice, some key measurements are usually identified, which characterise human body figures and are used to determine wearing ease in patternmaking.

In this study, factor analysis was used to analyse the 30 body measurement data of the 5 subjects in the static state, so as to determine the key measurements. The results of the factor analysis are shown in Tables 5-4 and 5-5. In Table 5-4, 9 factors were identified that explains 100% of the total sample variance. The data in Table 5-5 show that neck base girth (0.945), chest girth (0.777), waist girth (0.934), hip girth (0.719), across shoulder width (0.636), across chest width (0.885), across back width (0.623), front waist length (0.898), back waist length (0.972), underarm to waist (0.609), 7th-cervical to waist length (0.692), and total crotch length (0.730), as well as crotch depth (0.665) are 13 key torso measurements, because of their high loadings on Factors 2 to 8. Armscye girth (0.678), upper arm girth (0.916), elbow girth (0.802), as well as central arm length (0.898) are the 4 key arm measurements, because their high loading on Factors 4, 5 and 9. Thigh girth (0.922), knee girth (0.851), calf girth (0.736), ankle girth (0.937), inside leg length (0.620), front leg length (0.906) as well as back leg length (0.634) are the 7 key leg measurements, because of high loading on Factors 1, 2 and 8. In total, 24 out of the 30 body measurements are identified as key measurements to describe the geometric features of human body.

Table 5-4 Total variance explained

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8	Factor 9
Initial eigenvalues	29.389	20.209	13.026	10.252	8.879	7.555	4.688	3.830	2.172
Rotation sums of squared loadings	4.232	4.127	4.100	3.884	3.468	3.052	2.750	2.692	1.693
% of variance explained	14.107	13.758	13.668	12.948	11.561	10.173	9.167	8.974	5.643
Cumulative variance explained (%)	14.107	27.865	41.533	54.481	66.042	76.215	85.383	94.357	100.00

Table 5-5 Rotated Component Matrix

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8	Factor 9
Neck base girth	-0.066	0.125	0.053	-0.104	0.136	-0.145	**0.945**	0.180	-0.042
Chest girth	-0.099	0.133	0.192	0.192	**0.777**	0.058	0.531	0.088	0.052
Waist girth	0.004	**0.934**	-0.102	0.035	0.238	-0.179	-0.034	0.089	-0.136
Hip girth	0.194	0.341	-0.415	0.168	0.250	-0.153	0.144	**0.719**	-0.147
Armscye girth	0.462	0.482	0.018	0.296	0.152	0.124	0.301	0.051	**0.678**

Upper arm girth	0.085	0.175	-0.086	0.202	**0.916**	-0.120	0.134	0.172	-0.114
Elbow girth	0.244	-0.055	-0.167	-0.107	**0.802**	-0.144	-0.328	0.032	0.355
Forearm girth	0.469	-0.475	0.205	0.228	0.163	0.467	0.108	0.451	-0.023
Wrist girth	0.425	0.047	0.220	0.456	0.255	0.581	0.356	-0.127	0.125
Thigh girth	-0.207	-0.104	0.096	0.206	0.121	-0.001	0.170	**0.922**	0.033
Mid thigh	0.423	0.231	0.259	0.147	0.544	0.408	0.299	0.185	-0.305
Knee girth	**0.851**	0.094	-0.255	-0.061	0.039	0.262	-0.181	-0.246	0.187
Calf girth	0.447	0.149	0.216	**0.736**	0.284	0.229	-0.208	0.100	0.058
Ankle girth	**0.937**	0.069	0.003	0.179	0.137	0.176	0.018	0.130	0.136
Across shoulder width	0.576	0.065	-0.026	0.076	0.038	0.279	**0.636**	0.363	0.207
Across chest width	0.188	-0.217	-0.145	0.145	-0.214	**0.885**	-0.101	0.041	0.188
Across Back width	0.129	0.002	-0.144	**0.623**	-0.117	0.041	0.517	0.540	0.020
Front waist length	-0.273	-0.275	**0.898**	-0.114	-0.125	-0.076	-0.086	0.004	0.048
Back waist length	-0.086	-0.067	**0.972**	0.051	-0.085	0.042	0.115	-0.074	-0.115

7th-cervical to waist length	0.236	0.205	**0.692**	-0.222	0.313	0.031	0.165	0.461	0.190
Underarm to waist length	-0.089	0.139	**0.609**	-0.302	-0.663	-0.263	-0.017	0.005	-0.042
Total crotch length	0.288	0.506	-0.095	**0.730**	0.181	0.107	0.133	0.215	0.105
Crotch depth	0.360	-0.312	-0.185	**0.665**	0.059	0.510	0.011	-0.173	-0.058
Central arm length	-0.235	0.113	-0.245	**0.898**	0.115	-0.067	-0.061	0.202	-0.049
Inside arm length	-0.052	-0.610	-0.226	-0.606	-0.133	-0.336	-0.053	-0.115	0.245
Outside arm length	-0.404	0.215	-0.606	-0.059	-0.143	-0.496	-0.058	0.238	-0.306
Outside leg length	-0.239	0.439	-0.054	0.091	-0.038	-0.196	0.028	0.011	-0.835
Inside leg length	**0.620**	0.577	-0.192	0.089	0.045	-0.173	0.375	-0.251	-0.039
Front leg length	0.189	**0.906**	-0.190	0.163	-0.079	-0.197	0.165	-0.048	-0.080
Back leg length	-0.190	**0.634**	-0.569	0.009	-0.030	-0.604	0.282	0.079	0.009

5.3.5 Effects of Different Dynamic Postures on Body Measurements

After identifying the key body measurements, one-way ANOVA was used to analyse how body movement would affect those key measurements. Tables 5-6, 5-7 and 5-8 show the analysis results of one-way ANOVA on the relationship between 17 dynamic postures and 24 key measurements. Table 5-6 reveals the relationship between waist movements and the 24 identified key measurements. It is shown that waist movements cause significant changes of circumferential measurements, including chest girth (p=0.000), waist girth (p=0.044), hip girth (p=0.001), armscye girth (p=0.000), upper arm girth (p=0.000), and elbow girth (p=0.006), for which p values are less than 0.05. In contrast, p values of thigh (p=0.665), knee (p=0.294) and calf girth (p=0.982) are more than 0.05, which indicate that these measurements do not vary significantly due to the waist movement. Moreover, waist movements do not affect the neck base girth and ankle girth because their measurements do not change at all (refer to the data in Table 5-3). In terms of width measurements, p values of across shoulder, across chest and across back are 0.000 which means that the waist movements have significant impact on these measurements. For length measurements, except crotch depth (p=0.942) and inside leg length (p=0.293), the other 8 key length measurements are obviously influenced by waist movements because their p values are less than 0.05.

Table 5-6 Tests of the impact of waist movements (postures a, b, c, and d) on key measurements

Body measurements		Degree of freedom	F-values	P(Sig.)
Girth	Neck base	3	_	_
	Chest	3	9.830	0.000*
	Waist	3	2.976	0.044*
	Hip	3	6.514	0.001*
	Armscye	3	27.631	0.000*
	Upper arm	3	13.040	0.000*
	Elbow	3	4.935	0.006*
	Thigh	3	0.529	0.665
	Knee	3	1.286	0.294
	Calf	3	0.056	0.982
	Ankle	3	_	_
Width	Across shoulder	3	18.017	0.000*
	Across chest	3	42.752	0.000*
	Across back	3	16.398	0.000*
Length	Front waist	3	34.720	0.000*
	Back waist	3	29.724	0.000*
	7^{th} -cervical to waist	3	26.747	0.000*
	Underarm to waist	3	9.280	0.000*
	Total crotch	3	4.000	0.015*
	Crotch depth	3	0.129	0.942
	Central arm	3	18.447	0.000*

	Inside leg	3	1.289	0.293
	Front leg	3	41.262	0.000*
	Back leg	3	34.939	0.000*

* $p \leq 0.05$: significance

The analysis results of one-way ANOVA on the relationship between elbow and shoulder joint movements and the 24 key measurements are listed in Table 5-7. It is shown that elbow and shoulder joint movements only influence 13 of the 24 key measurements, including chest girth, waist girth, armscye girth, upper arm girth, elbow girth, across shoulder width, across chest width, across back width, front waist length, back waist length, the 7^{th} cervical to waist length, underarm to waist length, and central arm length. As shown in Table 5-3, the mean changing values of the other 11 key measurements are 0.00 which indicate that the elbow and shoulder joint movements do not affect these key measurements.

Table 5-7 Tests of the impact of elbow and shoulder joint movements (postures e, f, g, h and l) on key measurements

Body measurements		Degree of freedom	F-values	P(Sig.)
Girth	Neck base	7	_	_
	Chest	7	10.916	0.000*
	Waist	7	6.753	0.000*
	Hip	7	_	_
	Armscye	7	34.091	0.000*
	Upper arm	7	33.814	0.000*
	Elbow	7	100.568	0.000*
	Thigh	7	_	_

	Knee	7	_	_
	Calf	7	_	_
	Ankle	7	_	_
Width	Across shoulder	7	31.775	0.000*
	Across chest	7	41.558	0.000*
	Across back	7	35.493	0.000*
Length	Front waist	7	10.432	0.000*
	Back waist	7	14.867	0.000*
	7th-cervical to waist	7	6.082	0.000*
	Underarm to waist	7	39.498	0.000*
	Total crotch	7	_	_
	Crotch depth	7	_	_
	Central arm	7	19.383	0.000*
	Inside leg	7	_	_
	Front leg	7	_	_
	Back leg	7	_	_

* $p \leq 0.05$: significance

The analysis results of one-way ANOVA on the relationship between hip and knee joint movements and the 24 key measurements are listed in Table 5-8. The calculated results indicate that the knee and hip joint movements have significant effects on 7 of the 24 key measurements, including hip girth, thigh girth, knee girth, calf girth, inside leg length, front leg length, and back leg length, for which p values are less than 0.05. The p values of waist girth (p = 0.777), ankle girth (p = 0.518), total crotch length (p = 0.492) and crotch depth (p=0.546) are more than 0.05 which reveal that the effects of hip and knee joint movements are not significant. As shown in Table 5-3, the hip and knee joint movements do not affect the measurements of the neck base girth, chest girth, armscye girth, upper arm girth, elbow girth, across shoulder width, across chest width, across back width, front waist length, back waist length, 7th-cervical to waist length, underarm to waist length, nor central arm length.

Table 5-8 Tests of the impact of hip and knee joint movements (postures m, n, o, p, and q) on key measurements

Body measurements		Degree of freedom	F-values	P(Sig.)
Girth	Neck base	4	_	_
	Chest	4	_	_
	Waist	4	0.443	0.777
	Hip	4	15.693	0.000*
	Armscye	4	_	_
	Upper arm	4	_	_
	Elbow	4	_	_
	Thigh	4	18.627	0.000*
	Knee	4	25.800	0.000*
	Calf	4	6.520	0.000*
	Ankle	4	1.000	0.518*
Width	Across shoulder	4	_	_
	Across chest	4	_	_
	Across back	4	_	_
Length	Front waist	4	_	_

Back waist	4	_	_
7th-cervical to waist	4	_	_
Underarm to waist	4	_	_
Total crotch	4	0.865	0.492
Crotch depth	4	0.777	0.546
Central arm	4	_	_
Inside leg	4	16.713	0.000*
Front leg	4	51.384	0.000*
Back leg	4	25.458	0.000*

* $p \leq 0.05$: significance

By comparing the results of Tables 5-6, 5-7 and 5-8, neck base girth, ankle girth and crotch depth are not affected by any of the 17 body movements. The remaining 21 key measurements are significantly influenced by body movements. In order to ensure clothing freedom, the variation of these 21 key measurements due to body movement must be carefully analysed for wearing ease design in dynamic block patternmaking. These 21 key measurements include: (1) Girth measurements: chest, waist, hip, armscye, upper arm, elbow, thigh, knee, as well as calf; (2) Width measurements: across shoulder, across chest and across back; (3) Length measurements: front waist, back waist, the 7^{th} cervical to waist length, underarm to waist length, total crotch, central arm length, inside leg, front leg, as well as back length

5.3.6 Determination of Wearing Ease Values in Key Body Measurements

Upon analysing the impact of dynamic postures on body measurements, the necessary wearing ease values for key body measurements are determined, which are the maximum measurement increases in different dynamic postures (section 5.3.2). The results are summarized in Tables 5-9, 5-10 and 5-11. All wearing ease values must be correctly added to the static fit block pattern, so as to meet the requirements of body movement. The construction of dynamic block pattern will be discussed in Chapters 8.

Table 5-9 Wearing ease values in key measurements of girth

Girth (cm) / percentage (%)								
Chest (UB)	Waist (UB/LB)	Hip (LB)	Armscye (UB/A)	Upper arm (A)	Elbow (A)	Thigh (L)	Knee (L)	Calf (L)
3.00/ 3.11	2.00/ 2.54	5.60/ 5.86	4.50/ 10.92	3.10/ 11.31	7.40/ 30.08	2.80/ 5.08	5.60/ 15.05	1.40/ 3.77

Table 5-10 Wearing ease values in key measurements of width

Width (cm) / percentage (%)		
Across shoulder (UB)	Across chest (UB)	Across back (UB)
2.80/ 6.93	4.00/ 10.36	5.00/ 12.76

Table 5-11 Wearing ease values in key measurements of length

Length (cm) / percentage (%)								
Front waist (UB)	Back waist (UB)	7^{th}-cervical to waist (UB)	Under arm to waist (UB)	Total crotch (LB)	Central arm (A)	Inside leg (L)	Front leg (L)	Back leg (L)
4.40/ 9.65	4.60/ 9.20	4.20/ 9.11	4.40/ 14.24	1.70/ 2.58	5.40/ 9.84	1.00/ 1.38	2.20/ 2.36	5.50/ 5.55

5.4 Conclusions

In this chapter, the changes of human body measurements in static and dynamic postures have been investigated. Experiments have been carried out to study 30 body measurements in the static state and in 17 dynamic postures. Among the 30 body measurements, neck base, wrist and ankle girth have been found to remain unchanged in different dynamic postures, while the elbow girth, across back width and outside arm length varied significantly. Factor analysis has been used to analyse the data from 30 body measurements in the static state, and 24 body measurements have been identified as key measurements to describe human body characteristics. One-way ANOVA has also been used to understand the effects of dynamic postures on the key measurements. Twenty-one out of the 24 key measurements have been found to be influenced by dynamic postures except for the neck base girth, ankle girth and crotch depth. The application of the dimensional changes of the key body measurements in body movement has been suggested to be used in ease design for dynamic block patternmaking.

CHAPTER 6 ANTHROPOMETRY STUDY IN RUNNING STATE

6.1 Introduction

Running is one of the most important sports. When people run, bones and muscles work together based on the connections of joints. The positions of different joints change significantly during body movement. Meanwhile, the body skin surfaces around the joints are extended and contracted, and causes the corresponding body measurements to change. In order to provide necessary rooms for unrestricted body movements, suitable garment eases should be determined and incorporated into the clothing products. Therefore, measuring the body in running state and analysing the differences between body measurements in static and running states are necessary for effective product development of clothing.

Many anthropometric methods have been developed over the years. Among these methods, manual tape measurement method is the traditional approach for static state measurement taking. It is also an effective method to collect body measurements when people make different body postures (Liu & Kennon, 2006). Linear body measurements, such as the circumferences of the human body, can be obtained by this method based on identified anatomical landmarks on the body skin surface. In recent years, 3D body scanning technique has been used widely in clothing product development, because of its advantages of efficiency, contactless and availability of body and shape information (Mickinnon & Istook, C., 2001, Loker et al, 2005). In 3D body scanning, normal or laser light reflection is utilized to capture data points from the body surface (Istook & Hwang, 2001). A 3D point cloud with points recorded in x, y and z coordinates is obtained from the scanning process. Many important information can be generated by processing, filtering and compressing raw data from the scan. Basically, critical anthropometric measurements can be extracted in the 3D body scanning system, which include linear circumferences of the human body and non-linear data, such as volume and cross section areas of the human body (Liu & Kennon, 2006).

A number of body measurement surveys were carried out in the last century and different sizing standards were established accordingly. As early as in 1951, a large-scale survey on British women was carried out. The USA government carried out a survey with 10,000 female subjects, in which 49 body measurements of each subject were taken between 1948 and 1959. In 1986, the Chinese government organized a national wide anthropometry survey. From the survey result, the Size Designation of clothes, GB1335-1991, was published in 1991 as a national standard in China. In the 1990s, the standard was updated, which resulted in the GB1335-1997 standard. These body measurement surveys were mainly carried out by the traditional manual measurement method, while 3D body scanning was used to collect static state body measurements in recent years.

By defining landmarks on the body skin surface, body measurements of a subject with a static posture can be easily acquired either by the manual method or the 3D body scanning. However, if a subject is in motion, for example when he is running, his body skin surface extends or contracts, therefore the landmarks on his skin surface are no longer steady. Consequently, the traditional manual method and 3D body scanning technique are not suitable to collect body measurements when the body is in dynamic movement.

In order to correctly acquire body measurements in running state, a new anthropometric method is introduced in this chapter. Experiments are carried out to collect measurement data. The effectiveness of the proposed technique is compared to that of the manual method and 3D body scanning. The body measurements collected in the experiment are analysed to calculate the variation of measurement in running, which are used for the determination of wearing ease values in running wear design.

6.2 A New Anthropometric Method for Running State Measurements

6.2.1 Body Motion Analysis System

A number of body motion analysis systems have been developed to record three dimensional movements and body characteristics in motion state. The analysis results are used in many applications, such as medicinal treatment, movie animation and sports design (Dobrian & Bevilacqua, 2003). In general, body motion analysis systems consist of both hardware and software, examples can be found in Figures 6-1 and 6-2. The hardware system includes passive or active markers, cameras, controller, and host computer. The passive (or active) markers are used for landmarking body surfaces. Cameras are used to capture the landmark locations during body movement. The controller provides power and links up the cameras and other devices in the system. Software is installed on the host computer. The body motion analysis system can complete the following tasks: (a) tracking landmarks on the human body in motion; (b) processing the data and displaying the motion process; (c) analyzing the body structure and the motion characteristics (Chang & Huang, 2000).

a) markers b) camera c) controller d) host computer

Figure 6-1 Hardware system of Vicon body motion analysis system

(Source of image: http://www.vicon.com/products/)

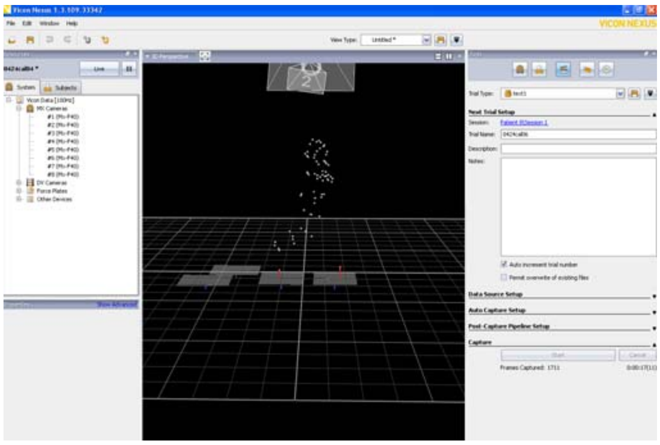


Figure 6-2 Software system of Vicon body motion analysis system

The process of body motion analysis is shown in Figure 6-3, which involved a few steps: Firstly, markers of diameter 8-12 mm are covered with reflective fabric and placed on different parts of the body. For example, in order to analyse the movement of joints in sports, markers are fixed on body joints. The body motion analysis system is calibrated and set up, including the determination of the sampling rate, the adjustment of the camera locations, and the identification of the x, y and z coordinate system and so on. Next, when subjects perform the designed body movement, the movement of the markers are tracked by cameras and location data are stored in a data-station. The data are extracted and processed, so as to define the paths of marker movement. 3D models of body motion are also created (Kapur et. al, 2005). Therefore, body characteristics in motion state can be analysed, including segment positions, angles of joints movement and others.

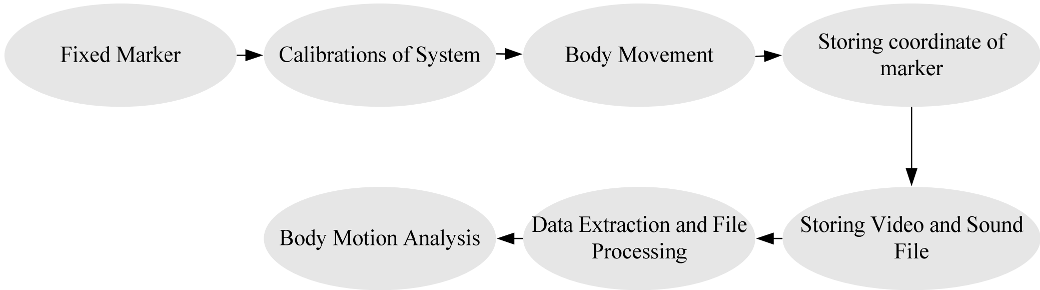


Figure 6-3 Procedures for body motion analysis

6.2.2 Anthropometry Study by Body Motion Analysis System

The body motion analysis system provides a platform to measure the body in running state, because it can accurately capture the marker locations. As given in the ISO 8559-1989 standard, landmarking is the foundation for all body measurements. The distances between landmarks are defined as various body measurements. For example, the chest girth is the maximum horizontal girth measurement passing over the shoulder blades (scapulae), under the armpits (axillae), and across the nipples. Shoulder width is the horizontal distance between the acromion extremities. If markers are placed at the same positions as the body measurement landmarks, body measurements in running state can be obtained by the body motion analysis system.

6.2.3 Extraction of Body Measurements

When a subject runs, the marker locations are captured by the body motion analysis system as sequential data in x, y and z coordinates. By calculating the linear distances between two markers or curve passing several markers, body measurements can be obtained in every recoding time. Finally, the variation of body measurements during the running process can be presented.

Bézier curve（B-spline curve）is often used to model a smooth curve by two or several points in 3-dimensional space (Böhm, 1977, Song & Zhang, 2001). Body measurements are defined as the straight lines or smooth curves between two marker points or passing through a few marker points. Therefore, B-spline curves are modelled to obtain the body measurements in this study.

6.3 Research Methodology

6.3.1 Experiment Design

Experiments were designed to collect the body measurements in running state. As shown in Table 6-1, the experiments consist of the three exercises: 1) Exercise One: static-state body measurements are collected by 3D body scanning. 2) Exercise Two: dynamic posture body measurements are acquired by manual method. 3) Exercise Three: body measurements are collected by body motion analysis system when the body is in static state and running state.

Table 6-1 Experiment contents and measurement methods

Number	Experimental contents	Measurement methods
1	Body measurements in static state	3D body scanning
2	Body measurements in static state and dynamic postures	Manual method
3	Body measurements in static and running state	Motion capture by body motion analysis system

6.3.2 Subjects

Exercises one and two have been discussed in Chapters 3 and 5. This chapter describes the final exercise of the experiment. In the experiment, the same 5 Chinese male subjects aged 20-24 in the previous experiment were recruited as volunteers in this study. The heights of all subjects are between 170-175 cm and values of BMI (Body Mass Index) are 21-23. Before the experiment, researchers explained to all subjects about the experiment and obtained their approvals.

6.3.3 Body Measurements and Landmark (Marker) Definitions

According to the experimental objectives, 30 body measurements were measured in this study. These body measurements include girths, lengths and widths: (a) girth: neck base, chest, waist, hip, armscye, upper arm, elbow, forearm, wrist, thigh, mid thigh, knee, calf as well as ankle; (b) length: front and back waist, the 7th cervical to waist, total crotch, crotch depth, central arm, inside arm, outside arm, inside leg, outside leg, front leg and back leg; (c) width: across shoulder, across chest and across back.

a b c d

Figure 6-4 Marker locations on body skin: a) front view, b) side view, and c) back view of upper body, and d) back view of lower body

In order to collect these body measurements in running state, markers covered with reflective tape are fixed on the subject's body surface at landmark positions defined according to ISO8559-1989 standard. A total of 74 landmarks (markers) are defined for each subject, as shown in Figure 6-4, on different parts of the body: neck (4 markers), chest (16 markers), waist (8 markers), hip (8 markers), shoulder (2 markers), arm (16 markers), as well as leg (20 markers).

6.3.4 Experiment Instruments

The VICON 8.0 body motion analysis system (Figures 6-1 and 6-2) with 8 cameras was used to capture the location and movement of markers. Each subject was required to stand upright and remain steady to collect static state marker data. Next, he was required to run on a treadmill at a speed of 10 km/h, for a few minutes, as shown in Figure 6-5. The data of the 74 markers are captured every second in the running process.

Figure 6-5 Star-Trac treadmill – equipment for collecting running state measurements

6.3.5 Experiment Protocol

All experiments were carried out in a controlled environment with regular room temperature of 24ºC, 65% relative humidity. In order to reduce the influence of air motions, wind speed is designed at less than 0.1m/s. Each subject carried out a defined sequence of exercise as follows:

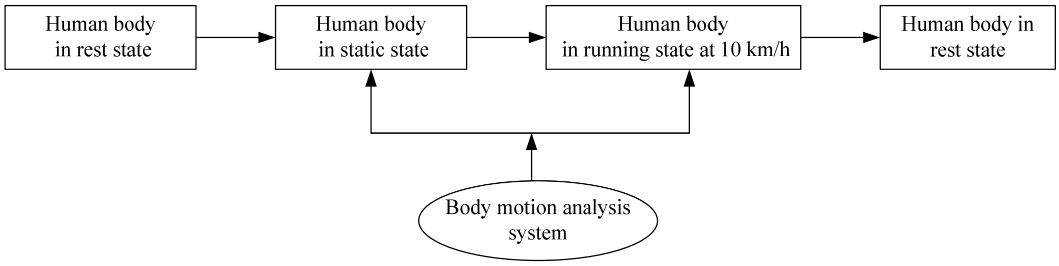


Figure 6-6 Experiment protocol

First, 74 markers with reflective tape are fixed on the 74 landmark positions for each subject. After fixing the markers, the body motion analysis system was calibrated and set up. Each subject was required to keep the natural standing posture on the treadmill for 1 minute, and the marker positions of the standing pose (static state) are stored. Next, each subject was required to run on the treadmill at 10 km/h for 3 minutes. The marker position was recorded every second throughout the entire running exercise. In addition, video of the subject in the running exercise are recorded. The experiment was repeated three times.

6.3.6 Data Collection

In the experiment, the data recorded by the body motion analysis system are 3-dimensional coordinates of marker positions. By processing these marker coordinates, the body measurements at the corresponding recording time can be calculated.

6.4 Results and Discussions

6.4.1 Accuracy of the New Anthropometric Method in Static State

30 Body measurements in static state acquired with the 3D body scanner and the body motion analysis system are compared in Table 6-2. S indicates the body measurements acquired by the 3D body scanning method, and B indicates the measurements acquired by the body motion analysis system. In order to examine the effectiveness of the body motion analysis system for the proposed application, body measurements acquired by the two methods are compared: Body measurements acquired by the 3D body scanning method are different from that by body motion analysis system -0.11 to -1.92 cm. The 7^{th} cervical to waist length has the largest difference, -1.92 cm. The crotch depth has the smallest difference, -0.11cm. It is clear that all body measurements acquired by the body motion analysis system are slightly bigger than the values acquired by the 3D body scanning method.

T-test was carried out to examine if there is any significant difference between body measurements acquired by the two methods. The result of the t-test is also shown in Table 6-2. The p-values of all body measurements in the t-test are more than 0.05, which reveal that there are no significant difference in the body measurements acquired by the 3D body scanning method and the body motion analysis system. It means that data acquired by the body motion analysis system is accurate and the method itself is effective to collect body measurements in static state.

Table 6-2 Comparison of measurement results in static state

Body measurements		S		B		S-B	t-value	P(Sig.)
		Mean (cm)	Std. Dev	Mean (cm)	Std. Dev			
Girth	Neck base	39.93	0.40	40.79	1.30	-0.86	-1.95	0.12
	Chest	96.48	1.62	97.18	1.80	-0.70	-1.33	0.25
	Waist	79.19	1.54	79.39	2.38	-0.20	-0.44	0.68
	Hip	95.95	2.58	96.98	2.49	-1.03	-1.78	0.15
	Armscye	41.50	2.17	42.26	2.93	-0.75	-1.49	0.21
	Upper arm	27.07	1.36	27.49	1.81	-0.42	-1.38	0.24
	Elbow	24.66	0.14	25.85	0.56	-0.20	-0.85	0.45
	Forearm	24.92	0.50	25.14	0.70	-0.22	-0.85	0.44
	Wrist	16.14	0.35	16.38	0.69	-0.24	-0.90	0.42
	Thigh	55.12	2.27	55.66	2.46	-0.54	-1.31	0.26
	Mid thigh	46.18	2.17	46.68	2.00	-0.50	-1.50	0.21
	Knee	37.12	1.30	37.50	1.69	-0.38	-1.20	0.30
	Calf	37.10	1.47	37.44	1.53	-0.34	-1.14	0.32
	Ankle	25.22	1.04	25.97	1.05	-0.75	-1.88	0.13
Width	Across shoulder	40.25	0.71	40.49	1.13	-0.24	-0.79	0.47
	Across chest	38.31	0.68	38.91	0.73	-0.60	-1.32	0.26
	Across back	39.11	0.60	39.69	1.51	-0.59	-1.20	0.30
Length	Front waist	45.50	0.67	46.22	1.45	-0.72	-1.60	0.19
	Back waist	49.97	0.69	50.70	1.33	-0.73	-1.42	0.23

7^{th}-cervical to waist	49.64	1.31	50.41	1.61	-0.77	-1.92	0.13
Underarm to waist	45.76	1.55	46.22	1.01	-0.46	-1.14	0.32
Total crotch	65.10	5.73	65.57	5.38	-0.48	-1.12	0.33
Crotch Depth	19.82	0.25	19.93	0.38	-0.11	-0.42	0.70
Central arm	54.78	1.08	55.39	1.74	-0.62	-1.27	0.27
Inside arm	51.62	0.96	52.14	1.35	-0.52	-1.26	0.28
Outside arm	53.51	1.28	54.10	0.62	-0.59	-1.39	0.24
Inside leg	72.73	1.62	73.68	2.31	-0.96	-1.72	0.16
Outside leg	102.65	1.28	103.58	2.12	-0.93	-1.39	0.24
Front leg	93.27	1.62	93.95	2.47	-0.68	-1.16	0.31
Back leg	99.19	0.76	100.10	0.72	-0.92	-1.88	0.13

* S=3Dbody scanning method, B= Body motion analysis system

* $p \leq 0.05$: significance

6.4.2 Accuracy of the New Anthropometric Method in Running State

By analysing the data collected with the body motion analysis system, the 30 body measurements of each subject can be obtained every second during the 3-minute running. The variation of body measurements in dynamic postures (M) and running state (B) are compared in Table 6-3.

T-test was carried out to examine if there is significant difference between changes of the body measurements in dynamic postures and the changes in running state. The neck base, wrist and ankle girth measurements acquired by both the manual method and the body motion analysis systems do not show any changes (0.00) in dynamic postures and running state. As shown in Table 6-3, 11 body measurements, including chest girth, waist girth, calf girth, across shoulder width, across back width, across chest width, front waist length, back waist length, the 7^{th} cervical to waist length, underarm to waist length and inside arm length, have p values less than 0.05. It means that these body measurements of dynamic postures are significantly different from that of running state. The rest of the 16 body measurements have p values more than 0.05, which means that the differences between dynamic postures measurements and running state measurements are not significant.

Although 11 body measurements acquired in dynamic postures and running state are significantly different, they have similar characteristics: the measurements acquired in running state are smaller than that in dynamic postures. By comparing the running postures and the 17 designed dynamic postures (Chapter 5), it is not difficult to find that people usually keep the torso in upright posture during running to avoid falling down or being injured. The corresponding body measurements should have smaller changes compared to that of the dynamic postures, because the body torso would not have extensive movement during running motion.

The result of the t-test can prove that the body motion analysis system is an effective method to collect body measurements in running state.

Table 6-3 Comparison of body measurement variations in dynamic postures and running state

Body measurements		M (in dynamic postures) size difference (cm)	M (in dynamic postures) change rate (%)	B (running state) Size difference (cm)	B (running state) Change rate (%)	M-B	t-value	P(Sig.)
Girth	Neck base	0.00	0.00	0.00	0.00	0.00	-	-
	Chest	3.00	3.11	2.65	2.73	0.35	4.72	0.01*
	Waist	2.00	2.54	1.59	2.01	0.41	3.98	0.02*
	Hip	5.60	5.86	5.82	6.00	-0.22	-0.73	0.51
	Armscye	4.5	10.92	4.76	11.26	-0.26	-0.97	0.39
	Upper arm	3.10	11.31	3.28	11.93	-0.18	-0.91	0.42
	Elbow	7.40	30.08	7.52	30.25	-0.12	-0.90	0.42
	Forearm	1.10	4.33	0.80	3.18	-0.30	0.69	0.53
	Wrist	0.00	0.00	0.00	0.00	0.00	-	-
	Thigh	2.80	5.08	3.42	6.14	-0.62	-1.79	0.15
	Mid thigh	1.80	3.91	2.52	5.40	-0.72	-1.41	0.23
	Knee	5.60	15.05	6.54	17.44	-0.94	-1.36	0.25
	Calf	1.40	3.77	1.22	3.26	0.18	0.484	0.65
	Ankle	0.00	0.00	0.00	0.00	0.00	-	-
Width	Across shoulder	2.80	6.93	1.56	3.85	1.24	2.95	0.04*
	Across chest	4.00	10.36	2.22	5.71	1.78	2.73	0.05*
	Across back	5.00	12.76	2.24	5.64	2.76	8.23	0.00*
Length	Front waist	4.40	9.65	1.10	2.38	3.30	15.06	0.00*

Back waist	4.60	9.20	1.41	2.78	3.19	7．64	0.00*
7^{th}-cervical to waist	4.20	9.11	1.06	2.10	3.14	5.40	0.01*
Underarm to waist	4.40	14.24	0.82	1.77	3.58	13.59	0.00*
Total crotch	1.70	2.58	1.83	2.79	-0.13	-0.97	0.39
Crotch Depth	1.10	5.50	1.14	5.72	-0.04	-0.28	0.79
Central arm	5.40	9.84	5.58	10.07	-0.18	-0.81	0.46
Inside arm	3.50	6.80	3.46	6.64	0.04	0.25	0.82
Outside arm	3.50	6.53	3.54	6.54	-0.04	-0.22	0.84
Inside leg	1.00	1.38	1.06	1.44	-0.06	-0.24	0.82
Outside leg	2.80	2.72	3.42	3.30	-0.62	-1.53	0.20
Front leg	2.20	2.36	2.57	2.74	-0.37	-1.19	0.30
Back leg	5.50	5.55	5.72	5.71	-0.22	-0.98	0.38

M=by manual method, B= by body motion analysis system, * $p \leq 0.05$: significance

6.4.3 Differences of Body Measurement in Running State

Table 6-3 indicates that the neck base, wrist and ankle girth measurement do not change whilst in running motion. Among the rest of the 11 girth measurements, the elbow girth has the largest variation of 7.52 cm, meaning a 30.52% change. Forearm girth has the smallest variation (0.80 cm) and waist girth has the smallest percentage of change (2.01%). In term of width measurements, across chest width has the largest percentage of change (5.71%), and across back width has the largest variations in size measurement (2.22 cm). Among the 13 length measurements, the back leg length vary most significantly in size (5.712cm) and central arm length has the largest percentage of change (10.07%).

Underarm to waist length has the smallest size variation (0.82cm) and inside leg length has the smallest percentage of change (1.44%).

As shown in Table 6-3, total 11 running state body measurements acquired by the body motion analysis system are smaller than the dynamic posture measurements, including chest girth, waist girth, calf girth, across shoulder width, across chest width, across back width, front waist length, back waist length, the 7th cervical to waist length, underarm to waist length and inside arm length. The variations of running state measurements are smaller than that of the dynamic posture measurements by 0.04 to 3.58cm. Thirteen running state body measurements acquired by the body motion analysis system vary more compared to the dynamic posture measurements obtained manually, by 0.04 to 0.94cm.

In summary, three measurements: neck base, wrist and ankle girth do not change in either dynamic postures or in running state. In the rest of the 27 body measurements, elbow has the largest variations in running state measurements (7.52cm) and in percentage of change (30.25%). Forearm girth has the smallest variations (0.80cm) and inside leg length has the smallest percentage of change (1.44%). When people run, the body measurements of the upper body have smaller variation compared with the dynamic posture measurements, and the other running state measurement variations are larger than that of the dynamic postures. The results on the body measurement variations in running state provide the foundation for ease design in running wear.

6.5 Ease Design Based on Changes of Body Measurement in Running State

6.5.1 Key Measurements of Human Body

Based on research results in Chapter 5, 24 key measurements have been determined to explain the body characteristics, which include 1) 13 key measurements of torso: neck base girth, chest girth, waist girth, hip girth, across shoulder width, across chest width, across back width, front waist length, back waist length, underarm to waist, 7th-cervical to waist length, and total crotch length, as well as crotch depth, 2) 4 key measurement of arm: armscye girth, upper arm girth, elbow girth, as well as central arm length, 3) 7 key measurements of leg: thigh girth, knee girth, calf girth, ankle girth), inside leg length, front leg length as well as back leg length.

6.5.2 Determination of Ease Design in Running Wear

Upon analysing the changing characteristics of the 30 body measurements in running state and the determination of 24 key body measurements, the necessary wearing ease values for key body measurements should be determined. These ease values should be the range of variation in running state measurement of the 24 key body measurements (Table 6-3). The results are summarised in Tables 6-4, 6-5 and 6-6. These defined ease values must be correctly incorporated into running wear pattern design.

Table 6-4 Wear ease values in key measurements of girth

Girth (cm) / percentage (%)								
Chest	Waist	Hip	Armscye	Upper arm	Elbow	Thigh	Knee	Calf
2.65 /2.73	1.59 /2.01	5.82 /6.00	4.76 /11.26	3.28 /11.93	7.52 /30.25	3.42 /6.14	6.54 /17.44	1.22 /3.26

Table 6-5 Wearing ease values in key measurements of width

Width (cm) / percentage (%)		
Across shoulder	Across chest	Across back
1.56/3.85	2.22/5.71	2.24/5.64

Table 6-6 Wearing ease values in key measurements of length

Length (cm) / percentage (%)								
Front waist	Back waist	7th-cervical to waist	Under arm to waist	Total crotch	Central arm	Inside leg	Front leg	Back leg
1.10/2.38	1.41/2.78	1.06/2.10	0.82/1.77	1.83/2.79	5.58/10.07	1.06/1.44	2.57/2.74	5.72/5.71

6.6 Conclusions

In this chapter, a new anthropometric method of human body in running state has been proposed and systematically verified. The variation of body measurements in running state has been investigated. From the experiment data, the wearing ease values for running wear pattern design have been determined.

The research results indicated that the body motion analysis system is an effective and accurate method for measuring the body in static state and in running state. In static state, body measurements obtained by 3D body scanning and body motion analysis systems are similar, and all p-values in t-test are more than 0.05, which means that there is no significant change between the two methods. For running state measurements, p-values in t-test indicate that there are significant changes in 9 measurements of the upper body including chest girth, waist girth, across shoulder width, across back width, across chest width, front waist length, back waist length, the 7th cervical to waist length and underarm to waist length. But there is no significant change found in other body measurements. By analysing people's running posture and the measurement results, it is found that the body motion analysis system can correctly reflect the changing characteristics of the human body in running state. Furthermore, measurements of the upper body have small changes, because of the upright body posture in running. Therefore, the result has indicated that the body measurements in running state acquired by the body motion analysis system are accurate.

The changing characteristics of body measurements in running state has been analysed, and the results reveal that neck base girth, wrist girth and ankle girth measurements do not change in running. Eleven body measurements in running state, including chest girth, waist girth, calf girth, across shoulder width, across back width, across chest width, front waist length, back waist length, the 7th cervical to waist length, underarm to waist length and inside arm length, have smaller changes than that in dynamic postures. The other 16 body measurements in running state have larger changes than in dynamic postures. In all body measurements, elbow has the largest changing values (7.52cm) and rate (30.25%) in running state. Forearm girth has the smallest changing values (0.80cm) and inside leg length has the smallest changing rate (1.44%).

24 key body measurements have been identified from the experiment result, including 11 girth measurements, 3 width measurements and 10 length measurements. Finally, the range of variations of the 24 key body measurements in running state are obtained and used as the wear ease values in running wear design.

CHAPTER 7 SKIN SURFACE CHANGES OF HUMAN BODY IN RUNNING STATE

7.1 Introduction

As discussed in Part I of the thesis (Chapters 1 and 2), the physical characteristics of the human body in running state decides the proper ergonomic functional design of running wear. Among various body physical characteristics, the skin surface changes in body movements have the most significant impacts on the decision of ease allowance to use in the clothing product and the detailed pattern structure design (Fuzek, 1981, Firgo, et al, 2006)**.**

When people run, the extension and contraction of skin surfaces in different parts of the body can be measured using the method described in Chapters 5 and 6, therefore the corresponding ease allowances to be used in running wear can be determined. When ease allowances are incorporated to the block pattern, the final shape of the running wear pattern is determined (Wang, et al, 2006). The body skin surfaces change most significantly around joints during body movements, while other areas do not have such substantial changes. The change characteristics divide the body skin surfaces into different regions. To design high-performance running wear, the pattern structure must be carefully constructed, taking into account of the skin surface regions. The boundary lines of the regions can be the references for structural line design in sportswear pattern (Yuan, et al, 2006).

In this chapter, an experiment was designed to investigate and develop a map of skin surface changes in running state. The relationship between skin surface changes and clothing pattern structure design are then discussed. The analysis results will be used for structure line design in high performance running wear pattern construction.

7.2 Experimental Works

7.2.1 Subjects and Clothing Sample

a b c d

Figure 7-1 Gird line on the clothing sample: a) top front, b) top back, c) bottom front, and d) bottom back

The five male subjects participated in the experiments described in Chapters 3, 4, 5 and 6 were again recruited to take part in this experiment. Five fitted clothing samples were made based on the further improved static fitted block patterns (Chapter 4), using the style and material specification shown in Figure 4-2 and Table 4-2 on page 114. To facilitate the observation of skin surface changes, gird lines were marked on the clothing sample. The gird size is 2×2cm, as shown in Figure 7-1. Reference circumference lines at the neck base, chest, waist, hip, armscye, elbow, wrist, mid-thigh, knee, calf and ankle levels, and length reference lines of the front centre, back centre, side, sleeve centre, front leg centre and back leg centre were also marked.

7.2.2 Experiment Environment and Equipment

The experiment was conducted in the clothing functional evaluation laboratory of The Hong Kong Polytechnic University, where the temperature was controlled at 24°C and the relative humidity was about 65%. The air velocity was less than 0.1m/s to lower the influence of air motions on the experiment.

A digital camera (OLYMPUS FE-4010) was used to take photos of each subject performing designed dynamic postures.

7.2.3 Experimental Method

The experiment was carried out by the observation method, which is regarded as an effective approach to understand body skin surface changes in motion state (Richard, et al., 1994).

It is difficult to capture skin surface changes in running state, the 17 dynamic postures described in Chapter 5 were used to mimic the human body running postures. In the experiment, each subject started off by putting on the sample clothing, and then performed 17 dynamic postures one by one. Images of the body skin surfaces were taken for each dynamic posture.

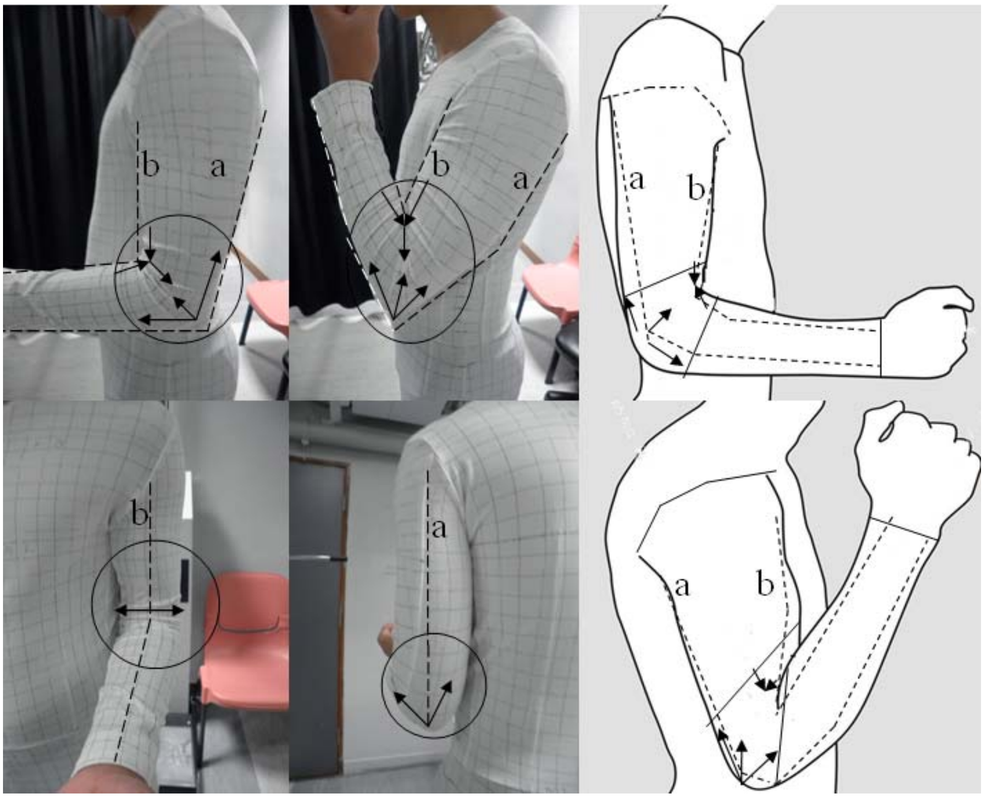
By analysing the acquired images, the skin surfaces changes of the body in each posture were marked by the author, and further confirmed by three experts who have more than five years of experience in anthropometry study and pattern making. Therefore, the skin surface changes were summarised as a map, where boundary lines separating regions of different skin contractions and extensions were determined.

7.3 Results and Discussion

7.3.1 Skin Surface Changes around the Elbow Joint

When the human body bends his arm at 90° or maximum angle, the change of the skin surface around the elbow joint are shown in Figure 7-2. The grid lines of the sample clothing around the elbow joint have significant changes: The grid lines around the outer point of the elbow extend, and the grid lines around the inner concave of the elbow contract. Two reference lines can then be marked to indicate the extension and contraction areas around the elbow, and these are marked as dot lines “a” and “b” in Figure 7-2 (a). Line “a”, named outer arm length line, is the line connecting across back point, outer point of elbow joint and outer point of wrist joint. Line “b”, named inner arm length line, is the line connecting across chest point, inner concave of elbow and inner point of wrist joint.

In summary, the extension and contraction parts of the skin surface around the elbow joint are illustrated as dot lines in Figure 7-2 (b). These are the reference lines for structure line design in the sleeve pattern.



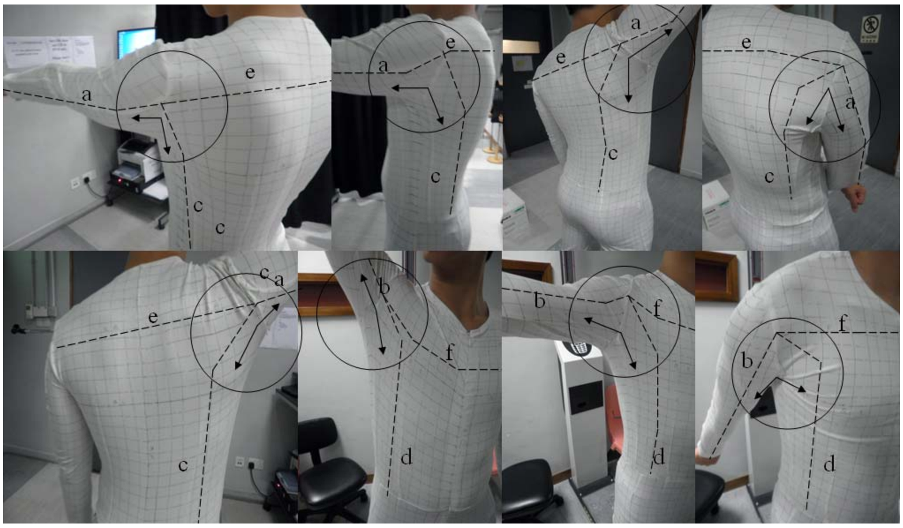
a b

Figure 7-2 Skin surface changes around elbow joint:

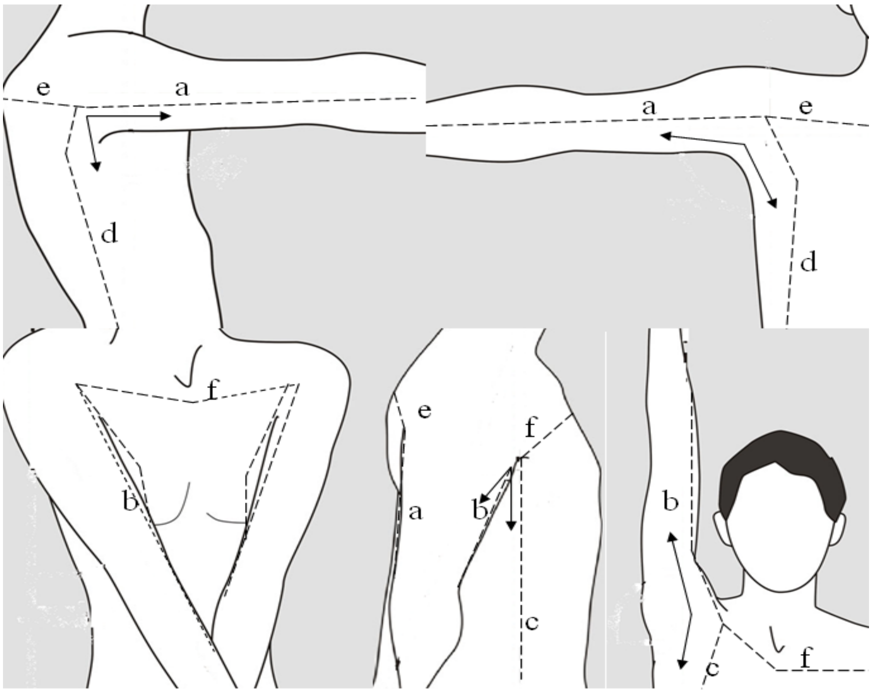
a) changes of grid line, b) illustration of body skin surface change

7.3.2 Skin Surface Changes around the Shoulder Joint

When subjects carry out different postures, the skin surface changes observed around the shoulder joint are shown in Figure 7-3. Figure 7-3 (a) shows the changes of the gird lines and the corresponding division lines. Illustrations of skin surface changes around the shoulder area are shown in Figure 7-3 (b).



a



b

Figure 7-3 Skin surface changes around shoulder joint:

a) changes of grid line, b) illustration of skin surface change

As shown in Figure 7-3 (a), the grid lines around the armscye, especially from across chest point to across back point, have significant extensions. The extensions are along the direction from inner and outer arm length, and also along the direction from underarm to waist length. Elastic materials must be used to ensure wearing comfort. At the same time, the grid lines between the front (back) waist length line and underarm to waist length line are extended in length and width during shoulder joint movements. Moreover, the grid lines around the scapular point, between chest line and shoulder line also have significant extensions.

According to these skin surface changes, four more division lines are defined in addition to the two division lines (dot lines “a” and “b”). As shown in Figure 7-3 (a), two division lines (dot lines “c” and “d”) are determined between the front (back) waist length line and underarm to waist length line. The two lines connect from across the chest (back) point to front (back) waist line. To indicate the skin surface change around scapular point, a division line (dot line “e”) is determined by joining across the back points through scapular points. Another division line (dot line “f”) is determined by joining both across chest points.

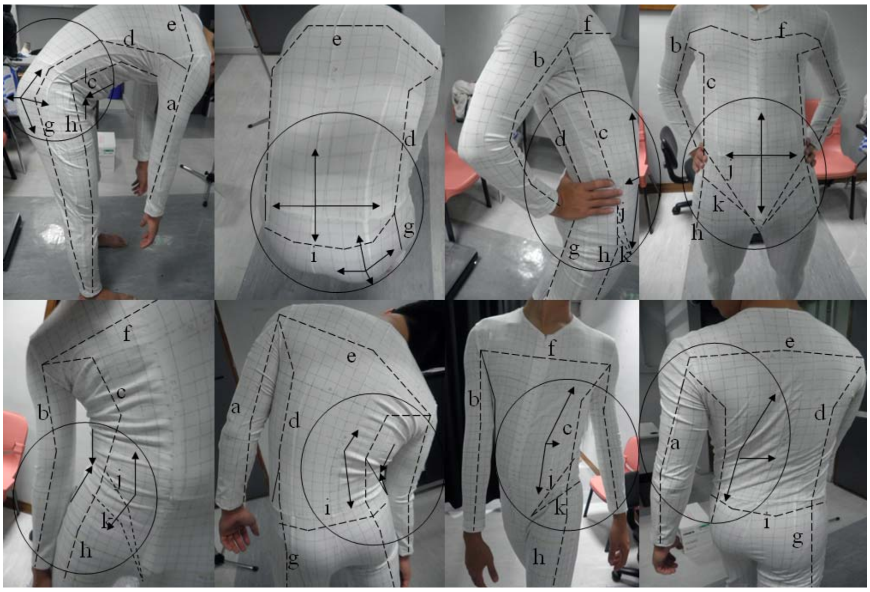
The corresponding division lines on the skin surfaces are illustrated in Figure 7-3 (b), and such division lines are good references for structure line designs in shirt block pattern.

7.3.3 Skin Surface Changes around the Waist

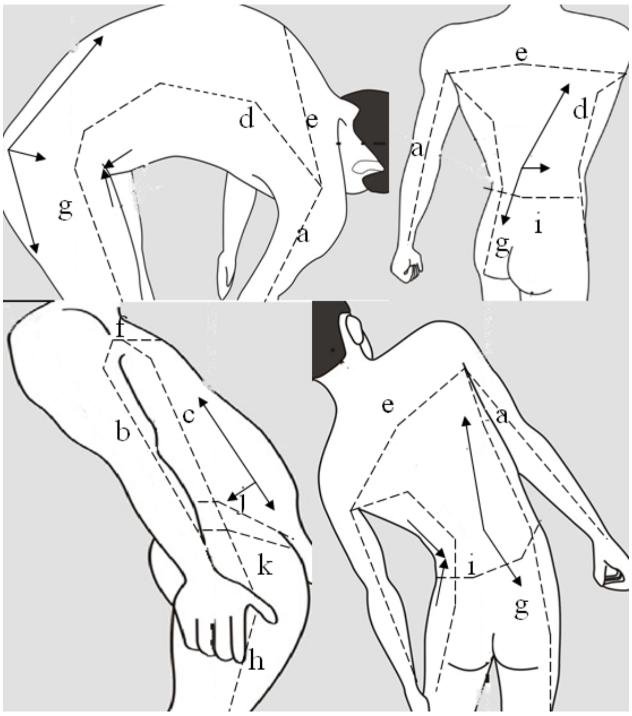
As discussed in Chapter 5, movement of the waist have significant impacts on the skin surfaces of the torso. The detail skin surface analysis is shown in Figure 7-4 (a): When people bend forward, the grid lines indicate that the skin surfaces of the back torso extend in both length and width. An area of extension is the skin surfaces between the scapular line and waist line. Other area of extension is the skin around the hip. Similarly, the grid lines on the front torso also have significant changes when bending the waist backward. Changes are observed in two regions: the region between the chest line and the waist line, and another region between the hip line and the waist line. The materials used in these extending parts should therefore be elastic to accommodate skin surface extension. In addition, bending the waist towards the side or twisting the waist causes the change of grid lines between the centre front (centre back) line and the side line. Meanwhile, these two postures also cause changes of grid lines in the groin area.

In addition to the six division lines, five more division lines were determined by analysing the skin surface change around the waist. Firstly, it is clear in Figure 7-4 (a), a division line (dot line "g") is marked from the hip along the leg skin surface between the centre back line and the outer side line. Line "g" links up with line "d", also connects downward to the ankle level. Secondly, another division line (dot line "h") was determined from the hip along the leg skin surface between the centre front line and the outer side line. Line "g" links up with line "c", and connects downward till the ankle level. The third division line (dot line "i") is the back waist reference line. Two more division lines (dot lines "j" and "k") were determined: Line "j" connects from the side point of the waist line to the crotch line, and line "k" connects a point at 6 cm below the side waist point to the crotch line.

These five division lines are illustrated on the skin surfaces, as shown in Figure 7-4 (b), which are the reference lines for structure line design in shirt and trousers block patterns.



a



b

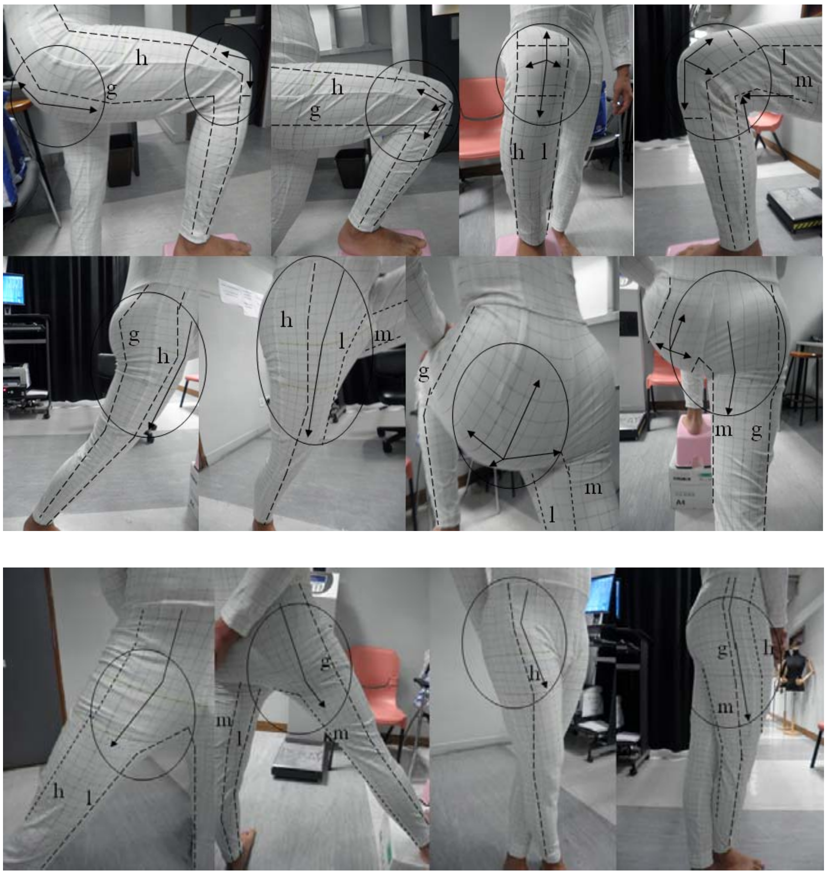
Figure 7-4   Skin surface changes around waist:

a) changes of grid line, b) illustration of skin surface change

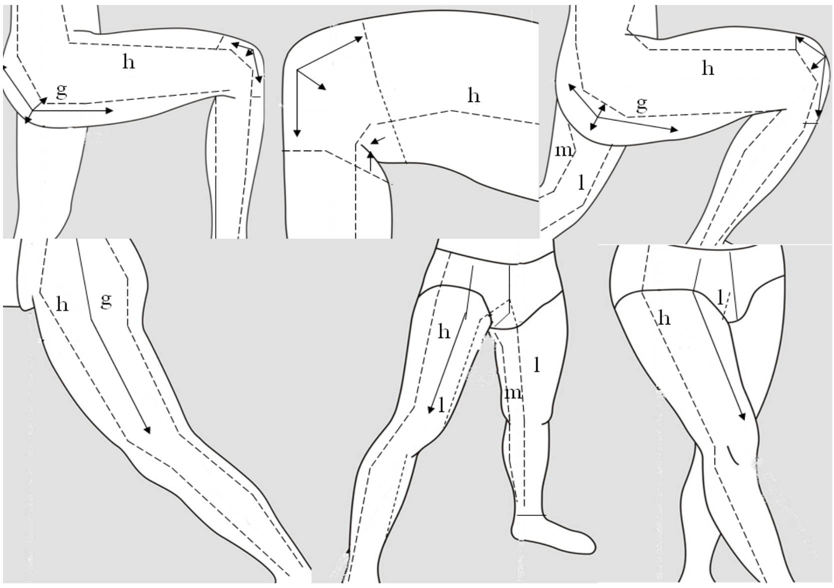
7.3.4 Skin Surface Changes around the Hip and the Knee Joints

When people run, significant changes are observed on the skin surface around the hip and knee joint areas. As shown in Figure 7-5 (a), four division lines can be determined based on the skin surface change. Two division lines (dot lines “g” and “h”) have already been determined in section 7.3.2, which defined the outer-side face of the leg. Another two division lines (dot lines “l” and “m”) defined the inner-side face of the leg. Line “l” started from the mid-point of the front crotch marking till the inner point of the ankle joint. Line “m” began from the mid-point of the back crotch drawing downward till the inner point of ankle joint. The region between lines “h” and “l” is the front face of the leg and the region between lines “g” and “m” is the back face of the leg.

These four division lines are illustrated in Figure 7-5 (b) dividing the leg skin surfaces into four faces: front face, back face, outer-side face and inner-side face. These division lines provide good references for structure line construction on the trousers block pattern.



a



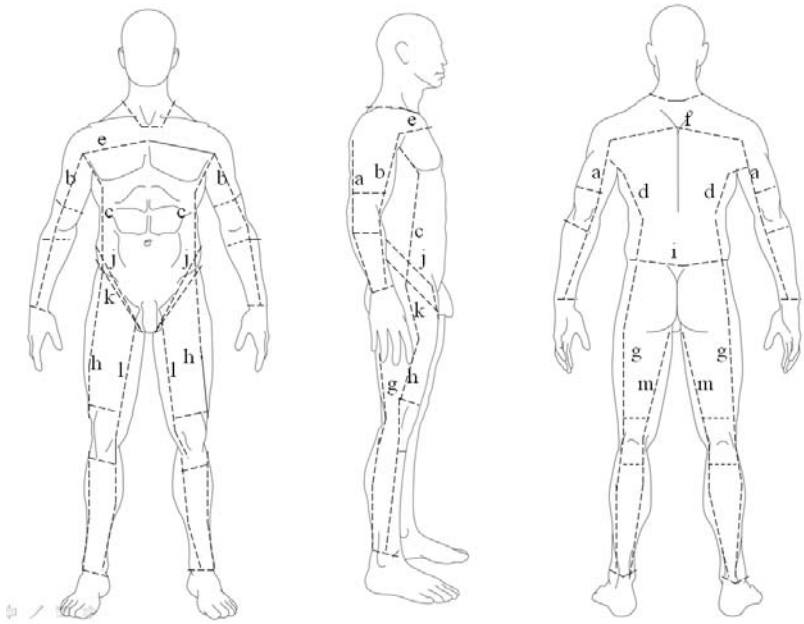
b

Figure 7-5 Skin surface changes around hip and knee joint:

a) changes of grid line, b) illustrations of skin surface change

7.3.5 Distribution Map on Skin Surface Changes

According to the deformation of the grid lines on different parts of the clothing sample, division lines were marked on skin surfaces, as shown in Figure 7-6. Among these lines, lines “a” and “b” are the reference lines on the skin surface of the arm. Lines “c”, “d”, “e”, “f”, “i”, “j” and “k” are the reference lines on the skin surface of the torso. Lines “g”, “h”, “l” and “m” are the reference lines on the skin surface of the leg.



a b c

Figure 7-6 Map of division lines on skin surface: a) front, b) side, and c) back

Lines “b”, “c” and “e” are joining at point of chest width, lines “a”, “d” and “f” are joining at point of back width. The division lines “g” and “h” connect with the division lines “d” and “c”. Lines “g”, “h”, “l” and “m” divide the skin surfaces of leg into four faces. In addition, lines “i” is the back waist line. Lines “j” and “k” form the groin region connecting the torso and the leg.

These division lines are the important references for structure line construction in pattern design. Lines “a” and “b” are reference lines of the sleeve block pattern. Lines “c”, “d”, “e”, “f” and “i” are the reference lines of the shirt block pattern. Lines “g”, “h”, “i”, “j”, “k”, “l” and “m” are the reference lines of trousers block pattern.

7.4 Pattern Structure Lines Design

7.4.1 The Relationship between Skin Surface Changes of Human Body in Running State and Pattern Construction

The study of skin surfaces changes of the human body in running state is the foundation for effective sportswear pattern construction. As shown in the above experiment, when different dynamic postures are performed mimicking the running exercise, the skin surfaces of the arm, torso and leg have significant changes. Different division lines of the body skin are determined accordingly, as shown in Figure 7-6. In running wear pattern construction, these division lines are reference lines for structure line design. Pattern structure lines separate the pattern into different pieces/regions, each region of the garment would extend and contact in the same manner as that part of the body skin. Therefore, body movement would not be constrained, and wearing comfort can be ensured.

7.4.2 Design of Structure Line in Running Wear Pattern Construction

Based on the above findings, the structure lines of running wear are designed, as shown in Figure 7-7. The whole garment is divided into 19 pattern pieces, including 1) torso front (1 piece), 2) torso back (2 pieces), 3) waist (2 pieces), 4) underarm (2 pieces), 5) outer shoulder-arm (2 pieces), 6) inner shoulder-arm (2 pieces), 7) front leg (2 pieces), 8) back leg (2 pieces), 9) outer leg (2 pieces), and 10) inner leg (2 pieces).

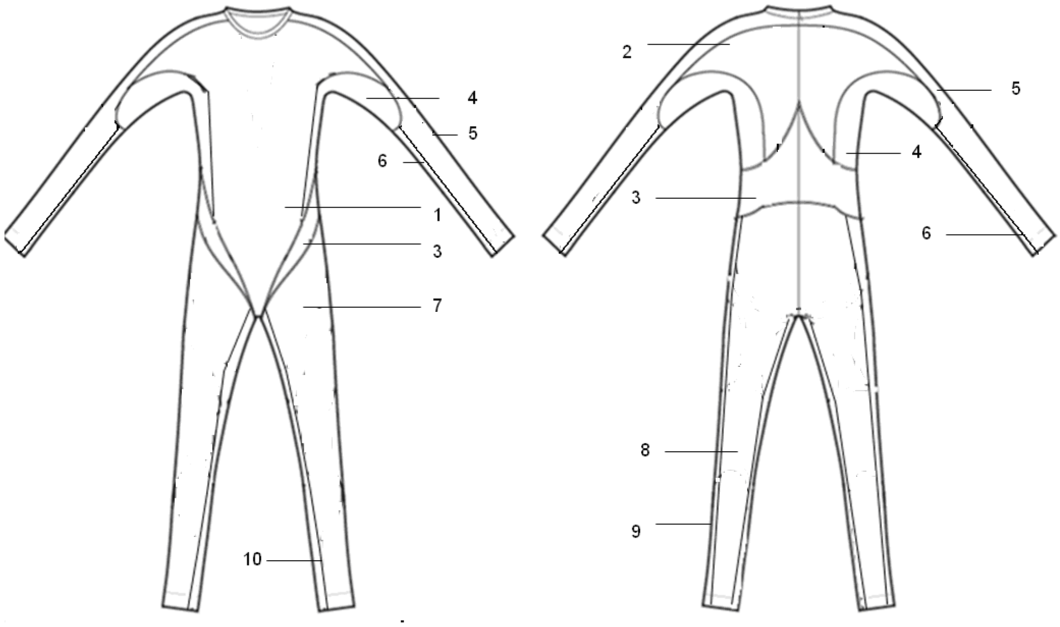


Figure 7-7 Structure lines in pattern construction of running wear:
1) torso front, 2) torso back, 3) waist, 4) underarm, 5) outer shoulder-arm,
6) inner shoulder-arm, 7) front leg, 8) back leg, 9) outer leg, and 10) inner leg

The torso part consists of the front, back, waist and armscye pieces. One vertical structure line for the opening is designed at the back. The arm part of the pattern consists of the outer shoulder-arm, inner shoulder-arm and underarm pieces. The outer shoulder-arm is a special pattern piece connecting the arm and the shoulder. On the outer shoulder-arm pattern piece, three structure lines (two straight lines and one circle line) are designed. The leg part consists of the front, back, outer and inner pieces. Four curve lines and one circle line are designed on the front leg pieces. On the back leg pieces, six curve lines are designed.

7.5 Conclusions

In this chapter, the skin surface changes of the human body in running state have been systematically investigated and analyzed. The research results indicate that the body skin surfaces vary in different manners when a person runs. Division lines are marked on the skin surface to divide skin surfaces into different parts. These division lines have a close relationship with the freedom of movement and pattern structure line construction. In clothing pattern design, if structure lines are designed according to skin surface change, the running wear will not restrict the body movements in running. The detail structure line designs of the dynamic block pattern will be discussed in Chapter 8.

CHAPTER 8 DYNAMIC PATTERN CONSTRUCTION OF RUNNING WEAR WITH JUST-FIT DESIGN

8.1 Introduction

As discussed in the introduction, the body measurements applied in the three main methods of pattern making, namely draping, drafting and block pattern construction, are all static state measurements. Thus, the resulted clothing patterns are regarded as static patterns, not suitable for high-performance clothing, such as sportswear and protective wear. In high-performance clothing, excellent functional design on mobility is a mandatory requirement.

A number of studies have been conducted on high-performance clothing's pattern constructions. Wang and Wang (2005) analysed the neck structure and body movement characteristics, and proposed a new method for collar design. Zhou (2004) analysed the structure and movement characteristics of torso and arms, and proposed a new method to construct dynamic sleeve pattern. Yoshihara (1987) studied the movement of muscles and proposed two pattern development methods to improve garment mobility. Kato (2001) observed and quantified skin surface changes in different parts of the body in motion state. He added special ease allowances to the corresponding parts of the garment patterns. Nakazawa (2000) proposed a 4D pattern construction method for sportswear. In his method, the structure lines and ease allowances were decided by analysing body skeleton in static state, body postures, and body skin surface changes in motion state, and the resulted clothing have good performance on mobility.

The previous works provide interesting results, but these studies are not complete. Some studies only focused on the pattern construction of particular components in a garment. Some worked on the body skin surface changes in dynamic postures, but the number of postures analysed was limited. In other words, a detailed map for skin surface changes is still absent. The application of the map to pattern construction has never been discussed.

Based on the findings of previous chapters, a dynamic pattern construction method is proposed in this chapter. In Chapters 3 and 4, the construction and evaluation method of static block pattern with just-fit design have been studied, and by the reflection method well fitted static block pattern can be obtained. In Chapters 5 and 6, the changes of body measurements in dynamic postures and running state have been analysed. Thus, the ease allowances to be used in dynamic block pattern can be determined accordingly. In Chapter 7, skin surface changes of the human body in dynamic postures and its impacts on body structure have been investigated. In the development of dynamic block pattern, the divisions of skin surface based on mechanical characteristics of human body in running state (as discussed in Chapter 7) can help researchers to determine the positions and shapes of different structure lines in running wear patterns. All these results provide the foundation to develop a new construction method for dynamic patterns. The dynamic patterns of one-piece running wear with just-fit design are constructed by this new method.

8.2 Methodology

In this chapter, dynamic pattern of running wear can be constructed by the following procedures: a) constructing static block pattern with just-fit design; b) designing optimal wearing ease values based on changes of body measurements in running exercise; c) constructing dynamic block pattern with just-fit design; d) constructing dynamic patterns for one-piece running wear.

8.2.1 Construction of Static Block Patterns with Just-Fit Design

The construction method for static block pattern with just-fit design has been proposed and discussed in Chapters 3 and 4, which can be summarised as follows:

a) Collect 50 body measurements in static state by 3D body scanning.

b) Determine anatomical points and body structure lines based on captured images of 3D body scanning, including 14 anatomical points and 13 body structure lines on the upper torso, 10 anatomical points and 8 body structure lines on the arms, 18 anatomical points and 13 body structure lines on the lower torso and legs.

c) Develop static block patterns of shirt, sleeve and trousers by the reflection method according to the body measurements, anatomical points and body structure lines.

d) Assess the resulted static block pattern from step (c) with objective fit evaluation method.

e) Identify areas for improvement in the static block patterns, and adjust the block patterns for better fit.

8.2.2 Design of Optimal Wearing Ease Values in Dynamic Block Pattern

As discussed in Chapters 5 and 6, key body measurement changes in different body motion states, namely static state, dynamic postures and running state. The changes of key body measurements indicate the extension or contraction of body skin surfaces in body movements, which determine the freedom of body motion. The maximum changes of body measurement can be regarded as the maximum wearing ease values in the corresponding locations of the clothing pattern. The maximum changes of body measurements in various dynamic postures and running states are determined as the optimal wearing ease.

8.2.3 Construction of Dynamic Block Patterns with Just-fit Design

By incorporating the optimal wearing ease values to the fitted static block patterns, dynamic block pattern with just-fit design can be constructed as follows:

a) Determine the locations for adding wearing ease values in static block patterns.
b) Add wearing ease values to the corresponding locations of the fitted static block pattern by special methods of cutting, moving and extending.
c) Re-construct patterns after adding wearing ease values in the fitted static block patterns as the dynamic block patterns with just-fit design.

8.2.4 Construction of Dynamic Patterns for One-piece Running Wear Design

Based on the findings of skin surface changes of human body in running state, cutting lines design of running wear have been determined in Chapter 7. With the acquired dynamic block patterns and the preferred cutting lines design, the running wear dynamic patterns are constructed as follows:

a) Determine cutting line locations in running wear, and mark labels for different pattern pieces. Determine the length of each cutting line.

b) Construct different dynamic patterns of the running wear based on dynamic block pattern and the defined cutting lines.

c) Complete the final dynamic patterns of the running wear by walking and truing the join seams on the pattern pieces.

8.3 Design of Static Block Patterns with Just-Fit Design

According to acquired body measurements, anatomical points, body structure lines and the construction steps outlined in section 8.2.1, fitted static block patterns can be developed, as shown in Figure 8-1 to Figure 8-3. The detailed steps are shown in section 3.6 and section 4.6.

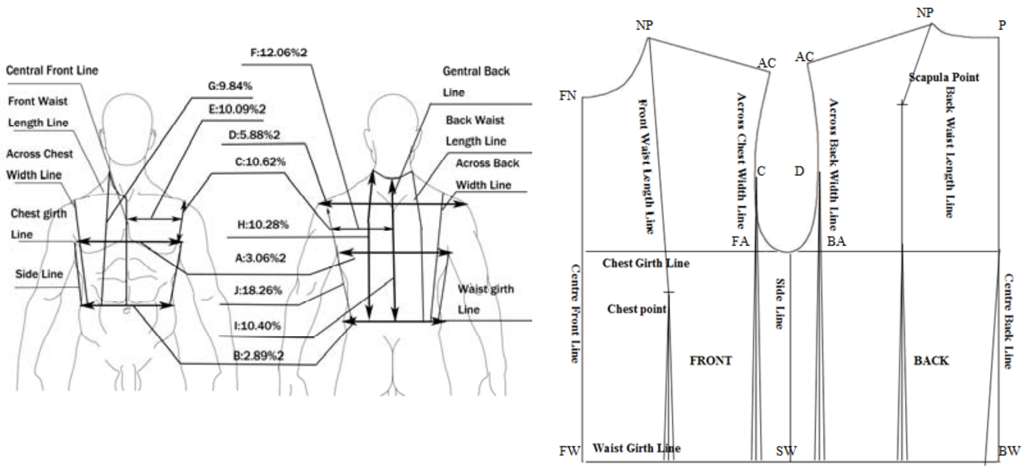


Figure 8-1 Static block patterns of shirt with just-fit design

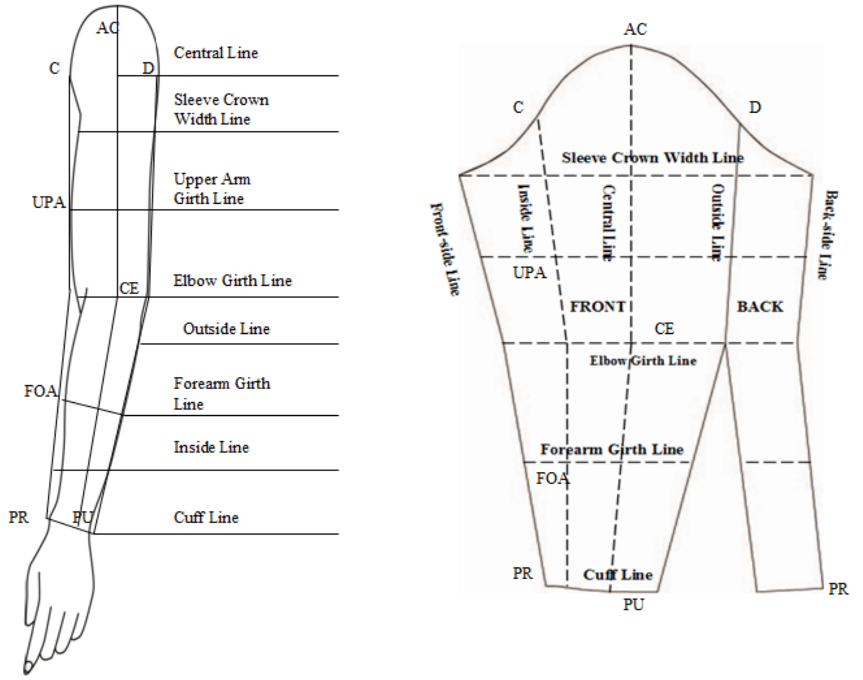


Figure 8-2 Static block pattern of sleeve with just-fit design

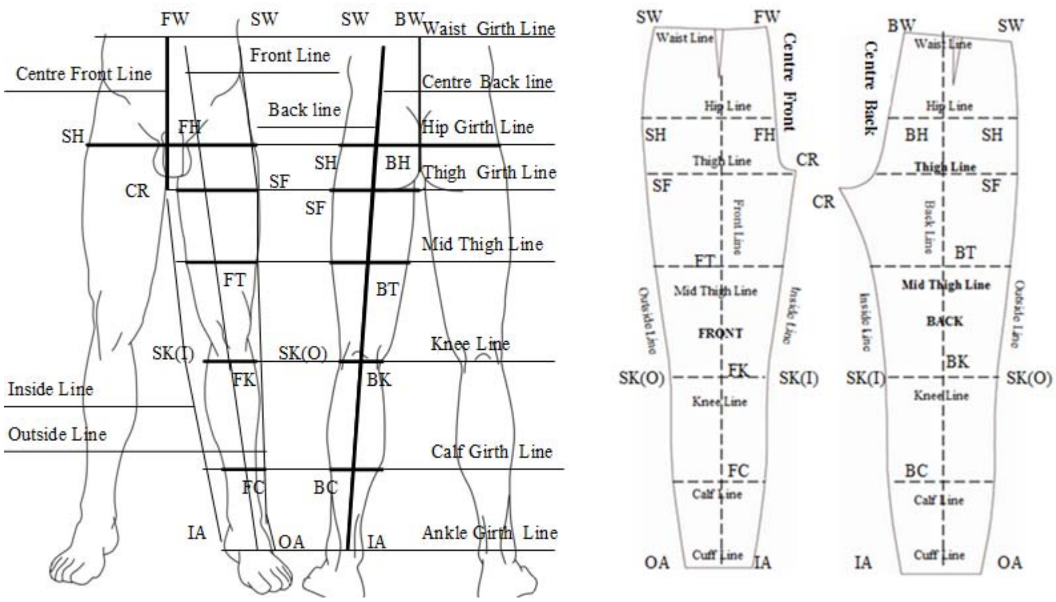


Figure 8-3 Static block patterns of trousers with just-fit design

8.4 Design of Optimal Wearing Ease Values in Dynamic Block Patterns

Wearing ease values of the 21 key measurements, which were obtained from investigation on measurement changes in dynamic postures and running state, have been determined in Chapters 5 and 6. The wearing ease values are summarised in Table 8-1 to Table 8-3, and the maximum values of the two states are highlighted with bold.

Table 8-1 Wearing ease values of key girth measurements in two states

States	Girth (cm) / percentage (%)								
	Chest (UB)	Waist (UB/LB)	Hip (LB)	Armscye (UB/A)	Upper arm (A)	Elbow (A)	Thigh (L)	Knee (L)	Calf (L)
Body postures	**3.00/ 3.11**	**2.00/ 2.54**	5.60/ 5.86	4.50/ 10.92	3.10/ 11.31	7.40/ 30.08	2.80/ 5.08	5.60/ 15.05	**1.40/ 3.77**
Running	2.65 /2.73	1.59 /2.01	**5.82 /6.00**	**4.76 /11.26**	**3.28 /11.93**	**7.52 /30.25**	**3.42 /6.14**	**6.54 /17.44**	1.22 /3.26

Table 8-2 Wearing ease values of key width measurements in two states

States	Width (cm) / percentage (%)		
	Across shoulder (UB)	Across chest (UB)	Across back (UB)
Body postures	**2.80/ 6.93**	**4.00/ 10.36**	**5.00/ 12.76**
Running	1.56/3.85	2.22/5.71	2.24/5.64

Table 8-3 Wearing ease values of key length measurements in two states

States	Length (cm) / percentage (%)								
	Front waist (UB)	Back waist (UB)	7^{th}-cervical to waist (UB)	Under arm to waist (UB)	Total crotch (LB)	Central arm (A)	Inside leg (L)	Front leg (L)	Back leg (L)
Body postures	**4.40/ 9.65**	**4.60/ 9.20**	**4.20/ 9.11**	**4.40/ 14.24**	1.70/ 2.58	5.40/ 9.84	1.00/ 1.38	2.20/ 2.36	5.50/ 5.55
Running	1.10/ 2.38	1.41/ 2.78	1.06/ 2.10	0.82/ 1.77	**1.83/ 2.79**	**5.58/ 10.07**	**1.06/ 1.44**	**2.57/ 2.74**	**5.72/ 5.71**

As shown in the tables, the wearing ease values of some key measurements in running state are smaller than that in dynamic postures. In order to meet the body motion freedom requirement, the maximum wearing ease values of the two states are adopted as the final wearing ease values to use in dynamic block pattern construction, which are shown in Table 8-4 to Table 8-6.

Table 8-4 Wearing ease values of key girth measurements in dynamic block pattern

Girth (cm) / percentage (%)								
Chest (UB)	Waist (UB/LB)	Hip (LB)	Armscye (UB/A)	Upper arm (A)	Elbow (A)	Thigh (L)	Knee (L)	Calf (L)
3.00/ 3.11	5.82 /6.00	4.76 /11.26	3.28 /11.93	7.52 /30.25	3.42 /6.14	6.54 /17.44	5.82 /6.00	1.40/ 3.77

Table 8-5 Wearing ease values of key width measurements in dynamic block pattern

Width (cm) / percentage (%)		
Across shoulder (UB)	Across chest (UB)	Across back (UB)
2.80/ 6.93	4.00/ 10.36	5.00/ 12.76

Table 8-6 Wearing ease values of key length measurements in dynamic block pattern

Length (cm) / percentage (%)								
Front waist (UB)	Back waist (UB)	7^{th}-cervical to waist (UB)	Under arm to waist (UB)	Total crotch (LB)	Central arm (A)	Inside leg (L)	Front leg (L)	Back leg (L)
4.40/ 9.65	4.60/ 9.20	4.20/ 9.11	4.40/ 14.24	1.83/ 2.79	5.58/ 10.07	1.06/ 1.44	2.57/ 2.74	5.72/ 5.71

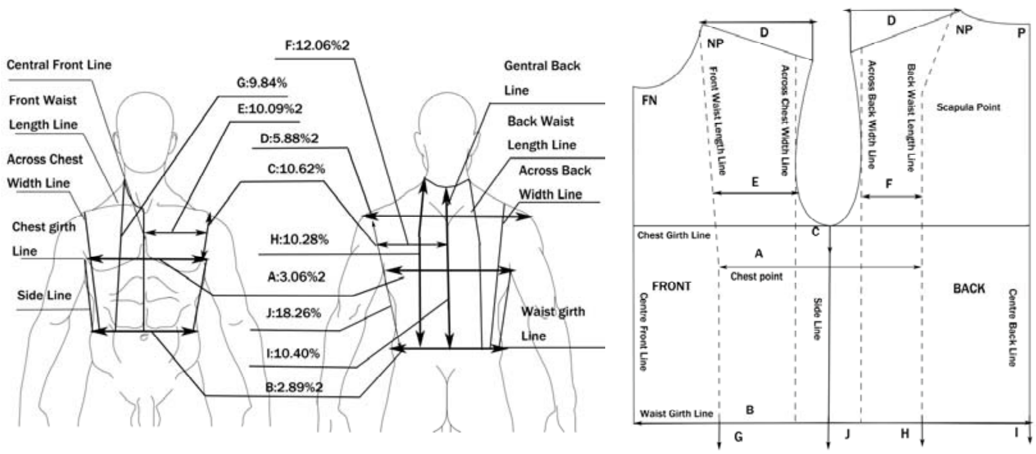
8.5 Construction of Dynamic Block Patterns with Just-Fit Design

In this chapter, a dynamic block pattern method is proposed, in which block patterns are constructed by incorporating into the fitted static block pattern the necessary wearing ease for body movements. The method can be used to develop garment patterns for high-performance clothing, such as sportswear or protective garments, in which high level of mobility functional design is required.

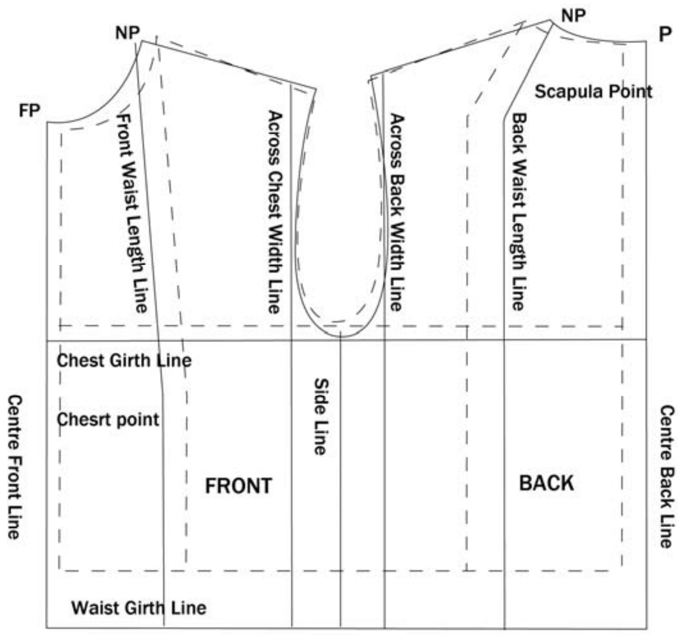
Among the 21 identified key measurements determined in Chapters 5 and 6, chest girth, waist girth, armscye girth, across shoulder width, across back width, across chest width, front waist length, back waist length, the 7^{th}-cervical to waist length, and underarm to waist length are measurements to use in the shirt block. Armscye girth, upper arm girth, elbow girth, and central arm length are measurements to use in the sleeve block. For the trouser block, waist girth, hip girth, thigh girth, knee girth, calf girth, total crotch length, inside length, front leg length, and back leg length are used.

8.5.1 Shirt Dynamic Block Pattern with Just-fit Design

To design dynamic block patterns, the fitted static block patterns for the shirt (front and back pieces) are first made (as shown in Figure 8-4(b)), based on the static body measurements acquired in Chapter 3. Anatomical structural lines of the human body are marked on the static block patterns, which include horizontal lines of chest girth line and waist girth line, and seven vertical lines: (i) centre front line, (ii) front waist length line, (iii) across chest width line, (iv) side line, (v) across back width line, (vi) back waist length line, and (vii) centre back line. With these defined anatomical structural lines, wearing eases are applied. The maximum extensions of skin surfaces in the upper body (as shown in Tables 8-4 to 8-6) are the necessary wearing eases. In Figure 8-4, the skin surface extension and the corresponding locations for adding wearing eases are marked with the same labels of A, B, C, and so forth. For example, the maximum extension of the skin surfaces in chest girth (label ‘A’) and the corresponding ease is added to the static shirt block area ‘A’.



a b



c

Figure 8-4 Development of shirt dynamic block patterns: (a) extension of skin surfaces in key measurements of upper-body, (b) shirt static block patterns, and (c) shirt dynamic block patterns

To develop a dynamic shirt block, wearing ease value in *across chest width* (E) should be added to the area between front waist length line and across chest width line, in order to ensure the width of armscye and the width of front neckline remain unchanged. Similarly, wearing ease value in *across back width* (F) should be added to the area between back waist length line and across back width line, as shown in Figure 8-4 (b). For *across shoulder width* (D), the ease adding locations are overlapped with those locations for across chest and across back eases, thus the requirement of across shoulder ease is automatically fulfilled in the process of incorporating across chest/across back width eases.

In the case of *chest girth* (A) ease, similar to the across shoulder ease, the requirement of wearing ease has been fulfilled when incorporating across chest and back width eases. For *waist girth* (B) ease, 2.00 cm ease should be used for fit waist design according to the data in Table 8-4. In order to achieve a fit waist design, the difference between the chest girth with ease and the waist girth with ease should be taken away by darts or pleats along the vertical structural lines except centre front or centre back lines. For *armscye girth* (C), the required wearing ease is usually incorporated by enlarging armscye depth.

In terms of length, wearing ease values in the *front waist length* (G), *back waist length* (H), *the 7th-cervical to waist length* (I) and *underarm to waist length* (J) are incorporated in the dynamic pattern by extending the waist girth line downward to a new horizontal waist girth line.

A new dynamic block pattern of upper-body with optimal ease is accordingly made, as shown in Figure 8-4 (c). Compared with the static block pattern, the dynamic shirt block pattern provides necessary room for unconstrained upper-body movements.

8.5.2 Sleeve Dynamic Block Pattern with Just-fit Design

As armscye is lengthened in the dynamic block pattern for shirt, therefore a new sleeve dynamic block pattern is necessary. The maximum skin extensions of arm measurements are displayed in Figure 8-5 (a). In order to correctly incorporate these wearing ease values in the dynamic sleeve block, ten anatomical lines are defined, including sleeve crown width line, upper arm girth line, elbow girth line, forearm girth line and cuff line in the horizontal direction; and central line, inside line, outside line, front side line and back side line in the vertical direction. With these ten structural lines, wearing ease values can be correctly integrated to obtain a new dynamic block pattern for the sleeve.

As discussed in sections 5.3.4 and 5.3.5 of Chapter 5, *armscye girth (A), Upper arm girth (B), elbow girth* (C), and *central arm length* (D) are important for wearing ease design in the dynamic block pattern of sleeve. In bending the arm, the skin surfaces around the elbow joint have maximum extension, which increases the elbow girth and central arm length. In addition to skin surface extension at elbow joint area, upper arm girth skin extensions also affect the arm lengths. To develop dynamic sleeve block, wearing ease of *elbow girth* (B) is firstly incorporated by cutting through the outside arm line and moving the two cut pieces outward, as shown in Figure 8-5 (b). After adding elbow ease, the amount of wearing ease in *Upper arm* (B) is added by adjusting and smoothing the front and back side of the upper arm line. In the sleeve dynamic block pattern, sleeve crown length (*armscye girth:* A) must also be adjusted to ensure the same amount of wearing ease added to the armscye in shirt block pattern must be evenly added to both sides of the sleeve crown length, refer to Figure 8-5 (b). In terms of central arm length in the sleeve block pattern, the necessary eases are incorporated by lowering the cuff line.

Figure 8-5 (c) shows a new dynamic block pattern for sleeve. It is shown that the dynamic block pattern for sleeve has a wider sleeve crown width and elbow width.

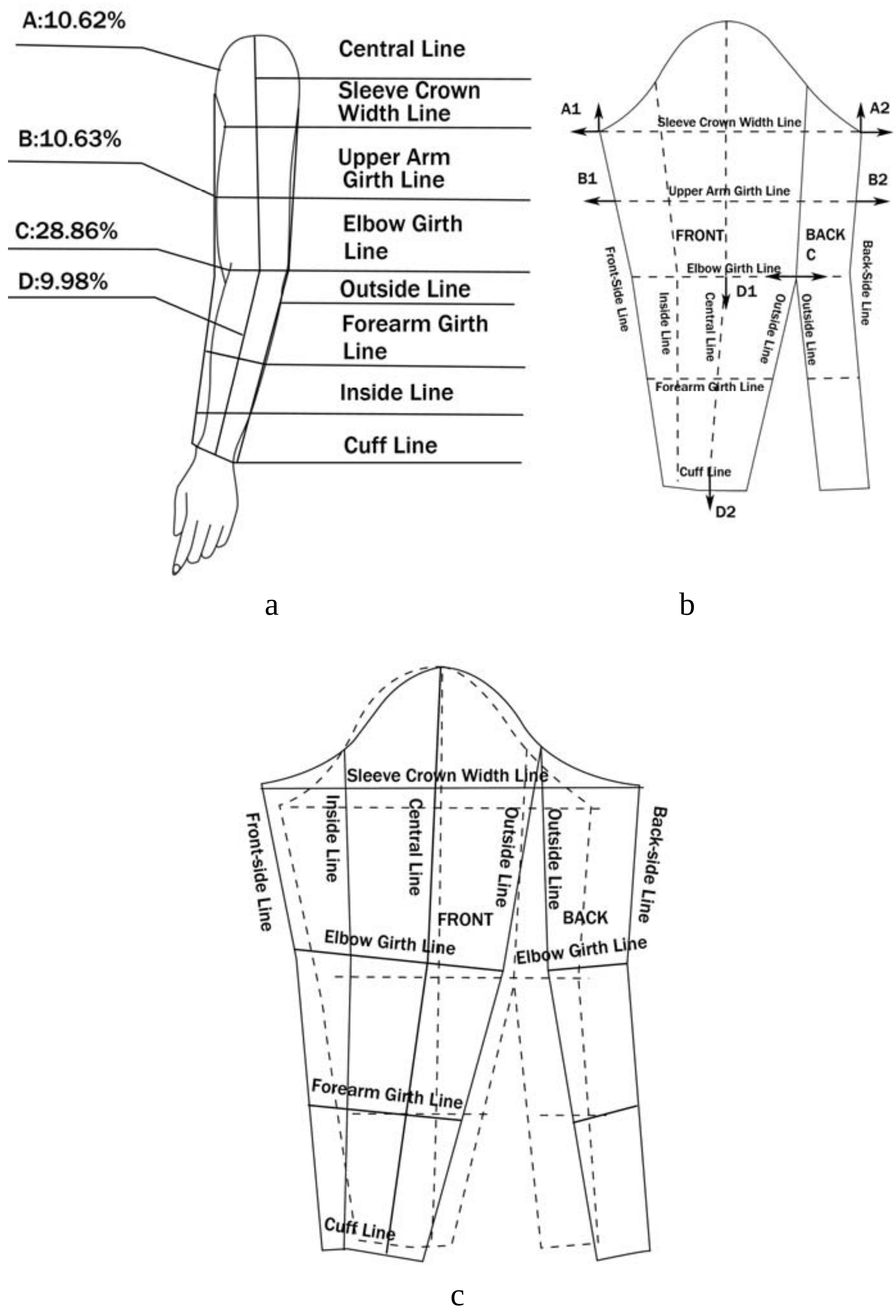
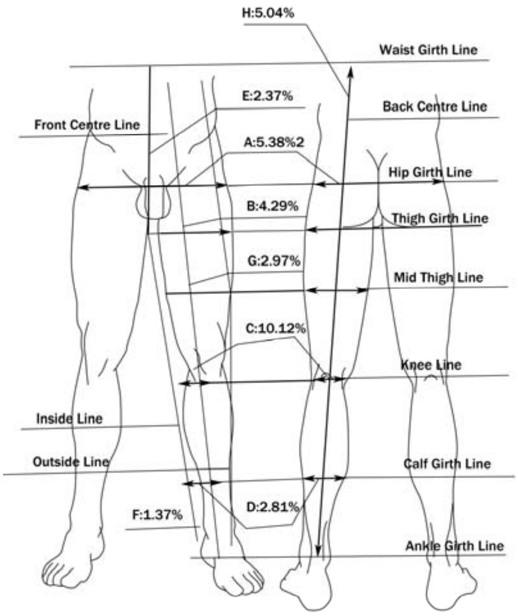
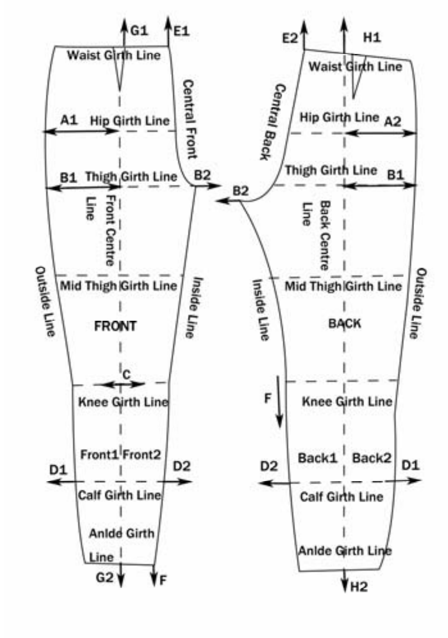


Figure 8-5 Development of sleeve dynamic block pattern: (a) extensions of skin surfaces in key measurements of arm, (b) sleeve static block pattern, and (c) sleeve dynamic block pattern

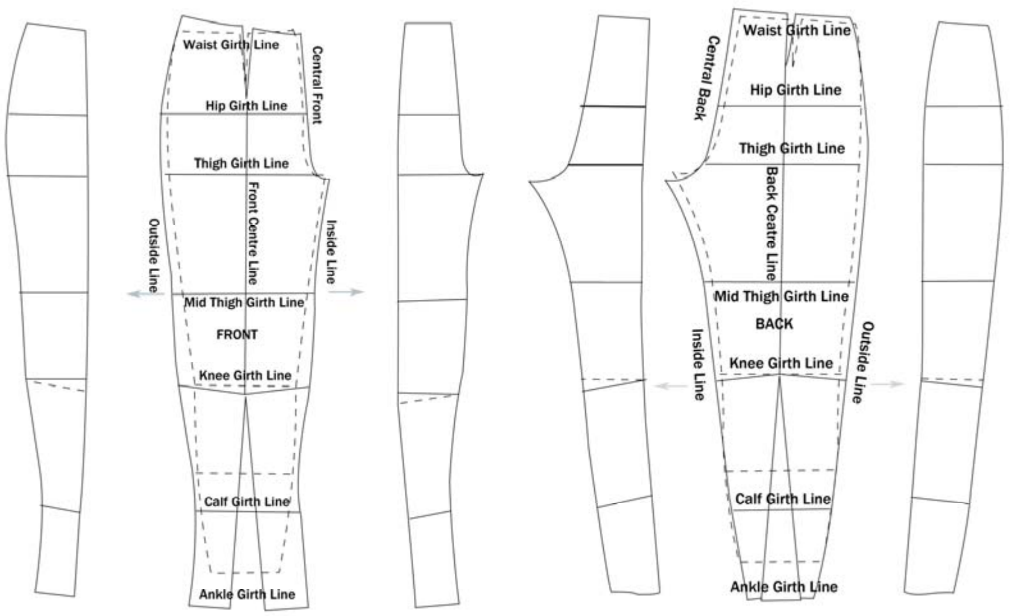
8.5.3 Bottom Dynamic Block Pattern with Just-fit Design



a



b



c

Figure 8-6 Development of trousers dynamic block patterns: (a) extension of skin surfaces in key measurements of lower-body and leg, (b) trousers static block patterns, and (c) trousers dynamic block patterns

The skin surfaces extensions of key measurements used in trousers block patternmaking are shown in Figure 8-6 (a). Trousers static block patterns are shown in Figure 8-6 (b), on which anatomical lines are marked: waist girth, hip girth, thigh girth, mid-thigh girth, knee girth, calf girth and ankle girth lines are horizontal lines; front centre line, back centre line, outside lines, and inside lines are vertical lines.

As discussed, *hip girth* (A) and *knee girth* (C) are important for wearing ease design in dynamic block patterns for trousers. Wearing ease of *hip girth* (A) is added to the area between the front centre line and outside line. For *thigh girth* (B), part of the wear ease is added to the area between the front centre line and outside line, while the remaining ease is added by extending thigh line “B2”. For *knee girth* (C), wear eases are applied only in the front piece, by cutting off the knee girth line and cutting along the front centre line from cuff line to knee girth line, and then rotating the divided pieces (*Front 1* and *Front 2*) as shown in Figure 8-6 (c). The *calf girth* (D) ease is incorporated by adjusting and smoothing the inside and outside lines around the calf girth area. For *total crotch length* (E), part of the ease is achieved when incorporating thigh girth ease (area: B2), and the remaining ease can be incorporated by extending crotch length line (areas: E1 and E2).

In terms of trouser length, wearing ease in *inside leg length* (F) of the back piece is added by cutting off knee girth line and cutting along the back centre line from cuff line to knee girth line, and then rotating the divided pieces (*Back* 1 and *Back* 2) as shown in Figure 8-6 (c). The same amount of ease is added to the *inside leg length* of the front piece by lowering the front ankle girth line. For *front leg length* (G), wear ease is added to the front piece by lowering the cuff line and extending the front centre line. Similarly, wearing ease in *back leg length* (H) can be incorporated to the back piece.

Figure 8-6 (c) shows the new dynamic block patterns of trousers with wider hip girth in the front and back pieces, and wider knee girth in the front piece. The resulting dynamic block pattern of trousers can accommodate different body movements.

8.6 Dynamic Pattern Construction of One-piece Running Wear with Just-Fit Design

8.6.1 One-piece Running Wear Design

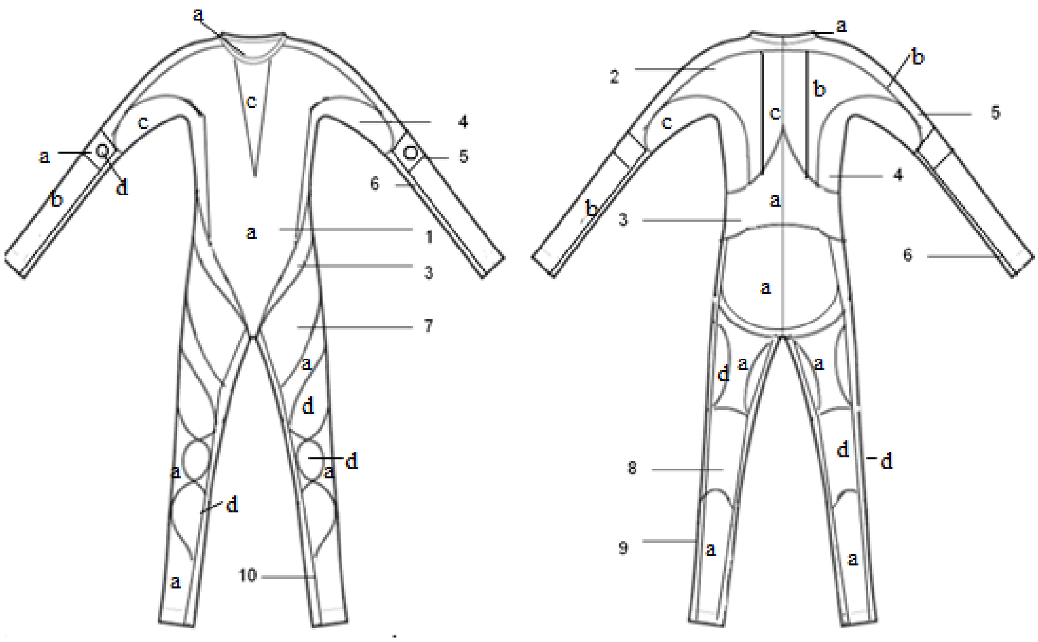


Figure 8-7 Style and cutting lines in dynamic pattern of one-piece running wear: 1) Front Shirt, 2) Back shirt, 3) Waist, 4) Side Shirt-sleeve, 5) Arm-shoulder Sleeve, 6) Inner Sleeve, 7) Front Trousers, 8) Back Trousers, 9) Side Trousers, and 10) Inner Trousers

Different from traditional style of vest and shorts as running wear design, the proposed style adopts a one-piece design. It is because the current study aims to obtain a complete map of body skin surface extensions when people run. The findings can be used for designing different styles of running wear, including one-piece design. It's noticed that one-piece sportswear has received much attention in recent year, and many athletes chose one-piece sportswear in recent important international competitions.

As discussed in Chapter 7, by analysing skin surface changes of human body in running state, the style and cutting lines of one-piece running wear can be designed for the betterment of ergonomic wearing comforts. As shown in Figure 8-7, the one-piece running wear consists of 10 components:

1). Front shirt: This component covers most part of the front upper-body, a small part of the front lower-body and the front upper-arm.

2). Back shirt: This component includes most part of the back upper-body and a small part of the back upper-arm.

3). Waist: This component is mainly used to support the steady posture of the torso in running state, which covers most part of the back waist and the groin.

The design of sleeve is divided into three components including side-shirt sleeve, arm-shoulder sleeve and inner sleeve.

4). Side-shirt sleeve: This component includes the side part of the upper-body and some areas of the upper sleeve (front and back) around the underarm.

5). Arm-shoulder sleeve: This component covers the shoulder part of the torso and the central part of upper arm.

6). Inner sleeve: This component includes most part of the side part of the front and back arms except the side shirt-sleeve part.

Just like the design of sleeve, trousers are also divided into four components to fit the motion of the legs in running state. The four components consist of front trousers, back trousers, side trousers and inner trousers.

7). Front Trousers: This component includes most part of the front leg from the groin.

8). Back trousers: This component includes most part of the back leg and the hips.

9). Side trousers: This component includes the side part of the leg from the waist.

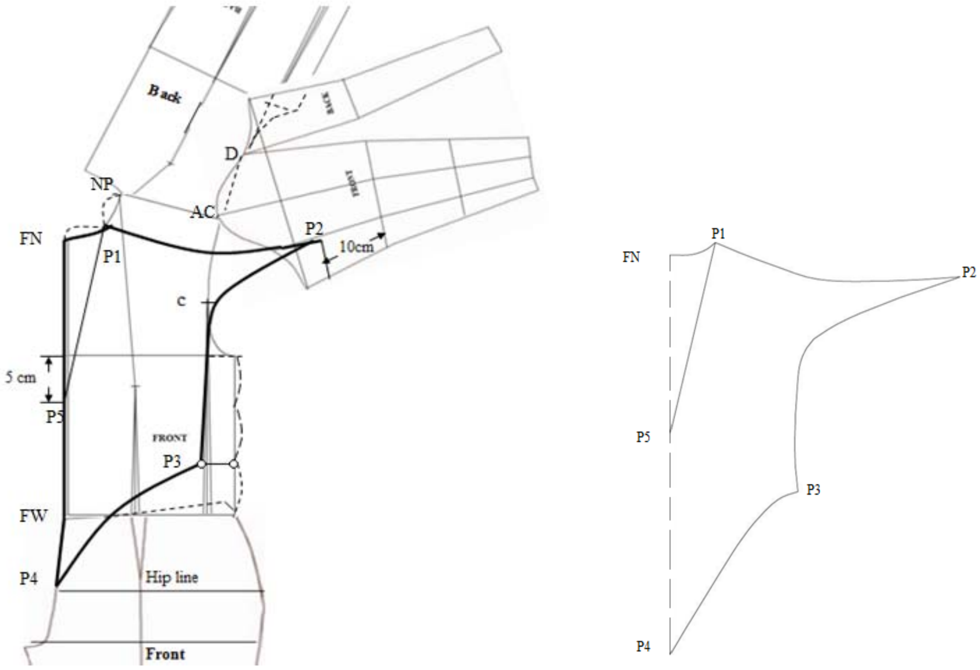
10). Inner trousers: This component includes the inner part of the front and back legs.

From the literature review, it is noticed that people have significant changes of the skin temperature and water content in running state: the head, hand, armpit, knee fossa and feet are areas with high skin temperature, while the abdomen and low back are areas with low skin temperature (Yao et al., 2010). In terms of water contents, no clear division is found on the body skin surfaces because the whole body is sweating when people run (Yao et al., 2010). Therefore, different materials should be applied to the pattern pieces for effective heat and moisture transmission. In this regard, alongside the cutting lines, inner lines are marked on the pattern pieces to indicate the areas for different material applications, as shown in Figure 8-7. On each pattern piece, the areas marked with “a” are required to have good supporting function for keeping the steady body shapes. The areas marked with “b” are required to have good stretching function and average heat and moisture transmission functions. The areas marked with "c" are required to have good thermal-moisture transmitting function. The areas marked with "d" parts are required to have excellent thermal-moisture transmitting function.

8.6.2 Dynamic Pattern Construction of One-piece Running Wear with Just-Fit Design

8.6.2.1 Dynamic pattern construction of the front and back shirt

As reviewed in Chapter 2, runners should keep their heads up and look ahead in running. The shoulders should be low and loose, and the two arms should swing forward and backward between the waist and lower chest level. Elbows should be bent at about 90 degrees and hands should be kept in an unclenched fist with the fingers lightly touching palms. Torso and hips are at 90 degree to the ground.



a b

Figure 8-8 Dynamic pattern construction of front shirt: (a) Illustration of front shirt pattern construction, (b) Dynamic pattern of front shirt

Based on body postures in running state introduced in Chapter 2, the front shirt dynamic pattern of the one-piece running wear can be constructed by the following steps:

Step 1: The front and back pieces of the shirt dynamic block pattern are aligned along the shoulder line from NP to AC. The front trousers pattern is aligned with the front shirt dynamic block pattern along point FW and the waist line, as shown in Figure 8-8 (a).

Step 2: Place the sleeve dynamic block pattern by matching point AC of the sleeve block with that of the shirt block. Rotate the sleeve block around point AC until point D of the sleeve block reach point D of the back shirt dynamic block.

Step 3: Divide the front neckline into two curve segments of equal length, point P1 is determined. Draw a line from P1 parallel to the shoulder line, and connect with a smooth curve to point P2 on the inside line of the sleeve block. Point P2 is above elbow line by 10 cm.

Step 4: By dividing the side line of the front block into three equal parts, the position of point P3 is determined. From point P2, draw a smooth curve connecting to point P3.

Step 5: Point P4 is the intersection point of central front line and front hip line. From point P4, draw a smooth curve connecting to point P3.

Step 6: Connect point FN to point P4. On the line, determine point P5 at 5cm below the chest line.

Step 7: Draw an inner line on the front shirt by connecting P5 to P1.

The front shirt dynamic pattern of one-piece running wear is constructed, as shown in Figure 8-8(b).

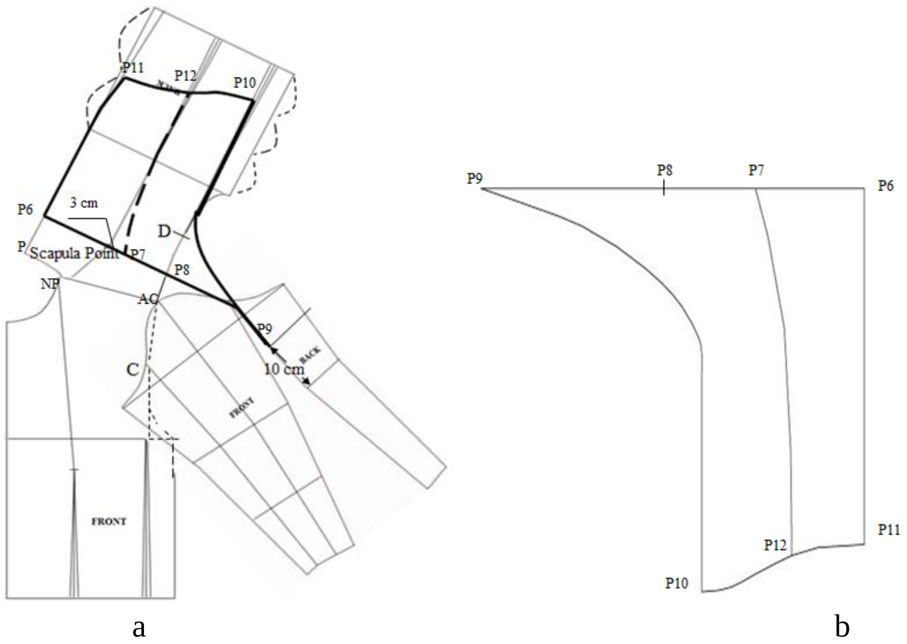


Figure 8-9 Dynamic pattern construction of back shirt: (a) Illustration of back shirt pattern construction, (b) Dynamic pattern of back shirt

Back shirt dynamic pattern of one-piece running wear can be constructed by the following steps:

Step 1: The front and back pieces of the shirt dynamic block pattern are aligned by joining the shoulder line from NP to AC, as shown in Figure 8-9 (a).

Step 2: Place the sleeve dynamic block pattern by matching point AC of the sleeve block with that of the shirt block. Rotate the sleeve block around AC until point C of the sleeve block reach point C of the front shirt dynamic block pattern.

Step 3: From the scapular point on the back shirt dynamic pattern, draw a line parallel to the chest line, intersecting with central back line at point P6 and back armscye line at point P8. Point P7 is determined along the line at 3cm away from the scapular point.

Step 4: On the outside line, point P9 is 10 cm above the elbow line. From P9, draw a smooth curve connecting to point P8.

Step 5: By dividing the side line of back block into three equal parts, the position of point P10 is determined. From point P10, draw a smooth curve connecting to point P9.

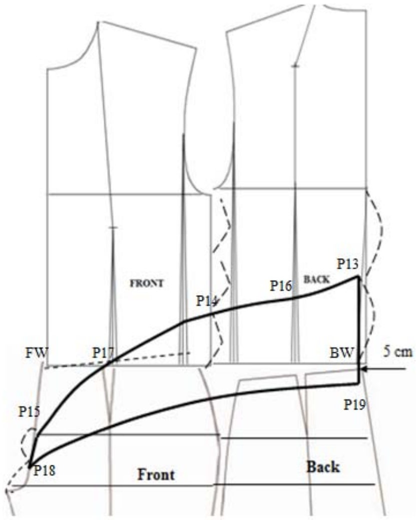
Step 6: The midpoint of the central back line segment between chest line and waist line is point P11. Construct back central line of back shirt pattern by connecting point P6 to P11.

Step 7: From point P11, draw a smooth curve connecting to point P10, intersecting with back waist length line at point P12.

Step 8: Draw an inner line on the back shirt pattern by connecting point P7 to P12 with a smooth curve.

Finally, back shirt dynamic pattern of the one-piece running wear is constructed, as shown in Figure 8-9 (b).

8.6.2.2 Dynamic pattern construction of waist piece



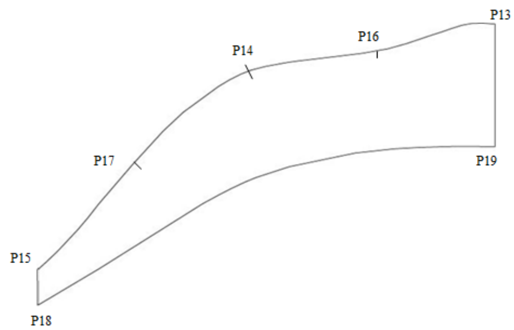


Figure 8-10 Dynamic pattern construction of waist piece**:** (a) Illustration of waits piece pattern construction, (b) Dynamic pattern of waist piece

Waist dynamic pattern piece of the one-piece running wear can be constructed by the following steps:

Step 1: Align the shirt dynamic block pattern with the trousers dynamic block pattern along a line from FW to BW, as shown in Figure 8-10 (a).

Step 2: The midpoint of the centre back line segment between chest line and waist line is point P13 (P11 on the back shirt). Point P14 is at one-third of the side line. From P13, draw a smooth curve passing trough point P14 and connecting to point P15, i.e., the intersection point of central front line and hip line of the front trousers (P4 on front shirt). The curve intersects back waist length line at point P16 and front waist length line at point P17.

Step 3: The midpoint of the curve central front segment between hip line and thigh line is point P18. Connect point P15 to P18 with a straight line.

Step 4: On centre back line, determine point P19 at 5 cm below the waist line. From P19, draw a smooth curve connecting to point P18.

Finally, waist dynamic pattern piece of the one-piece running wear is constructed, as shown in Figure 8-10 (b).

8.6.2.3 Dynamic pattern construction of sleeve

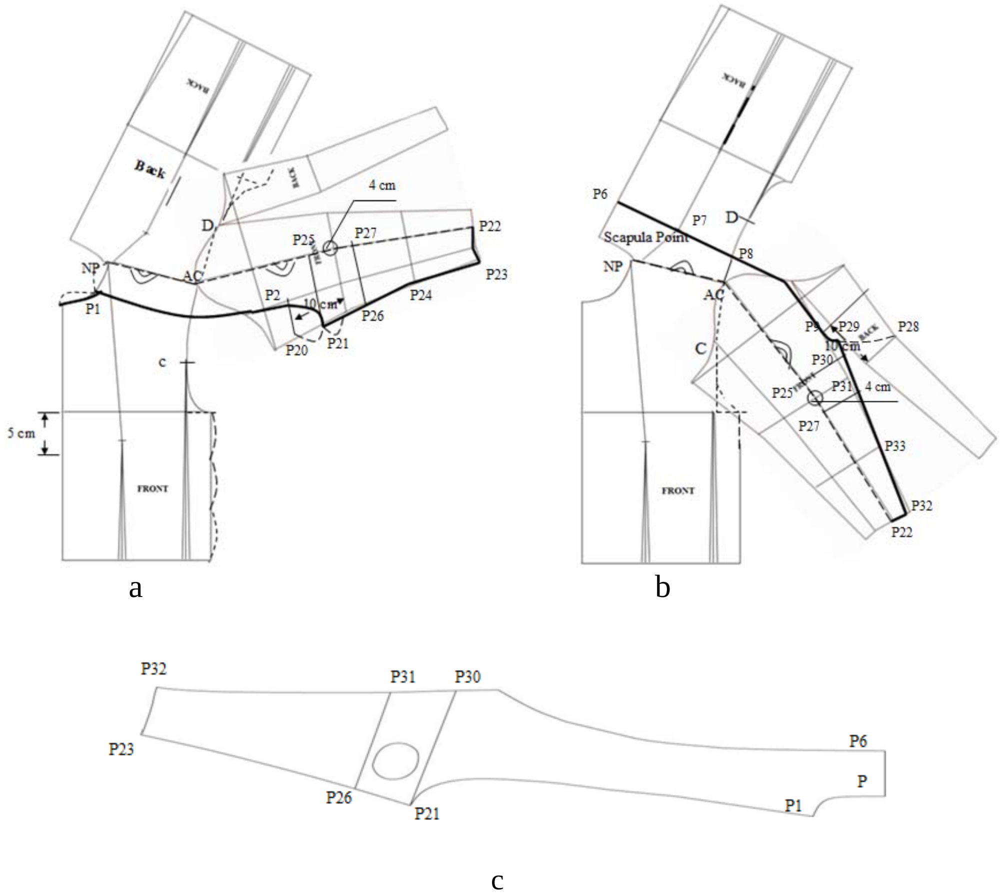


Figure 8-11 Dynamic pattern construction of arm-shoulder sleeve: (a) Illustration of front arm-shoulder sleeve pattern construction, (b) Illustration of back arm-shoulder sleeve pattern construction, (c) Dynamic pattern of arm-shoulder sleeve

The sleeve dynamic patterns consist of three components: arm-shoulder sleeve, side-shirt sleeve and inner sleeve. The arm-shoulder sleeve dynamic pattern of one-piece running wear can be constructed by the following steps:

Step 1: Arrange the shirt and sleeve dynamic block patterns as that in the construction of front shirt dynamic pattern, as shown in Figure 8-11 (a). Point P20 is 10 cm above the elbow line on the front side line of the sleeve block. The midpoint between point P20 and the intersection point of elbow line and front side line is point P21. Draw a smooth curve from point P1, passing through P2 and connecting to P21, which is a structure line of the front arm-shoulder sleeve pattern. Connect a smooth curve from point P1 to NP along the neckline curve, which forms another structure line of the front arm-shoulder sleeve pattern.

Step 2: Connect straight lines from point P21 to P24, P23 and P22, which are points on the sleeve dynamic block pattern, as shown in Figure 8-11 (a).

Step 3: Connect a dotted line through points NP and AC to P22, which is a reference line for joining the back arm-shoulder sleeve pattern.

Step 4: From point P21, draw one line parallel to elbow line intersecting with central line of the sleeve block at point P25. Point P26 is 10 cm below P21 on front side line of the sleeve. From point P26, draw a line parallel to elbow line intersecting with central line of the sleeve block at point P27. The two parallel lines are inner lines on the front arm-shoulder sleeve pattern. Draw an inner circle of diameter 4 cm with centre at the intersection point of elbow line and central line of the sleeve block.

After constructing the front arm-shoulder sleeve pattern, the back arm-shoulder sleeve pattern is constructed by step 5 to Step 9 below.

Step 5: Arrange the shirt and sleeve dynamic block patterns as that in the construction of back shirt dynamic pattern, as shown in Figure 8-11 (b). From P9, draw a reference smooth curve connecting to point P28, i.e., the intersection point of elbow line and back side line of the sleeve.

Step 6: Draw a line 5 cm above and parallel to elbow line, intersecting with the reference curve between P9 and P28 at point P29. Draw a smooth curve from point P6, passing through P7, P8, P9 and connecting to P29, which is a structure line of back arm-shoulder sleeve pattern.

Step 7: Connect straight lines from point P29 to P33, P32 and P22, which are points on the sleeve dynamic block pattern.

Step 8: Connect a dotted line through points NP and AC to P22, which is the reference line for joining the front arm-shoulder sleeve pattern.

Step 9: From points P25 and P27, draw two lines parallel to elbow line, intersecting the line constructed in Step 7 at points P30 and P31. The two parallel lines are the inner lines on the back arm-shoulder sleeve pattern. In addition, an inner circle of diameter 4 cm with centre at the intersection point of elbow line and central line of the sleeve.

Based on the reference lines developed in Steps 3 and 8, the front and back arm-shoulder sleeve patterns are integrated by coinciding shoulder slope line and central line of sleeve in two acquired pieces. Finally, the arm-shoulder sleeve dynamic pattern of one-piece running wear is constructed, as shown in Figure 8-11(c).

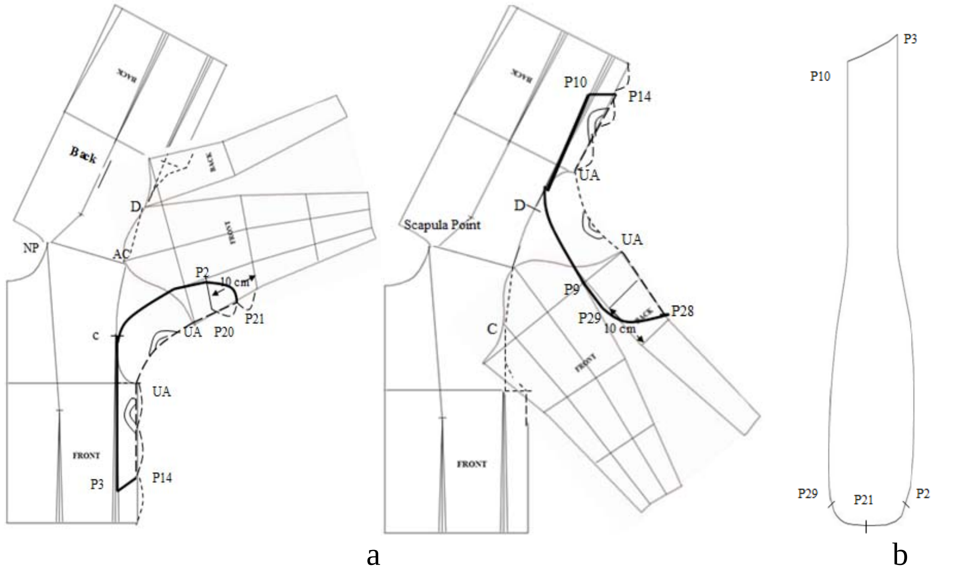


Figure 8-12 Dynamic pattern construction of side-shirt sleeve: (a) Illustration of front side-shirt sleeve pattern construction, (b) Illustration of back side-shirt sleeve pattern construction, and (c) Dynamic pattern of side-shirt sleeve

Side-shirt sleeve dynamic pattern of one-piece running wear can be constructed by the following steps:

Step 1: Arrange the shirt and sleeve dynamic block patterns as that in the construction of front shirt dynamic pattern, as shown in Figure 8-12 (a).

Step 2: From P2, draw a smooth curve passing through point P3 and connecting to P21. Connect a line from point P3 to P14. The curve and line form the structure line of the front side-shirt sleeve pattern.

Step 3: Connect a reference line from point P14 to point UA of the front shirt dynamic block pattern. Connect another reference line from point P21, passing through P20 to point UA of the sleeve dynamic block pattern. Finally, connect a smooth reference curve between the two points of UA. The reference line from P14 to P21 is for joining the back side-shirt sleeve.

The back side-shirt sleeve is constructed by step 4 to step 6:

Step 4: Arrange the shirt and sleeve dynamic block patterns as that in the construction of back shirt dynamic pattern, as shown in Figure 8-12 (b).

Step 5: From P10, draw a smooth curve passing through points P9, P29 and connecting to P29. Connect a line from point P10 to P14. The curve and line form the structure lines of back side-shirt sleeve pattern.

Step 6: Connect a reference line from point P14 to point UA of the back shirt dynamic block pattern. Connect another line from point P28 to UA of the sleeve dynamic block pattern. Finally, connect a smooth reference curve linking the two points of UA. The reference line from P14 to P28 is for joining the front side-shirt sleeve.

After the front and back side-shirt sleeve pattern are integrated, side-shirt sleeve dynamic pattern is constructed, as shown in Figure 8-12(c).

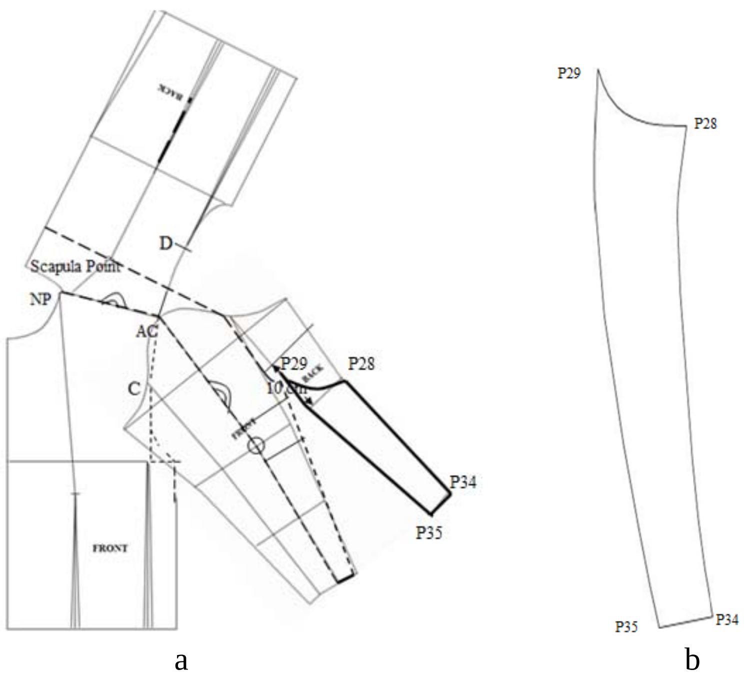


Figure 8-13 Dynamic pattern construction of inner sleeve: (a) Illustration of inner sleeve pattern construction, (b) Dynamic pattern of inner sleeve

Inner sleeve dynamic pattern of the one-piece running wear can be constructed by the following steps:

Step 1: Arrange the shirt and sleeve dynamic block patterns as that in the construction of back shirt dynamic pattern, as shown in Figure 8-13(a).

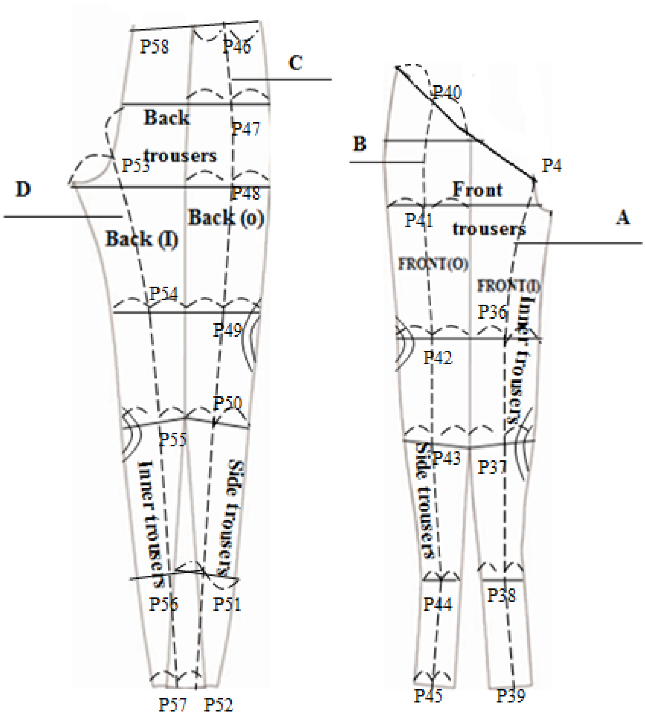
Step 2: Connect smooth curves from point P28 to P29 and from P29 to P35. Connect straight lines from point P34 to P35 and from P28 to P34.

Finally, inner sleeve dynamic pattern is constructed as shown in Figure 8-13(b).

8.6.2.4 Dynamic pattern construction of trousers

The style and cutting lines are marked on the front and back trousers dynamic block pattern of Figure 8-7 in Figure 8-14. Trousers dynamic patterns of the one-piece running wear consist of four components: front trousers, back trousers, side trousers and inner trousers. In Figure 8-14, “A” and “B” are the cutting lines on the front trousers dynamic block patterns, while “C” and “D” are the cutting lines on the back trousers dynamic block patterns.

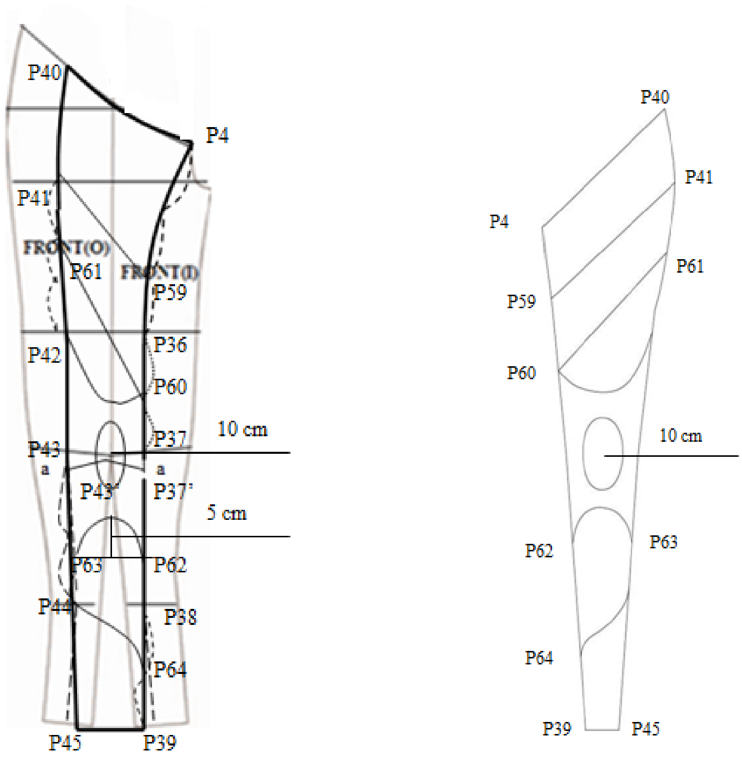
“A” line is the cutting line between front inner trousers and front trousers, which passes through points P4, P36, P37, P38 and P39. Except point P4, all points are the midpoints of the corresponding girth lines between front centre line and outside line. “B” line is the cutting line between front side trousers and front trousers, which passes through points P40, P41, P42, P43, P44 and P45. Except point P40, all points are the midpoints of the corresponding girth lines between front centre line and outside line. Point P40 is the midpoint of the curve between front centre line and outside line.



a back b front

Figure 8-14 Cutting line design on four trousers components

"C" line is the cutting line between back side trousers and back trousers, which passes through points P46, P47, P48, P49, P50, P51 and P52. Except point P46, all points are the midpoints of the corresponding girth lines between front centre line and outside line. Point P46 is the midpoint of the curve between back centre line and outside line. "D" line is the cutting line between back inner trousers and back trousers, which passes through points P53, P54, P55, P56 and P57. Except point P53, all points are the midpoints of the corresponding girth lines between front centre line and outside line. Point P53 is the midpoint of the curve between hip line and centre front line.



a b

Figure 8-15 Dynamic pattern construction of front trousers: (a) Illustration of front trousers pattern construction, (b) Dynamic pattern of front trousers

After determining the four cutting lines, the front trousers dynamic pattern of one-piece running wear can be constructed by the following steps:

Step 1: The area between the two cutting lines “A” and “B” on the front block pattern outlines the front trousers dynamic pattern, as shown in Figure 8-15 (a). On the front block pattern, the section below the knee line is separated into two parts along front centre line (see Figure 8-6). To complete the front trousers pattern, cut from cutting line “A” at point P37 and from cutting line “B” at point P43 along the knee line to front centre line. Close the two parts by pivoting around the intersection point of knee line and centre front line. Mark the end positions of points P37 and P43 as P37’and P43’, respectively.

Step 2: Trace smooth structure lines along points P4, P36, P37, P37’, P38, and P39, and along P40, P41, P42, P43, P43’, P44 and P45. Connect point P39 and P45 to form the structure line of front trousers.

Step 3: Draw inner lines on front trousers pattern based on points P59, P60, P61, P62, P63 and P64, as shown in Figure 8-15(a).

Finally, front trousers dynamic pattern is constructed, as shown in Figure 8-15(b).

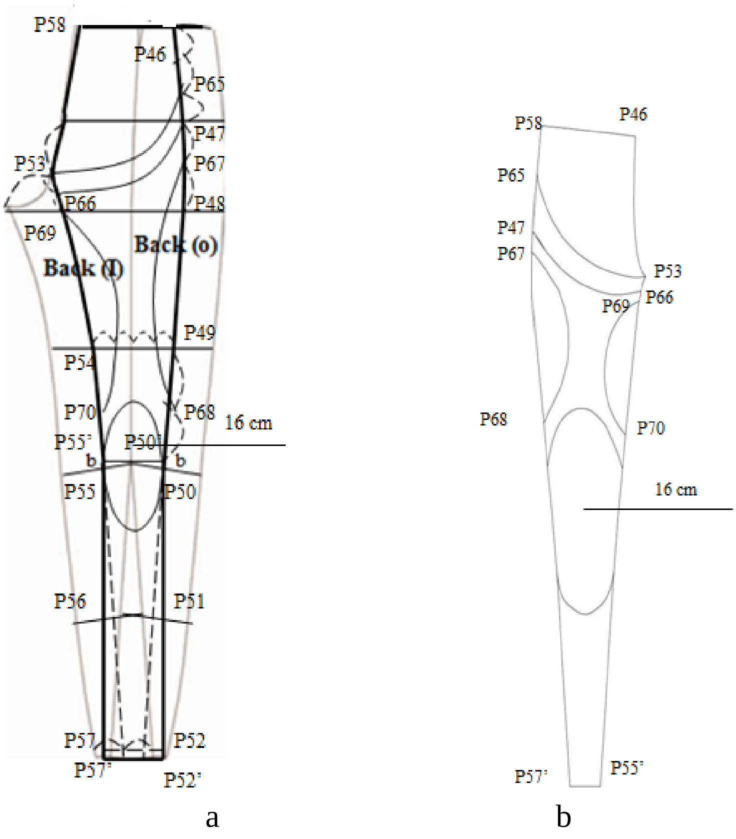


Figure 8-16 Dynamic pattern construction of back trousers: (a) Illustration of back trousers pattern construction, (b) Dynamic pattern of back trousers

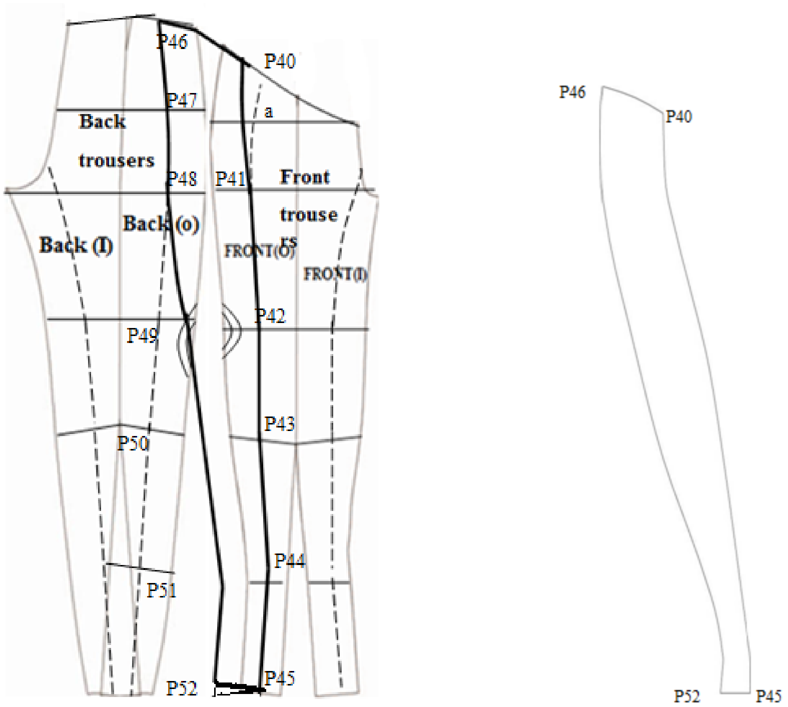
Back trouser dynamic pattern of the one-piece running wear can be constructed by the following these steps:

Step 1: The area between the two cutting lines “C” and “D” on the block pattern outlines the back trousers dynamic pattern, as shown in Figure 8-16 (a). On the back block pattern, the two parts below the knee line are overlapped at back centre line (see Figure 8-6). To complete the back trousers pattern, cut from cutting line “C” at point P50 and from cutting line “D” at point P55 along the knee line to back centre line. Rotate the two parts around the intersection point of knee line and centre back line in order to match them along back centre line. Mark the end positions of points P50 and P55 as P50’and P53’, respectively.

Step 2: Extend point P52 to a new position P52’ to taking up the shortened length of P50’ to P50. Extend point P57 to a new position P57’ to taking up the shortened length of P55’ to P55. Trace smooth outlines along points P46, P47, P48, P49, P50’, P51, and P52’, and along P58, P53, P54, P55’, P56, and P57’. Connect point 57’ and 52’ to form the structure line of back trousers.

Step 3: Draw inner lines on back trousers based on points P65, P66, P67, P68, P69 and P70, as shown in Figure 8-16 (a).

Finally, back trousers dynamic pattern is constructed, as shown in Figure 8-16 (b).



a b

Figure 8-17 Dynamic pattern construction of side trousers: (a) Illustration of side trousers pattern construction, (b) Dynamic pattern of side trousers

Side trouser dynamic pattern of the one-piece running wear can be constructed by the following steps:

Step 1: Trace out the side trousers parts from the front and back trousers blocks along the cutting line “B” and “C”, as shown in Figure 8-17 (a). Mark a reference point “a” at the intersection point of cutting line “B” and hip line on the side front piece.

Step 2: Match the side front piece with the side back piece along the outside line. To do so, cut from reference point “a” to outside line along hip line on the front side piece. On the back side piece, cut from point P48 to outside line along thigh line, from point P49 to outside line along mid-thigh line, from point P51 to outside line along calf line. Close the two side pieces along outside line by pivoting section by section of the front and back side pieces.

Step 3: Construct the structure lines of the side trousers pattern by connecting from P40, P41, P42, P43, P44, to P45, and from P46, P47, P48, P49, P50, P51 to P52.

Step 4: Complete the side trouser pattern by walking and truing the structure lines to ensure they have the same length with that of the cutting lines on the front and back trouser blocks.

The completed side trousers dynamic pattern is shown in Figure 8-17 (b).

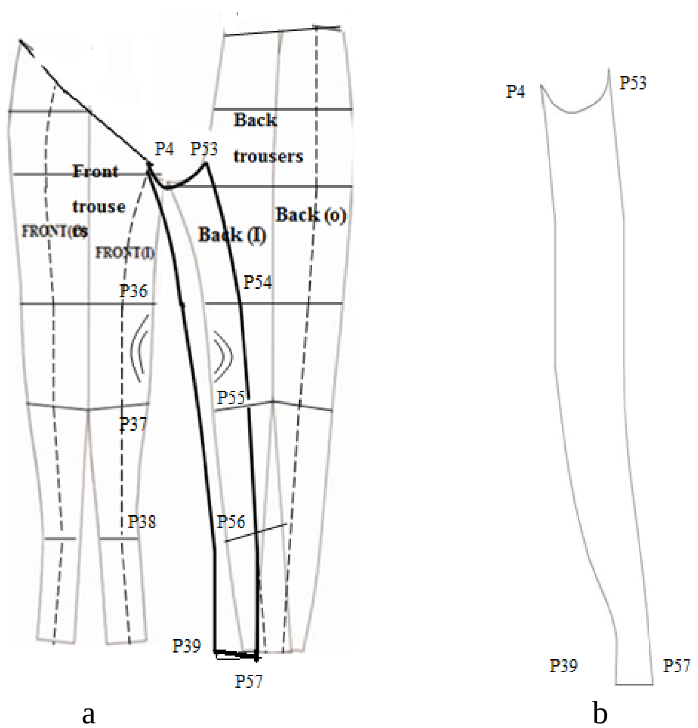


Figure 8-18 Dynamic pattern construction of inner trousers: (a) Illustration of inner trousers pattern construction, (b) Dynamic pattern of inner trousers

Inner trouser dynamic pattern of one-piece running wear can be constructed by the following these steps:

Step 1: Trace out the side trousers parts from the front and back trousers blocks along the cutting line “A” and “D”, as shown in Figure 8-18 (a).

Step 2: Match the side front piece with the side back piece along the outside line. To do so, on the side front piece, cut from point P36 to inside line along mid-thigh line, from point P37 to inside line along knee line, and from point P38 to inside line along calf line. Close the two side pieces at inside line by pivoting section by section of the front side piece.

Step 3: Construct the structure lines of the inner trousers pattern by connecting from P4, P36, P37, P38 to P39, and from P53, P54, P55, P56 to P57.

Step 4: Complete the inner trouser pattern by walking and truing the structure lines to ensure they are of the same length with the cutting lines on the front and back trouser blocks.

The completed inner trousers dynamic pattern is shown in Figure 8-18 (b).

8.7 Conclusions

In this chapter, dynamic pattern construction of running wear with just-fit design has been investigated. According to the research findings of Chapter 3 to Chapter 7, the detailed construction procedure for dynamic patterns of one-piece running wear with just-fit design have been explained, which include pattern pieces of front shirt, back shirt, waist, arm-shoulder sleeve, side-shirt sleeve, inner sleeve, front trousers, back trousers, side trousers and inner trousers.

The construction of dynamic pattern consists of a series of steps, including (1) determination of static-state body measurements, anatomical points and body structure lines; (2) construction and evaluation of static block pattern; (3) collection of body measurements in dynamic postures; (4) collection of body measurements in running state; (5) design of optimal wearing ease values based on body measurement changes in dynamic postures and in running state; (7) construction of dynamic block pattern; (8) design of cutting ling in running wear by measuring changes of body skin surfaces in running state, (9) optimisation of cutting line and inner line design of the running wear in accordance with the skin surface changes and thermal-moisture distributions of human body in running state, and finally, (10) construction of dynamic pattern.

By comparing dynamic pattern construction method with the tradition pattern making method, it can find that there exist significant differences between the two. In dynamic pattern construction, not only body measurements, anatomical points and body structure lines, but also characteristics of human body in dynamic postures and running state are studied. In addition, the skin surface changes and thermal-moisture distributions of the human body in running are also analysed for the development of dynamic patterns, which is absent from all the existing pattern making methods.

CHAPTER 9 FABRIC PROPERTY INVESTIGATION AND ITS APPLICATIONS IN FUNCTIONAL PATTERN DESIGN

9.1 Introduction

Fabric material properties directly influence the shape and functional performance of a garment. In recent two decades, a number of studies have been carried out on the relationship between the *mechanical-physical properties* of knitted fabrics and the sportswear *functional performance*. For example, the hydrophobic and hydrophilic effects on the rate of sweating at a high ambient temperature were studied by Ha et al. (1995) and they found that the local sweating rate was higher in polyester than in cotton. Choi (2000) studied the relationship among hand, structure and density of wet knits. The experimental results showed that the tensile strength increases for fabrics of higher density, so do the bending and shearing strengths. Surface properties such as softness and smoothness also increase with the density. However, compression values decrease as knit density increases but the decrease is not significant. Gersak (2004) studied knitted fabric elastic potentials and garment appearance quality. It is found that elastic potentials affect drape coefficient and crease depth. In which, tensile and bending elastic coefficients directly influence the drape, while shearing elastic coefficient's effect is indirect. Emirhanova and Kavusturan (2008) analysed the effects of knit structure on the dimensional and physical properties of knitted fabrics. They concluded that the effects of knit structure on the fabric properties are highly significant, in terms of bursting strength, air permeability, and bending rigidity. Tuck stitch fabrics have low resistance to abrasion. Links-links, seed stitch, and moss stitch fabrics have high resistance to pilling. To conclude, fibre content, structure and elasticity of knitted fabrics affect the *shape* and *functional performance of finished products* significantly.

For sportswear applications, it is found that fibre content, fabric structure and elasticity of knitted fabrics have major impacts on fabric's *physical-mechanical properties*. In terms of fibre content, natural fibres are usually regarded as the ideal materials for tight-fit sportswear, because of its good properties of hand and moisture absorption. However, natural fibres are proven inferior to synthetic fibres for sportswear design (Zhou et al., 2006, Sul et al., 2007) because their inferior performance in waterproof and moisture transition. Knitted fabrics made of fine synthetic fibres can better protect wearer from environmental injury, like wind and rain, and keep the body warm and dry.

In terms of fabric structures, plain, rib and mesh are the common knit structures for sportswear design. The properties of knitted fabrics with plain, rib and mesh structure are different, and the final applications of knitted fabrics are usually determined by the mechanical-physiological needs of the human body in various sports. For example, body temperature and humidity are increased when one person runs. In order to transmit the excess heat and moistures out of the body, knitted fabric with mesh structure is often used in sportswear design, particularly in the underarm area.

In tight-fit sportswear design, elastic knitted fabric is usually used because more rooms can be provided for body movement, minimising the resistance between the garment and the body skins. The application of elastic knitted fabric is necessary for a streamlined appearance and tight-fit sportswear design (Shishoo, 2005). The elasticity is different for knitted fabrics of different structures, which affect the material properties. For example, when fabric is stretched, basic properties, such as thickness, change significantly. It is also true for mechanical and physical properties such as air permeability and moisture transmission (Li et al., 2002). Because of the property changes for elastic knitted fabrics at different stretching levels, it is important to decide the right combination of stretching level and fabric structure in tight-fit sportswear design. In this Chapter, mechanical-physical properties of elastic knitted fabric with plain, rib, big mesh and small mesh structures were tested in relaxed state and at different stretching levels. The testing results were compared and analysed. Finally, applications of knitted fabrics to different parts of the running wear patterns were determined.

9.2 Experiment Details

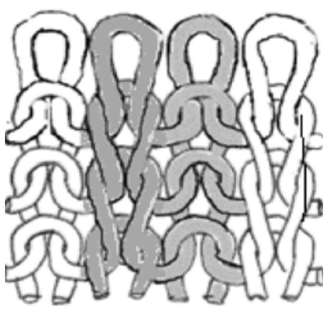
9.2.1 Materials

In this Chapter, four elastic knitted fabrics with the same fibre content but different knit structures were tested. The basic fabric characteristics are shown in Table 9-1. The knitting structures of the fabrics are shown in Figure 9-1, and the photomicrographs of the fabric samples are shown in Figure 9-2. Fabric samples with a standard size of 20 cm ×20 cm were cut for experiments. Fabric swatches are provided in appendix I.

Table 9-1 Basic characteristics of tested elastic knitted fabric samples

Sample code	Fibre content	Structure	Thickness *Mean±s.d* *(mm)*	Weight *Mean±s.d* *(g/m^2)*	Stitch numbers *(warp/weft)*
A	98% Nylon 2% Elastomeric yarn	Rib	1.22±0.01	296.92±3.41	80/60
B		Plain	0.71±0.01	212.68±1.92	70/70
C		Big mesh	0.94±0.01	206.87±2.15	100/100
D		Small mesh	0.77±0.01	192.36±2.41	84/70

Rib structure



Plain structure

Mesh structure

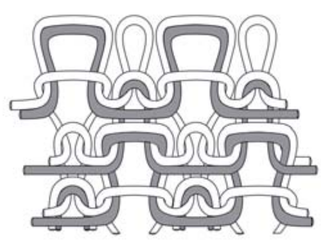
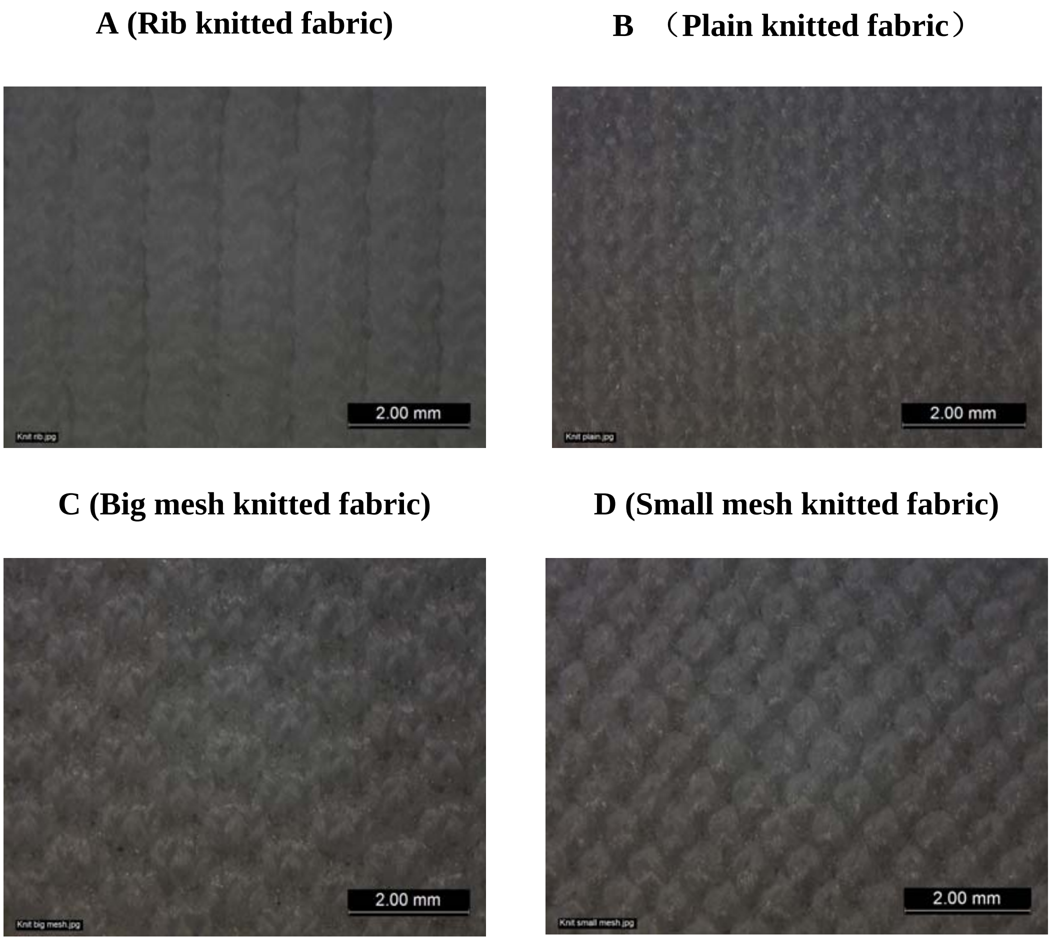


Figure 9-1 Knitted structures used in tested fabric samples



(Amplified scale 1: 50)

Figure 9-2 Photomicrographs of different knit fabric samples

9.2.2 Experiment Objectives and Instrumental Setup

In this study, the material properties were tested under the standard testing conditions of Temperature at 22±1C° and Relative Humidity of 65±2%. The experiment aims to study fabric properties of three aspects: (a) basic properties including thickness and weight; (b) mechanical properties including tensile, bending, shearing, compression, surface properties and double stretching capacity; and (c) physical properties including air resistance, thermal conductivity and thermal insulation (dry and wet conditions), contact angle, water vapour permeability (abbreviation WVP) and overall moisture management capacity (abbreviation OMMC). The indices of these properties and the corresponding instrument setting are shown in Table 9-2, and experimental instruments are shown in Figure 9-3. In addition to testing the material properties in relaxed state (stretching level of 0%), physical properties of the four kinds of knitted fabrics were tested at three stretching levels of 20%, 40% and 60%.

Table 9-2 An outline of material properties involved in the physical-mechanical tests

Groups	Properties	Indices	Symbol	Unit	Instrument settings
Basic	Thickness	Thickness	T	mm	Thickness tester Thickness at 0.5gf/cm²
	Weight	Weight	W	mg/cm²	Weight recorder Weight per unit area
					KES-FB1
Mechanical	Tensile	Linearity	LT	--	Elongation: 50mm/10v
		Tensile energy	WT	gf. cm/cm²	Velocity: 0.2mm/s
		Tensile resilience	RT	%	Processing rate: 2.5 s,
		Tensile strain	EM	%	Maximum load: 50gf/cm
					KES-FB2
	Bending	Bending rigidity	B	gf. cm²/cm	Rate of bending: 2.5/cm
		Hysteresis of bending	2HB	gf. cm/cm	$K=0.5$ to 1.5 cm^{-1}
		Moment			$K=1.0\ cm^{-1}$
					KES-FB1
	Shearing	Shearing stiffness	G	gf/cm.	Shearing tension:
		Hysteresis at $\varphi=0.5°$	2HG	degree	10gf/cm
		Hysteresis at $\varphi=5.0°$	2HG5	gf/cm	Shearing angle: -0.8 to +8.0
				gf/cm	2HG=0.5, 2HG=5.0
					G= 0.5 to 2.5

					KES-FB3
	Compression	Linearity	LC	--	Velocity: 50s/mm
		Compression energy	WC	gf. cm/cm²	Compression area: 2 cm²
		Resilience	RC	%	Processing rate: 0.1 s
					Maximum load: 50gf/cm²
	Surface	Coefficient of friction	MIU	--	KES-FB4
		Mean deviation of MIU	MMD	--	Velocity: 1.0 mm/s
		Geometrical roughness	SMD	μm	Roughness contactor Comp: 10gf
	Double stretching capacity	Double stretching capacity	DS		KES- G2
Physical	Air resistance	Air resistance	AP	Kpa.s/m	KES-F8-API
	Thermal insulation	Thermal insulation	TI	clo	KES-F7
	Thermal conductivity	Thermal conductivity	TC	W/ cm. K	KES-F7
	Contact angle	Contact angle	CA	°	Contact angle Meter
	Water vapor permeability (WVP)	Water vapor permeability	WVP	g/ m².24h	Water Cup
	Overall moisture management capacity (OMMC)	Overall moisture management capacity	OMMC	--	Moisture Management Tester (MMT)

Thickness tester

Weight recorder

KES-FB1

KES-FB2

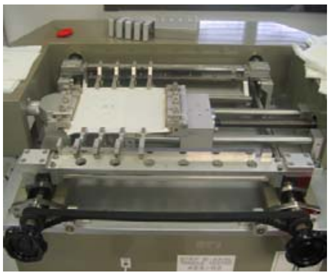
KES-FB3

KES-FB4

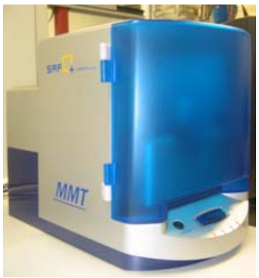
KES-F7

KES-F8-API

KES-G2-S81



Moisture Management Tester (MMT)



Contact Angle Meter

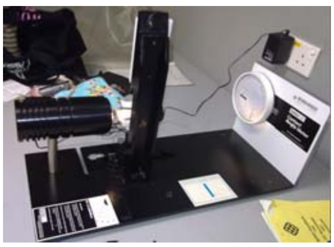


Figure 9-3 Experiment instruments

9.2.3 Experiment Protocol

For basic properties, such as thickness and density, each sample was measured in five different locations. For mechanical properties, such as tensile, bending, shearing and surface properties, each sample was measured five times in the directions of wale and course; for the compression property, each sample was tested in five different locations. For physical properties, such as air resistance, contact angle and thermal conductivity, each sample was measured with the same setting as that for compression property. Five samples were measured for properties of water vapour permeability, moisture management and thermal insulation (dry and wet conditions). In order to minimize the shape instability of knitted fabrics, all samples were placed on a flat surface in standard atmosphere (Temperature = 22±1C°, Relative Humidity = 65±2%) for 24 hours before experiment.

9.3 Experimental Results

9.3.1 Basic Structural Characteristics

Figures 9-4 and 9-5 show that elastic knitted fabric with rib structure has the maximum thickness and weight. The elastic knitted fabric with plain structure has the minimum thickness, and the elastic knitted fabric with small mesh structure has the minimum weight. As shown in Figure 9-6, among the four elastic knitted fabrics, small mesh knitted fabric has the loosest stitch density and rib knitted fabric has the densest stitch density.

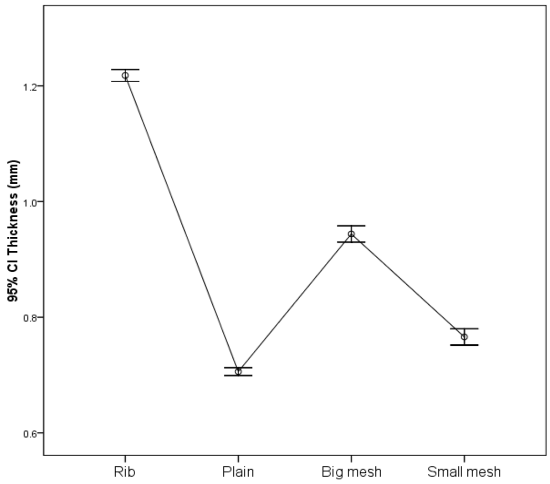


Figure 9-4 Thickness of elastic knitted fabrics

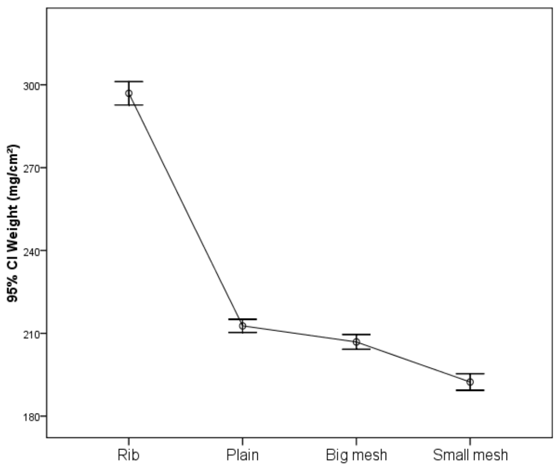


Figure 9-5 Weight of elastic knitted fabrics

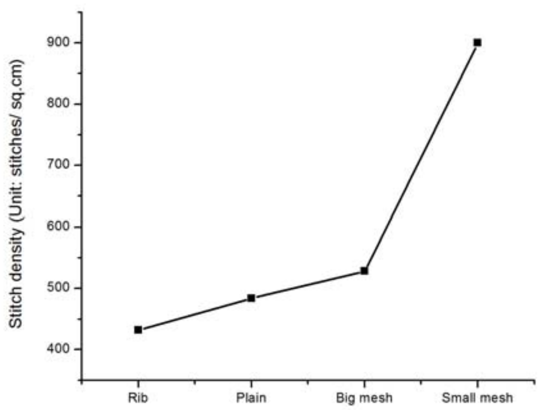


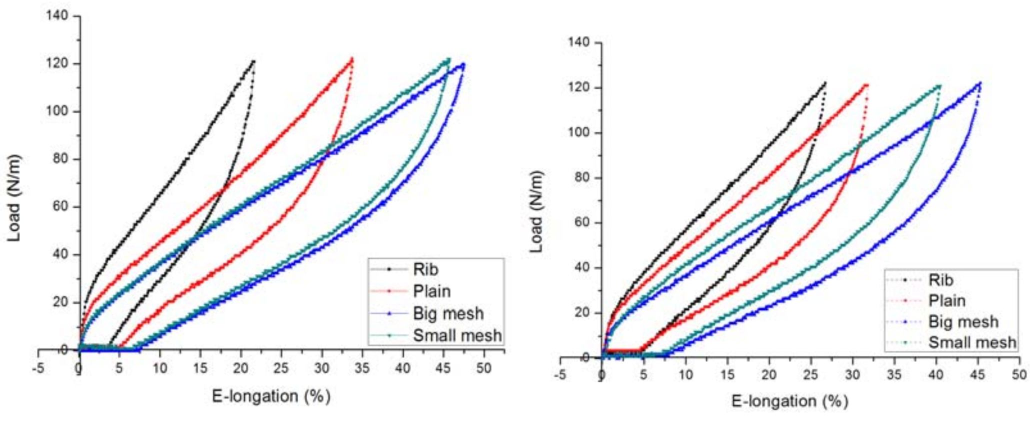
Figure 9-6 Stitch densities of the four elastic knitted fabrics

9.3.2 Mechanical Properties

The testing results of the mechanical properties for the four elastic knitted fabrics are shown and analysed in Figure 9-7 to Figure 9-14.

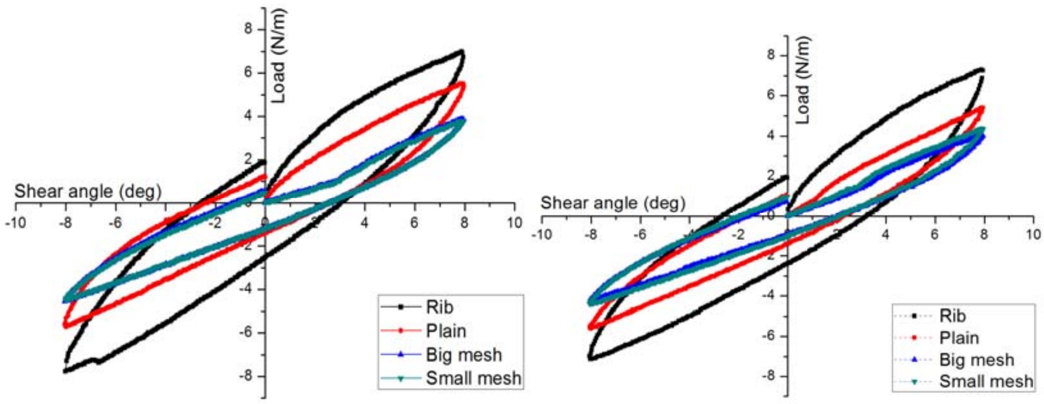
9.3.2.1 Tensile and shearing properties

Extensibility is a measure of the fabric extension at a given load. Figures 9-7 and 9-8 show the typical curves of tensile and shearing properties of elastic knitted fabrics with rib, plain, big mesh and small mesh structures along the wale and course directions. It can be seen from Figure 9-7 that when the tensile forces reach 120 N/m, the fabric elongation (%) in the wale and course directions increased from rib knitted to plain knitted, to big mesh knitted, and to small mesh knitted fabrics.



(a) Wale (b) Course

Figure 9-7 Force-extension tensile curves of elastic knitted fabrics



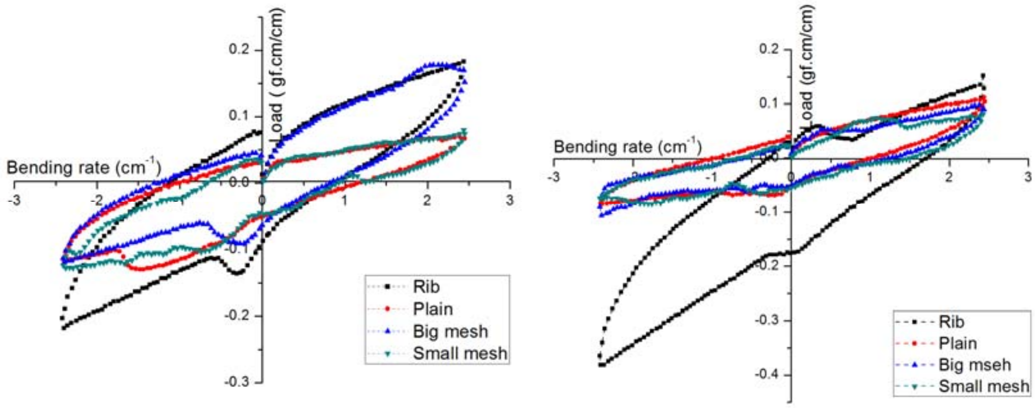
(a) Wale (b) Course

Figure 9-8 Shear properties of elastic knitted fabrics

Shearing stiffness measures how easy a fabric can be deformed on a plane. When the shear angle is at 8° to the wale direction, rib elastic knitted fabric has the maximum shearing force among the four fabrics, while the plain elastic knitted fabric has the second largest shearing stiffness. The big mesh and small mesh knitted fabrics have very similar shearing forces, as shown in Figure 9-8 (a). Shearing force in course direction is similar to that in the wale direction, as shown in Figure 9-8 (b).

9.3.2.2 Bending and compression properties

Fabric bending rigidity and compression properties are closely related to fabric basic structural characteristics, such as thickness, weight and density. The bending hysteresis curves of the four elastic knitted fabrics are shown in Figure 9-9. The results show that, in the wale direction, rib knitted fabric has the largest bending rigidity. Big mesh and small mesh knitted fabrics have similar bending rigidities but smaller than plain knitted fabrics. In the course direction, rib knitted fabrics still has the largest bending rigidity and the other three fabrics have similar values.



(a) Wale (b) Course

Figure 9-9 Bending properties of elastic knitted fabrics

The experimental results of compression deformation are shown in Figure 9-10. It is shown that the thickness of elastic knitted fabrics with small mesh structure change most significantly under 50 gf/cm² loading, and the plain elastic knitted fabric has the smallest compression deformation.

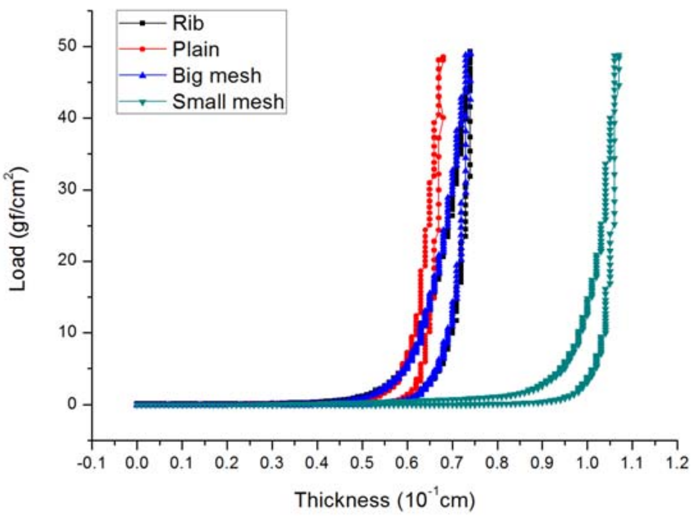
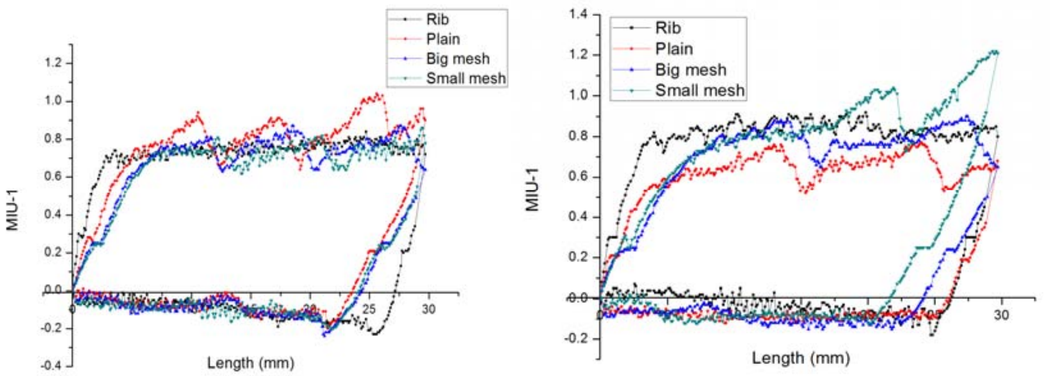


Figure 9-10 Compression property curves of elastic knitted fabrics

9.3.2.3 Surface properties



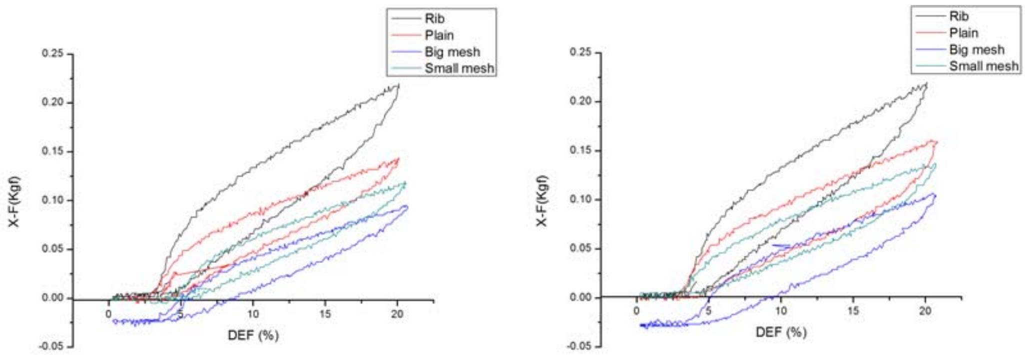
(a) Wale (b) Course

Figure 9-11 Surface properties of elastic knitted fabrics

Fabric surface properties are highly correlated to fabric hand. The surface evenness and geometrical roughness of the tested fabrics in the wale and course directions are shown in Figure 9-11. As shown in Figure 9-11 (a), plain knitted fabric has MIU values ranging from 0.6-1.0 in the wale direction, which is higher than that of all the other three fabrics, indicating that the plain knitted fabric has the roughest surface. The curves in Figure 9-11 (b) reveal that small mesh knitted fabric has largest variation in MIU values in the course direction which range from 0.6-1.2. Small mesh knitted fabric has the roughest surface in the course direction.

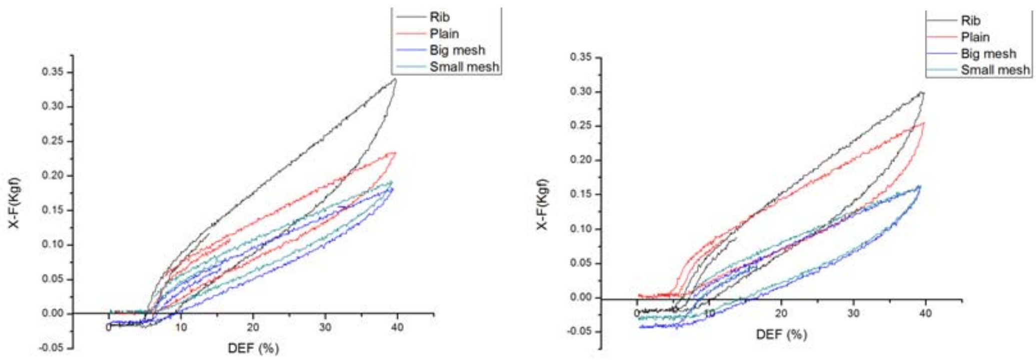
9.3.2.4 Double stretching capacities

The double stretching capacity test is to understand the possible fabric deformation when a fabric is stretched at different levels. The results of the four elastic knitted fabrics stretched 20%, 40% and 60% in wale and course directions are shown in Figures 9-12 to 9-14.



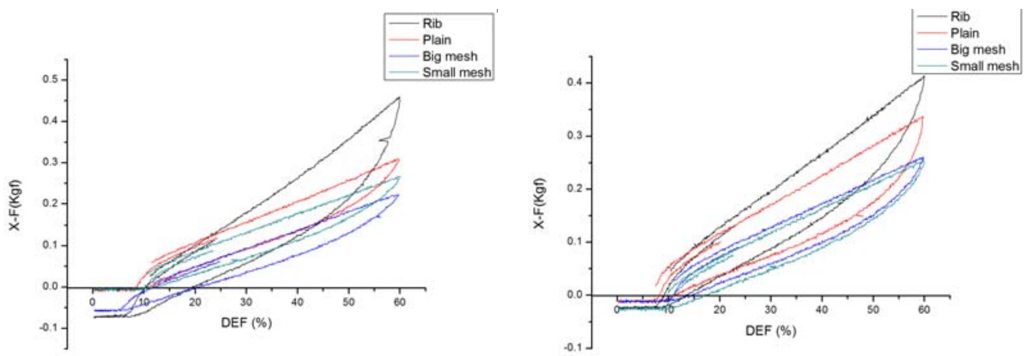
(a) Wale (b) Course

Figure 9-12 Double stretching properties of fabrics in 20% stretching



(a) Wale (b) Course

Figure 9-13 Double stretching properties of fabrics in 40% stretching



(a) Wale (b) Course

Figure 9-14 Double stretching properties of fabrics in 60% stretching

As shown in the figures, the rib knitted fabric requires the largest force to deform/stretch 20%, 40% and 60%, in both wale and course directions. Big mesh fabric requires the smallest force to stretch 20%, 40% and 60% in wale direction. In the course direction, big mesh fabric requires the smallest force to stretch 20% and 40%, while small mesh knitted fabric has the smallest force requirement to stretch 60%.

The results indicate that fabrics deform more with the increase of stretching level. Among all tested fabrics, small mesh knitted fabric has the maximum deformation along wale and course directions at all three stretching levels because the smallest amounts of force (Kgf) are required to achieve the required level of stretching, and big mesh fabric has the same deformations along course direction as the small mesh fabric when stretched 40% and 60%. Rib fabric has the minimum deformations in both directions at all three stretching levels. Moreover, rib knitted fabric required larger forces to stretch in wale direction than in course direction at all stretching levels, meaning that course direction of fabric is easier to deform than in wale direction. Plain knitted fabric is easier to deform in wale direction at all stretching levels than in course direction. Big mesh fabric is easier to deform in wale direction than in course direction at stretching level of 20% and 60%. But when stretched 40%, it requires less force to deform in course direction than in wale direction. For small mesh knitted fabric, it is easier to deform in wale direction than in course direction at 20% stretching level. When stretched 40% and 60%, it is more difficult to deform in wale direction than in course direction.

9.3.3 Physical Properties of Elastic Knitted Fabrics at Four Stretching Levels

The physical properties of elastic knitted fabrics at four stretching levels of 0% (normal state), 20%, 40% and 60% are listed in Tables 9-3 to 9-9. The variations of physical properties at different stretching levels are analysed, as shown in Figures 9-15 to 9-19.

9.3.3.1 Air resistance

Table 9-3 Air resistances of the four knitted fabrics at four stretching levels

	Air Resistance (Unit: KPa.s/m)			
Stretching	Rib	Plain	Big mesh	Small mesh
levels (%)	*Mean / s. d*	*Mean / s. d*	*Mean / s. d*	*Mean / s. d*
0	0.853/*0.030*	0.836/0.033	0.429/0.020	0.454/0.023
20	0.148/0.002	0.144/0.003	0.088/0.012	0.110/0.006
40	0.042/0.010	0.019/0.003	0.012/0.004	0.011/0.002
60	0.004/0.001	0.002/0.001	0.002/0.001	0.002/0.001

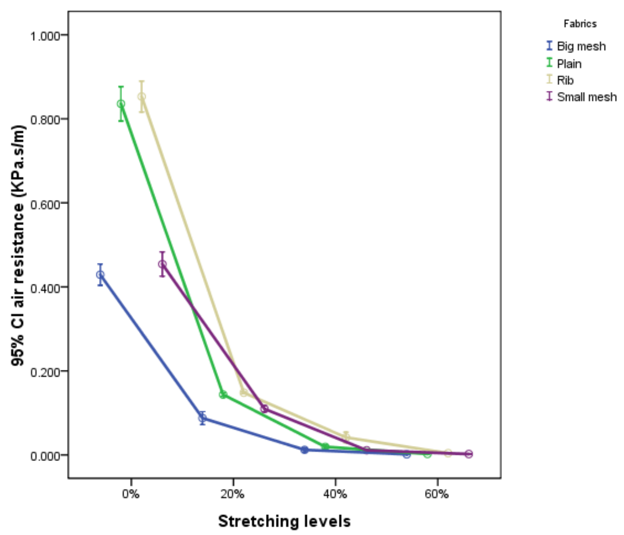


Figure 9-15 Air resistances of fabrics in different stretching levels

Air resistance is an index of air permeability which determines air exchange between a clothing and an external environment in microclimate. Air resistance significantly affects the wearer's evaporative and dry heat losses (Havenith, 1990, Bouskill et al., 2002). People sweat in running. If clothing fabric has good property of air permeability, moisture can be diffused out of the garment effectively, which takes away evaporative heat and improves the wearing comfort. As shown in Table 9-3 and Figure 9-15, rib fabric has the maximum air resistance at all four stretching levels. In contrast, big mesh fabric has the minimum air resistance at stretching levels of 0%, 20% and 60%. Moreover, the air resistance of four knitted fabrics vary significantly when stretched 0% and 20%. However, the variation is not significant between stretching levels of 40% and 60%. All four fabrics have similar air resistances when stretched 60%.

9.3.3.2 Thermal Conductivity and Insulation

Body heats are generated to support the muscle movements in exercise. In order to maintain a constant body temperature, the excess body heats must be released to the environment by dry heat losses and evaporation. Thermal conductivity and insulation of material are two important properties for heat transfer between body, clothing and the environment.

Thermal conductivity refers to the ability of a material to conduct heat, and thermal insulation refers to the ability of a material to prevent heat release from a container or enter a container. In other words, thermal insulation of fabric can keep an enclosed area warm, or keep it cool. The thermal conductivities of fabrics at 0%, 20%, 40% and 60% stretching levels are shown in Table 9-4 and Figure

9-16. Thermal insulation of fabrics in dry and wet conditions, simulating a dry body and a sweating body, were measured at four stretching levels, and the results are shown Table 9-5, Table 9-6 and Figure 9-17

Table 9-4 Thermal conductivities of the four knitted fabrics at four stretching levels

Stretching levels (%)	Thermal conductivity (Unit: w/cm.K)			
	Rib	Plain	Big mesh	Small mesh
	Mean / s. d	*Mean / s. d*	*Mean / s. d*	*Mean / s. d*
0	0.061/*0.002*	0.061/0.002	0.058/0.001	0.058/0.001
20	0.052/0.001	0.051/0.001	0.041/0.001	0.051/0.001
40	0.041/0.002	0.034/0.001	0.027/0.001	0.038/0.001
60	0.040/0.003	0.033/0.001	0.027/0.001	0.037/0.001

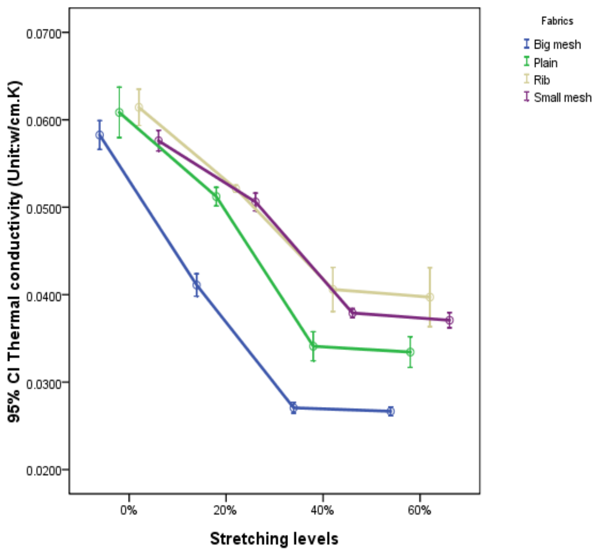


Figure 9-16 Thermal conductivities of fabrics in different stretching levels

The data in Table 9-4 and curves in Figure 9-16 show that the thermal conductivities of the four fabrics change in similar manner: thermal conductivity decreases with increasing level of stretching. Thermal conductivity drops significantly from stretched 0% to 40%, but of the drop become less obvious from stretched 40% to 60%. Among the four fabrics, rib fabric has the maximum thermal conductivity at four stretching levels, which indicate that rib fabric is good at heat loss by conduction. At 0% of stretching, big and small mesh fabrics have the minimum value of thermal conductivity. At 20%, 40%, and 60% of stretching, big mesh fabric has the minimum value of thermal conductivity. It indicates that bid mesh fabric has poor ability to lose heat by conduction.

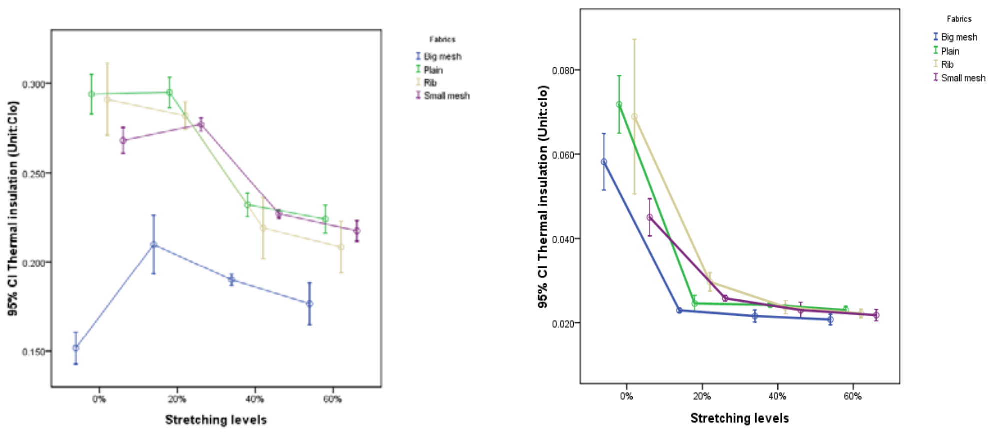
The data in Table 9-5 and curves in Figure 9-17 (a) show that the thermal insulation indices for fabrics in dry condition. Big mesh fabric has the minimum value of thermal insulation (dry condition) among the four fabrics in all four stretching levels, implying that it is most effective in dry heat loss. In contrast, plain knitted fabric has the worst dry heat loss property. All the four fabrics have the maximum value of thermal insulation when the fabrics stretch 20%. The values decrease from stretching level of 20% to 60%. The data in Table 9-6 and curves Figure 9-17 (b) reveal the profile of wet thermal insulation. All four fabrics wet thermal insulation decreases from stretching level of 0% to 60%. It indicates that heat loss through evaporation is the worst if the fabrics do not stretch (stretching level at 0%). Among the four fabrics, the small mesh fabric has the minimum value and plain fabric has the maximum value of wet thermal insulation at 0% of stretching. At 20%, 40% and 60% of stretching, the big mesh fabric has the minimum value of wet thermal insulation. These results indicate that the small mesh fabric can lose heat most effectively in wet condition at state of no stretch. But when the four fabrics are stretched, the big mesh fabric can better lose heat in wet condition. Moreover, the wet thermal insulation index decreases significantly from the stretching levels of 0% to 20%, and the decrease becomes less significantly from 20% to 60%.

Table 9-5 Thermal insulations of the four knitted fabrics in dry condition at four stretching levels

	Thermal insulation-dry condition (clo)			
Stretching	Rib	Plain	Big mesh	Small mesh
levels (%)	*Mean / s. d*	*Mean / s. d*	*Mean / s. d*	*Mean / s. d*
0	0.117/*0.009*	0.294/0.009	0.152/0.008	0.268/0.006
20	0.282/0.006	0.295/0.007	0.229/0.043	0.278/0.001
40	0.219/0.014	0.232/0.005	0.198/0.018	0.227/0.002
60	0.208/0.012	0.224/0.006	0.177/0.009	0.217/0.005

Table 9-6 Thermal insulations of the four knitted fabrics in wet condition at four stretching levels

	Thermal insulation-wet condition (clo)			
Stretching	Rib	Plain	Big mesh	Small mesh
levels (%)	*Mean / s. d*	*Mean / s. d*	*Mean / s. d*	*Mean / s. d*
0	0.069/*0.015*	0.072/0.006	0.058/0.005	0. 045/0.007
20	0.030/0.002	0.025/0.002	0.023/0.001	0.026/0.001
40	0.024/0.001	0.024/0.001	0.022/0.001	0.023/0.002
60	0.022/0.001	0.023/0.001	0.021/0.001	0.022/0.001



(a) Dry condition (b) Wet condition

Figure 9-17 Thermal insulations of fabrics in different stretching levels

9.3.3.3 Contact Angle, Water Vapour Permeability and Overall Moisture Management Capacity

Apart from thermal regulation properties, material properties in relation to moisture management must also be studied for effective functional design. Contact angle, water vapour permeability (abbreviation: WVP) and overall moisture management capacity (abbreviation: OMMC) are important parameters to assess fabric moisture management property. Contact angle determines whether the fabric is hydrophilic or hydrophobic. WVP and OMMC assess moisture transfer through fabric in forms of liquid water and water vapour.

As shown in Table 9-7, all the four fabrics have “0” contact angles, which indicate that they are all hydrophilic fabrics with good water absorption capacity.

Table 9-7 Contact angles of four knitted fabrics at four stretching levels

Stretching levels (%)	Contact angle (°)			
	Rib	Plain	Big mesh	Small mesh
	Mean / s. d	*Mean / s. d*	*Mean / s. d*	*Mean / s. d*
0	0.000	0.000	0.000	0.000
20	0.000	0.000	0.000	0.000
40	0.000	0.000	0.000	0.000
60	0.000	0.000	0.000	0.000

The data in Table 9-8 and curves in Figure 9-18 reveal that all indices of WVP increase when the fabrics are stretched. The big mesh fabric has the maximum WVP indices among the four in all stretching levels, and the plain knitted fabric gives the minimum WVP. The results indicate that the big mesh fabric has the best performance in water vapour transmission in all stretching levels and the plain fabric has the worst performance.

Table 9-8 Water vapour permeabilities of the four knitted fabrics in wet condition at four stretching levels

Stretching levels (%)	Water vapour permeability (g/m².24h)			
	Rib	Plain	Big mesh	Small mesh
	Mean / s. d	*Mean / s. d*	*Mean / s. d*	*Mean / s. d*
0	645.435/*48.115*	476.292/36.311	688.606/91.135	578.202/16.331
20	760.793/50.973	507.643/57.992	774.239/46.704	622.788/62.853
40	786.270/60.436	565.039/72.960	840.764/124.294	658.174/44.969
60	863.411/47.144	609.625/74.909	937.013/24.182	936.306/57.799

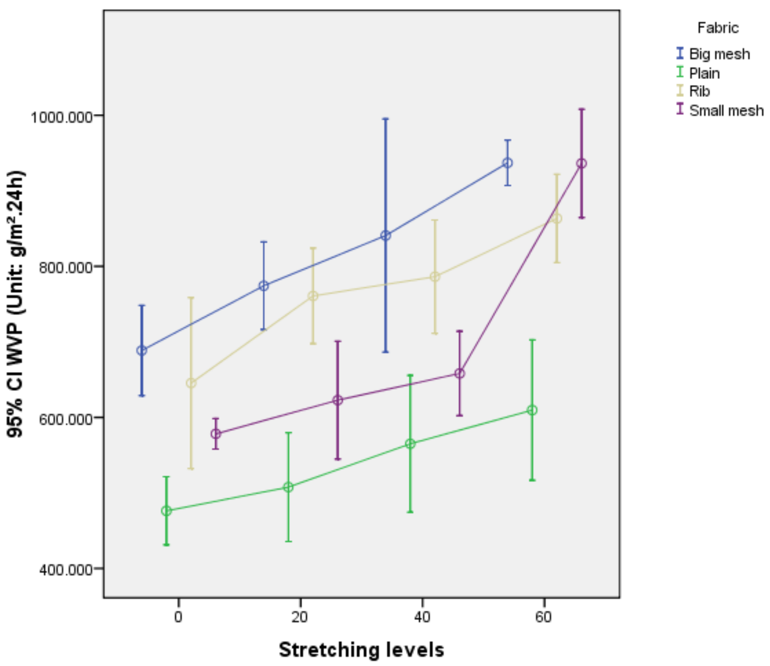


Figure 9-18 Water vapour permeabilities of fabrics in different stretching levels

The data in Table 9-9 and curves in Figure 9-19 make the further descriptions about the overall moisture management capacities of fabrics with the increasing level of stretching. The OMMC indices of fabrics increase significantly from 0% to 60% of stretching. On average, the big mesh fabric has the best capability for liquid water transfer because of higher OMMC index values, while the plain knitted fabrics has poor performance in liquid water transfer. The results indicate that the big mesh has the best performance in liquid water transmission in different stretching levels. At 0% of stretching, the rib fabric has the worst performance and the plain fabric has the worst performance at 20%, 40% and 60% of stretching.

Table 9-9 OMMC of four knitted fabrics in wet condition at four stretching levels

	OMMC			
Stretching	Rib	Plain	Big mesh	Small mesh
levels (%)	*Mean / s. d*	*Mean / s. d*	*Mean / s. d*	*Mean / s. d*
0	0.370/*0.082*	0.405/0.104	0.585/0.034	0.359/0.022
20	0.311/0.024	0.299/0.029	0.406/0.062	0.365/0.073
40	0.492/0.045	0.371/0.089	0.615/0.087	0.596/0.083
60	0.712/0.045	0.685/0.038	0.715/0.037	0.713/0.042

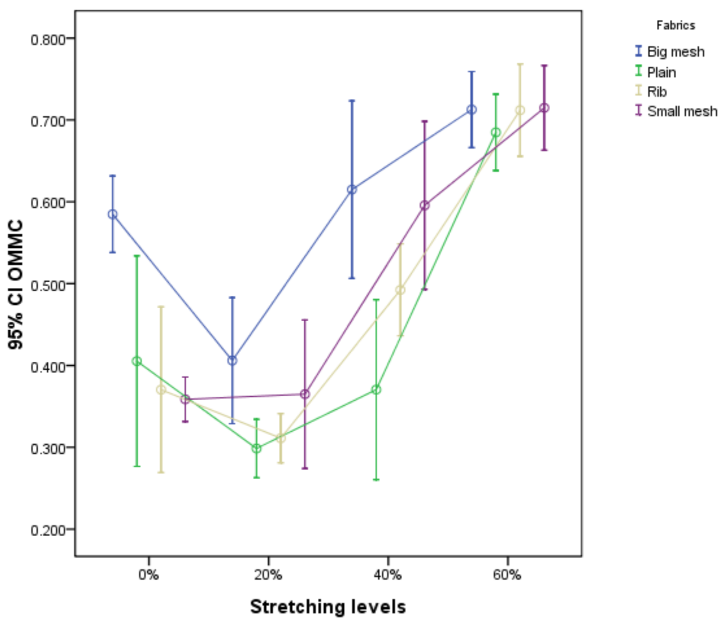


Figure 9-19 Overall moisture management capacities of fabrics in different stretching levels

9.4 Comparative Analysis of Mechanical-Physical Properties

In order to better understand the mechanical-physical properties of knitted fabrics with different structures and the variation of physical properties when the fabrics are stretched, comparative analyses are carried out in this section.

9.4.1 Comparison of Mechanical Properties of Knitted Fabrics with Different Structures

The mechanical properties of elastic knitted fabrics with rib, plain, small mesh and large mesh structure designs are listed in Tables 9-10 and 9-11. The properties are compared in Figures 9-20 to 9-21. In order to plot all the parameter indices on the same scale for comparison, the indices were normalized by the following formula:

$$x = (X - \bar{X}) / \delta$$

where x is a normalized index value, X is a mechanical property index, $\bar{X}$ is the mean value of that property index for the four fabrics, δ is the standard deviation of the property index.

Table 9-10 and Figure 9-20 show that the mechanical properties of the four knitted fabrics are different in wale direction. In terms of tensile property index, high index of LT and low indices of WT and EMT were obtained in rib knitted fabric, meaning that the rib knitted fabric is less extensible but the tension is linear. On the contrary, big mesh and small mesh knitted fabrics had low indices of LT and high indices of WT and EMT, meaning that they are more extensible but the tension is not linear.

Table 9-10 Mechanical properties of elastic knitted fabrics with different structures in the wale direction

Properties	Indices	Rib	Plain	Big mesh	Small mesh
		Mean / s. d	*Mean / s. d*	*Mean / s. d*	*Mean / s. d*
Tensile	LT	1.1340/0.024	1.077/0.007	1.078/0.031	1.075/0.013
	WT (gf.cm/cm²)	11.572/0.772	18.078/0.562	24.908/0.727	22.848/0.937
	RT (%)	55.524/2.077	56.490/0.402	54.332/2.159	55.480/3.029
	EMT (%)	41.628/2.213	68.544/2.272	94.292/0.126	86.736/3.361
Bending	B(gf.cm²/cm)	0.059/0.017	0.022/0.007	0.027/0.005	0.024/0.010
	2HB (gf.cm/cm)	0.135/0.016	0.071/0.009	0.077/0.007	0.077/0.025
Shearing	G (gf/cm.deg)	0.972/0.052	0.646/0.040	0.438/0.044	0.478/0.077
	2HG (gf/cm)	4.052/0.075	2.146/0.253	1.420/0.063	1.386/0.038
	2HG5 (gf/cm)	3.834/0.021	2.318/0.392	1.350/0.035	1.252/0.063
Compression	LC	0.431/0.069	0.415/0.063	0.442/0.042	0.359/0.097
	WC (gf.cm/cm²)	0.369/0.022	0.205/0.009	0.340/0.010	0.285/0.017
	RC (%)	39.996/0.736	41.432/1.216	38.342/0.713	37.688/2.035
Surface	MIU	0.448/0.027	0.465/0.020	0.448/0.027	0.426/0.013
	MMD	0.015/0.001	0.014/0.001	0.013/0.002	0.013/0.001
	SMD (um)	3.883/0.334	3.085/0.156	5.877/0.107	5.107/0.663

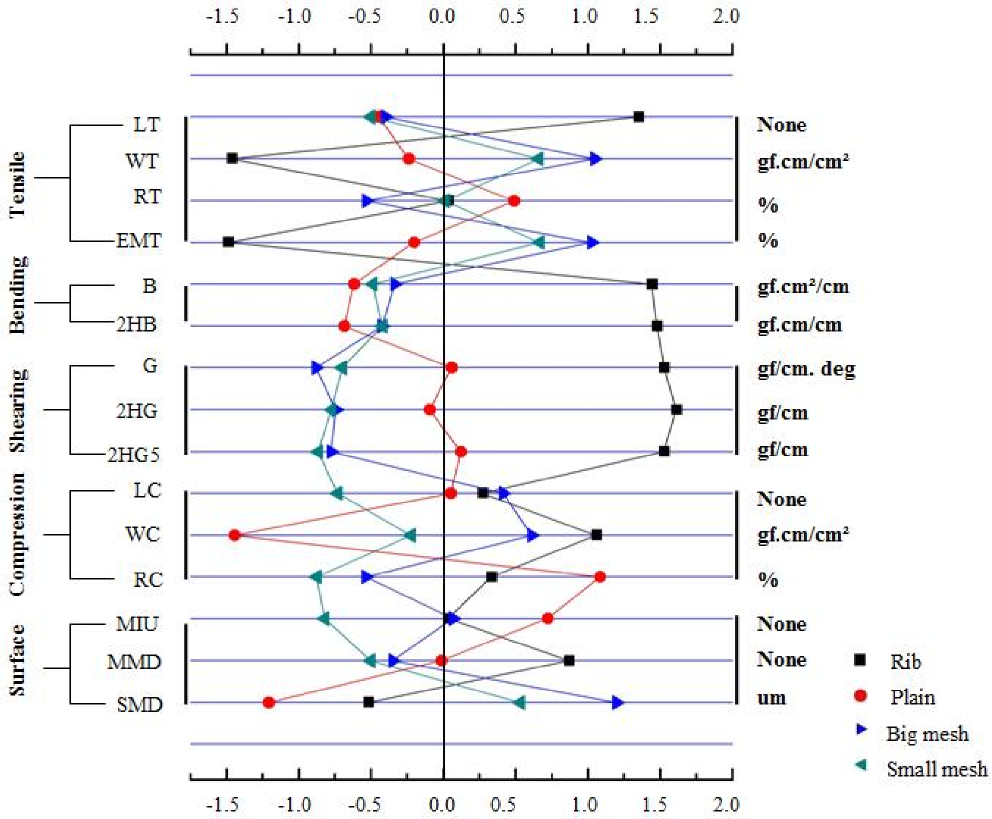


Figure 9-20 Comparison of mechanical properties in the wale direction for fabrics with different knit structures

In terms of bending and shearing, higher indices of bending rigidity (B) and shearing stiffness (G) were observed in rib knitted fabric, showing that rib knitted fabric possesses higher resistance to shearing and bending deformations than the other three fabrics. Comparing with rib knitted fabrics, plain, big mesh and small mesh knitted fabrics had low indices of bending rigidity (B) which means that these three fabrics have lower resistances to bending deformations than rib knitted fabric. The low indices of shear stiffness (G) in big mesh and small mesh knitted fabrics indicate that they have low resistances to shearing deformations.

In terms of compression and surface properties, rib knitted fabric had high indices of compression energy (WC), resilience (RC), but low index of geometrical roughness (SMD). These indices prove that rib knitted fabric has rough handle in wale direction and is difficult to compress. Small mesh knitted fabric had lowest compression energy (WC), resilience (RC), but highest geometrical roughness (SMD), meaning that it has soft handle in wale direction, and is easy to compress.

Table 9-11 Mechanical properties of elastic knitted fabrics with different structures in the course direction

Properties	Indices	Rib	Plain	Big mesh	Small mesh
		Mean / s. d	*Mean / s. d*	*Mean / s. d*	*Mean / s. d*
Tensile	LT	1.122/0.006	1.117/0.009	1.077/0.011	1.081/0.028
	WT(gf.cm/cm²)	14.796/0.251	17.764/0.832	22.770/0.762	21.500/0.806
	RT(%)	54.298/0.441	50.402/1.440	51.784/1.070	53.272/2.171
	EMT(%)	53.816/1.190	64.914/2.946	86.278/2.956	81.116/1.431
Bending	B(gf.cm²/cm)	0.066/0.014	0.024/0.006	0.018/0.004	0.027/0.010
	2HB (gf.cm/cm)	0.150/0.027	0.074/0.018	0.050/0.008	0.053/0.006
Shearing	G(gf/cm.deg)	0.898/0.033	0.682/0.037	0.514/0.078	0.488/0.019
	2HG(gf/cm)	3.772/0.198	1.998/0.054	1.518/0.138	1.506/0.061
	2HG5(gf/cm)	3.854/0.184	1.872/0.045	1.512/0.144	1.488/0.045
Surface	MIU	0.445/0.026	0.389/0.031	0.460/0.036	0.480/0.048
	MMD	0.018/0.001	0.012/0.001	0.010/0.001	0.011/0.001
	SMD (um)	10.866/1.902	2.771/0.396	4.007/0.407	2.623/0.177

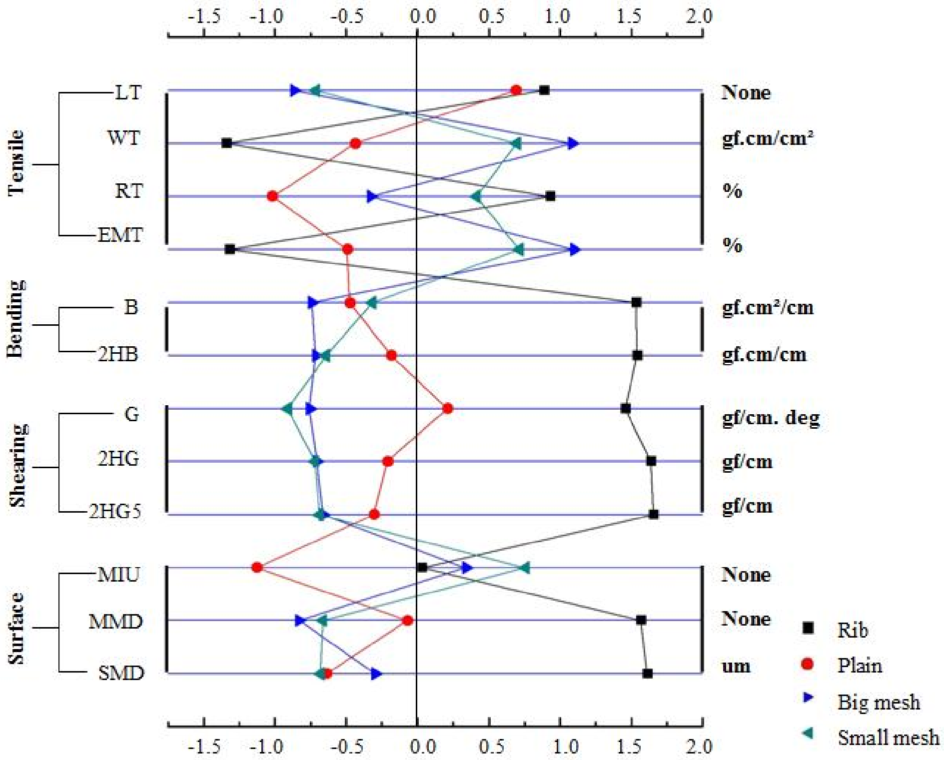


Figure 9-21 Comparison of mechanical properties in the course direction for fabrics with different knit structures

As shown in Table 9-11 and Figure 9-21, the profiles of tensile property index in the course direction of the four fabrics are similar to that in the wale direction except plain knitted fabric. The plain knitted fabric had high index of LT, and low indices of WT, RT and EMT. It means that plain knitted fabric is less extensible in the course direction but the tension is more linear. In terms of bending and shearing property indices, the property profiles in the course direction are similar to that in the wale direction. On the other hand, rib knitted fabric had high SMD index value of surface property in the course direction, which means that its surface is rougher in course than in wale. Comparatively, plain knitted fabric has soft handle in both wale and course directions.

9.4.2 Comparison of Physical Properties of Knitted Fabrics with Different Structures

As discussed in Section 9.3.3.3 on page 259, all the four fabrics had the same values of contact angle (0), meaning that all fabrics are hydrophilic materials. Fabrics with different structures have different physical properties, as shown in Figure 9-22. For instances, rib knitted fabric had the maximum air resistance and thermal conductivity indices, the minimum dry thermal insulation index among the four fabrics. Moreover, it had high wet thermal insulation and WVP, but low OMMC. These indices indicate that rib knitted fabrics have poor air permeability, less effective in heat losses through evaporation and moisture transfer in liquid form. However, rid knitted fabrics are good at heat conduction, dry heat losses, and moisture transfer in vapour form.

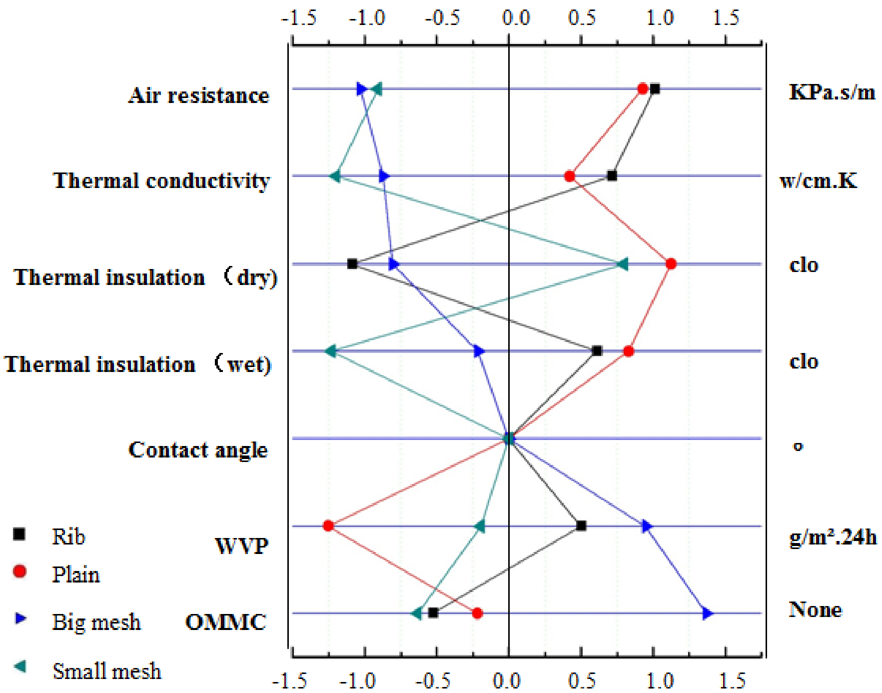


Figure 9-22 Comparison of physical properties of fabrics with different knit structures

With reference to the physical property index values, plain knitted fabrics are not good at heat losses (both dry and by evaporation) and with poor air permeability. However, plain knitted fabrics are good at moisture transfer in both vapour form and liquid form. It is also good at conducting heat.

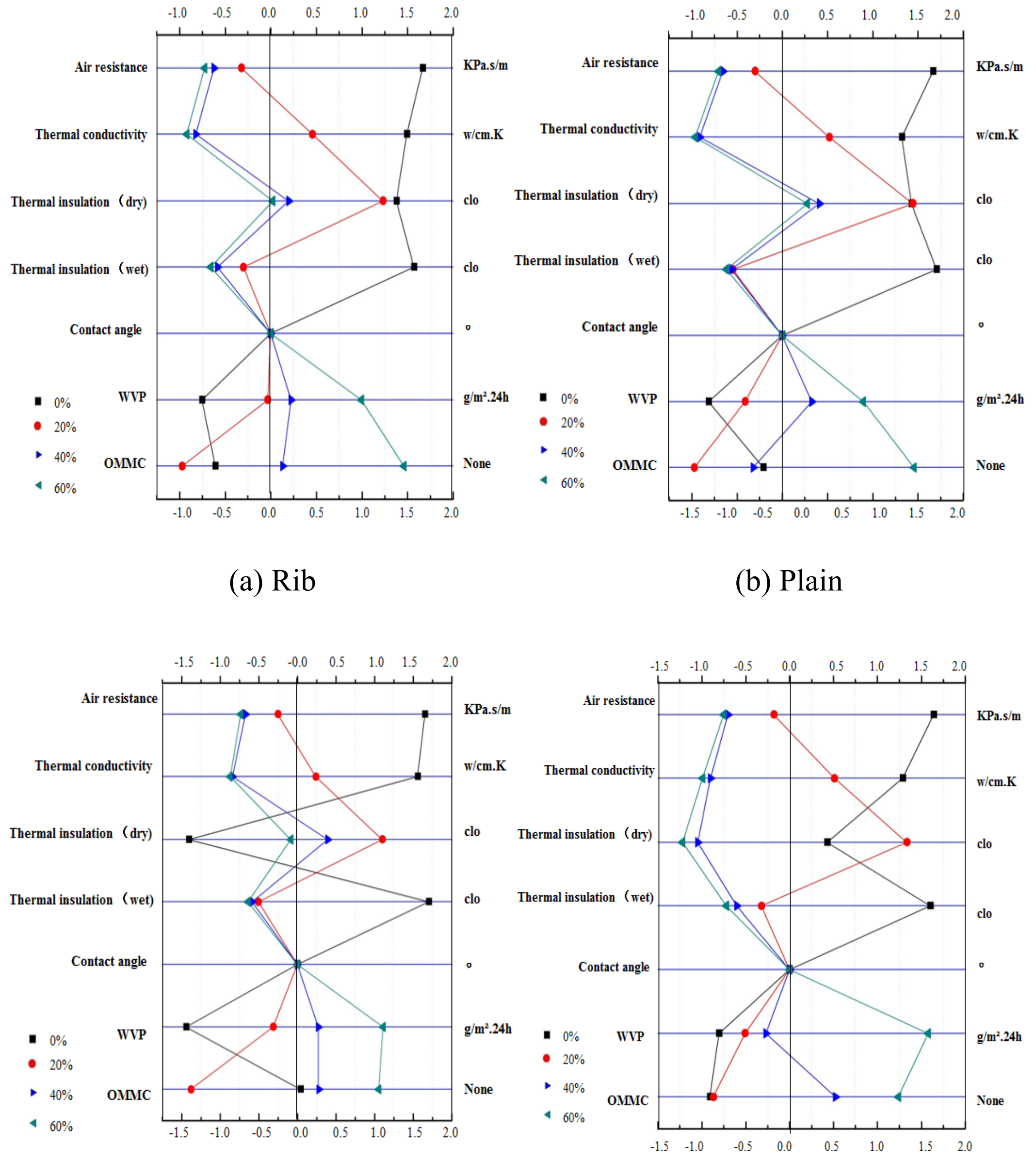
Among the four knitted fabrics, big mesh knitted fabric had the maximum index values of WVP and OMMC, which means that big mesh knitted fabrics are most effective in moisture management. Meanwhile, the minimum air resistance and low thermal insulation (dry and wet) imply that big mesh fabric is air permeable and good at heat losses.

Small mesh knitted fabric has good air permeability and thus is effective in evaporation. However, small meshes knitted fabrics are not good at dry heat losses and moisture management.

9.4.3 Comparison of Fabric Physical Properties under Different Levels of Stretching

In addition to the comparison of physical properties of knitted fabrics with different structures, the fabric properties under different levels of stretching are also compared. It is because in high performance sportswear design, elastic fabrics are used to provide sufficient room for movement by stretching the fabrics. Figure 9-23 exhibit the comparison of physical properties among the four elastic knitted fabrics when they are stretched 0%, 20%, 40% and 60%.

It is shown that the four fabrics exhibits similar profiles of property variations with the increase of stretching levels: When fabrics were stretched from 0% to 60%, the properties of air permeability, heat losses with evaporation and moisture transfer in water vapour form were improved significantly among all four fabrics. However, thermal conductivities reduced gradually. Moreover, the contact angle did not change in all stretching levels, which means that stretching would not affect hydrophilic property of the fabrics.



(a) Rib

(b) Plain

(c) Big mesh

(d) Small mesh

Figure 9-23　Comparison of fabrics properties under four levels of stretching

In addition, rib and plain knitted fabrics had similar improvement tendency in thermal insulation (dry condition) property from 0% to 60% of stretching. Dry heat loss property improved significantly between 20% and 40% of stretching. When fabrics were stretched further from 40% to 60%, the variation was not significant. For big mesh and small mesh knitted fabrics, this property reached the maximum at 20% of stretching, meaning that these two fabrics had the worst dry heat losses if stretched 20%. In terms of moisture transfer in liquid water form, all tested fabrics had the best performance at 60% of stretching. Rib, plain and big mesh fabrics had the worst moisture management in liquid from at the stretching level of 20%. Small mesh knitted fabric had the worst performance at 0% of stretching.

9.5 Discussions

9.5.1 The Effects of Stretching on Fabric Physical Properties

Table 9-12 Effects of stretching on physical properties

Properties	Rib		Plain		Big mesh		Small mesh	
Indices (Unit)	F-values	P (Sig.)	F-values	P (Sig.)	F-values	P (Sig.)	F-values	P (Sig.)
Air resistance (KPa.s/m)	0.003	0.000*	0.003	0.000*	0.001	0.000*	0.002	0.000*
Thermal conductivity (w/cm.K)	148.278	0.000*	364.503	0.000*	137.500	0.000*	894.226	0.000*
Thermal insulation								
-dry (clo)	204.470	0.000*	204.470	0.000*	56.229	0.000*	89.371	0.000*
-wet (clo)	43.645	0.000*	344.253	0.000*	210.234	0.000*	144.076	0.000*
Contact angle (°)	_	_	_	_	_	_	_	_
WVP (g/m².24h)	9.713	0.001*	4.517	0.018*	10.747	0.000*	54.544	0.000*
OMMC	55.322	0.000*	27.523	0.000*	22.899	0.000*	43.217	0.000*

* $P \leq 0.05$: significance

Table 9-13 Multiple comparisons of physical property between every two stretching levels

Properties/ Indices (Unit)	Stretching levels (%) in comparison		Rib		Plain		Big mesh		Small mesh	
			Mean difference	P(sig.)	Mean difference	P(sig.)	Mean difference	P(sig.)	Mean difference	P(sig.)
Air resistance (KPa.s / m)	0	20	0.705	0.000*	0.692	0.000*	0.341	0.000*	0.344	0.000*
	20	40	0.106	0.000*	0.124	0.000*	0.076	0.000*	0.099	0.000*
	40	60	0.038	0.002*	0.017	0.126	0.011	0.185	0.009	0.254
Thermal Conductivity (w/cm.K)	0	20	0.009	0.000*	0.010	0.000*	-0.098	0.020*	0.007	0.000*
	20	40	0.012	0.000*	0.017	0.000*	0.014	0.000*	0.013	0.000*
	40	60	0.001	0.473	0.001	0.517	0.001	0.489	0.001	0.103
Thermal insulation -dry (clo)	0	20	-0.165	0.000*	-0.166	0.000*	-0.070	0.000*	-0.019	0.000*
	20	40	0.063	0.000*	0.063	0.000*	0.020	0.003*	0.038	0.000*
	40	60	0.011	0.135	0.011	0.135	0.013	0.029*	-0.016	0.000*
Thermal insulation -wet (clo)	0	20	0.039	0.000*	0.047	0.000*	0.035	0.000*	0.019	0.000*
	20	40	0.006	0.224	0.001	0.860	0.001	0.061*	0.003	0.044*
	40	60	0.002	0.753	0.001	0.507	0.001	0.643	0.001	0.365
WVP (g/m^2.24hs)	0	20	-115.357	0.012*	-31.352	0.439	-85.633	0.077	-44.585	0.169
	20	40	-25.478	0.543	-57.396	0.166	-66.525	0.161	-35.385	0.270
	40	60	-77.141	0.078	-44.586	0.276	-96.249	0.050*	-278.132	0.000*
OMMC	0	20	0.059	0.097	0.179	0.000*	0.179	0.000*	-0.006	0.871
	20	40	-0.181	0.000*	-0.209	0.000*	-0.209	0.000*	-0.231	0.000*
	40	60	0.220	0.000*	-0.098	0.020*	-0.314	0.000*	-0.119	0.006*

* $P \leq 0.05$: significance

One-way ANOVA analysis was carried out to test if there is any significant change in physical properties when the fabrics are stretched in different levels. The F-values of each property index in four stretching levels were obtained and summarised in Table 9-12. It is shown that except contact angle, significant differences can be found in all physical property indices because all *p* values are less than 0.05. Therefore, stretching the fabrics has significant impacts on the material physical properties.

Table 9-12 indicates that physical properties of elastic knitted fabrics are influenced by different levels of stretching. Multiple comparisons on physical properties between every two stretching levels were carried out to understand that the detailed characteristics of physical property variations in different stretching levels. The analysis results are summarised in Table 9-13.

When fabrics were stretched from 0% to 20%, rib knitted fabric had significant changes in properties of air permeability, moisture transfer in water vapour form, heat conduction, dry heat losses as well as heat losses with evaporation. Plain knitted fabric had significant changes in properties of air permeability, moisture transfer in liquid water form, heat conduction, dry heat losses as well as heat losses with evaporation. Big mesh knitted fabric had significant changes in properties of air permeability, moisture transfer in liquid water form, heat conduction, dry heat losses as well as heat losses with evaporation. Lastly, small mesh knitted fabric had significant changes in properties of air permeability, heat conduction, dry heat losses as well as heat losses with evaporation.

When fabrics were stretched from 20% to 40%, rib knitted fabric had significant changes in the properties of air permeability, moisture transfer in liquid water form and heat conduction. Plain knitted fabric had significant changes in the properties of air permeability, moisture transfer in liquid water form, heat conducting as well as dry heat losses. Both big mesh and small mesh knitted fabrics had significant changes in all physical properties except moisture transfer in water vapour form.

When fabrics were stretched from 40% to 60%, rib knitted fabric had significant changes in the properties of air permeability and moisture transfer in liquid water form. Plain knitted fabric had significant changes in the property of moisture transfer in liquid water form. Both big mesh and small mesh knitted fabrics had significant changes in all physical properties except air permeability, heat conduction and heat losses with evaporation.

9.5.2 Application of Four Elastic Knitted Fabrics in Running Wear

As discussed, human body have special thermal-moisture characteristics and skin surface changes in running exercise, which determines the material property requirements in running wear design. As reported in Chapter 7, although significant muscle movements occur in limbs, around joints, and hip in running exercise, the body parts such as back waist, neck, wrist and ankle should also be kept in steady shape for safety purpose. Materials selected for these parts must be less extensible, with good tensile strength and be resistant to shearing and bending deformations. On the other hand, being the support point of the whole top garment, shoulder parts experienced the maximum pressure. Therefore, light and thin material should be used in shoulder parts. Meanwhile, the shoulders should be kept at steady shape, therefore the selected materials must have good resistance to fabric deformation. For other parts of the body, such as chest, front waist and limbs, significant skin extensions and contractions are expected during body movement, thus the materials used should have good tensile and bending strengths.

When people run, body temperature increases and people sweat to cool down the body, especially in area of front chest, back chest and underarm. In order to keep these parts of the body dry, materials selected must have excellent properties of air permeability, heat losses and moisture transfer. In addition, higher temperature and more sweat are found in areas of thigh (inner and outer), calf (front), knee joint (back) and elbow joint (inner), thus the selected materials to be used in these areas should be good at air permeability and moisture transfer.

Based on the functional design requirements, the applications of the four elastic knitted fabrics in running wear can be determined. The rib knitted fabric is suitable for back waist, neck, wrist, ankle, parts of limb, around joints, and hip areas. Big mesh fabric is suitable for centre front chest, back chest and armhole areas. Small mesh knitted fabric is suitable for thigh (inner and outer), calf (front), knee joint (back) and elbow joint (inner) areas. Plain knitted fabric is suitable for shoulder areas and the remaining parts.

9.5.3 Design of Material Stretching Levels in Tight-Fit Running Wear

The experiment data reported in section 9.4.3 reveal that at stretching level from 20% to 40%, the elastic knitted fabrics are most suitable for designing tight-fit running wear without considering the material pressure. When fabrics are stretched from 20% to 40%, rib and plain knitted fabrics have good air permeability and effective moisture transfer in liquid water form. Although heat conduction is reduced, dry heat losses and heat losses by evaporation are improved. For big mesh and small fabrics, they also have good air permeability, effective moisture transfer in liquid water form, dry heat losses and heat losses by evaporation between 20% and 40% of stretching. In summary, tight-fitting design with 20% to 40% of stretching is suitable for high-performance running wear design.

9.6 Conclusions

By investigating the material structural characteristics, mechanical-physical properties of elastic knitted fabrics with different structure designs and under different stretching levels, a number of conclusions can be drawn

Firstly, significant differences of material property are observed in elastic knitted fabrics with different structure designs. Material structural characteristic, mechanical (e.g. tensile, shearing, bending, compression, as well as double stretching capacity) and physical properties (air permeability, heat conducting, dry heat losses, heat losses with evaporation and moisture transfer in water vapour and liquid water forms) play prominent roles in fabric selection in sportswear design.

Secondly, tensile energy (WT), tensile strain (EMT), shearing (G), bending rigidity (B) and double stretching capacity (X-F) are indices that highly correlated to clothing shape and deformation. Air resistance, thermal conductivity, thermal insulation, water vapour permeability and overall moisture management capacity are key indices that highly correlated to the thermoregulation performance of the sportswear.

Thirdly, significant differences of material physical properties are observed when fabrics are stretched. The four elastic knitted fabrics exhibit varied physical properties among different levels of stretching.

Fourthly, based on the material property investigation, thermal-moisture distributions of human body in sports and functional requirements of running wear, the four fabrics are applied to different parts of the running wear. In addition, material at stretching levels of 20% to 40% is suitable for the design of tight-fit high-performance running wear, which provides good thermoregulation and ensures clothing comfort.

CHAPTER 10 FUNCTIONAL EVALUATION OF RUNNING WEAR WITH DIFFERENT FIT DESIGNS

10.1 Introduction

The functional design of clothing is vitally important, especially in running wear design. A clothing product with ergonomic wearing comfort means that the product can fulfil wearer's body mechanics requirements, including a) motion degree of freedom (DOF), b) range of motion (ROM), c) force and moment of human joints (Siguang, 1987, Li & Guo, 1996, Ji & Yuan, 1999, Zhou & Wei, 2005), and d) suitable clothing pressure. Therefore, a running wear with good ergonomic wearing comfort is a proof of its effective functional design.

As reviewed in Chapter 2, a number of factors determine the ergonomic wearing comfort of a clothing product, such as material application, style design, layer assembling, fit design as well as pattern construction (Fan & Chen, 2002). Pattern construction and fit design can be regarded as the two most important factors among these. First of all, no matter how well a fabric is engineered to have optimum values of heat, water or air transmission, any clothing product made of it cannot provide the desired comforts unless the garment fits well to the wearer. A poor fit garment would restrict cardio-vascular flow, cause skin abrasion, create unpleasant thermal or moisture conditions or include irritation that manifest to the wearer in the form of discomfort (Ljubi & Petar, 1999). On the other hand, pattern design directly influences the clothing fit, the shape and the structure. For instance, ease allowance design determines whether the garment is loose, normal, and tight fitting. For a same product type, different structure line designs create different functional performance. All in all, there are close relationships between ergonomic clothing comfort, fit design and pattern construction.

In Chapter 8, a dynamic pattern construction method for running wear has been proposed. To better understand the effectiveness of the dynamic patterns, a wearing trial experiment was designed and conducted in this chapter. Both subjective and objective methods were used to evaluate the ergonomic wearing comfort of the running wear developed by dynamic patterns with various fit designs. In such manner, the effectiveness of dynamic patterns for the improvement of running wear functional performance can be evaluated. Finally, the suitable fit design of high performance running wear is determined.

10.2 Research Methodology

Subjective evaluation by questionnaire survey and objective evaluation by pressure sensor method are the two main approaches for evaluating clothing ergonomic functionality (Vykukal, 1982, Newman et al., 2000, White et al., 1993, Kozycki, 1998). In this chapter, both methods were used in the wearing trial experiment for the running wear's ergonomic function evaluation.

10.2.1 Preparation of Running Wear Samples with Different Fit Designs

10.2.1.1 Construction of dynamic patterns with different fit designs

In Chapter 8, dynamic pattern construction for one-piece running wear with just-fit design was developed. To understand the effects of fit design on running wear functional performance, the pattern alteration is done to the just-fit one-piece running wear to obtain 20%, 40% and 60% tight-fit designs. The dynamic patterns were altered based on the following principles: a) All length measurements on the dynamic patterns with just-fit design remain unchanged in the three tight-fit designs; b) Girth measurements on the dynamic patterns are adjusted by this formula: $G' = G / (1+\tau)$, where G is the original girth measurement on dynamic patterns with just-fit design, G' is the adjusted girth measurement, and τ is the tight level percentage, i.e., 20%, 40% or 60%; c) Width measurements are adjusted to keep the smooth shape of the dynamic pattern structure lines. Dynamic patterns of one-piece running wear with just-fit, 20%, 40% and 60% tight-fits were prepared, as shown in Figure 10-1 to Figure 10-10. These patterns were used to prepare knitting patterns and running wear samples.

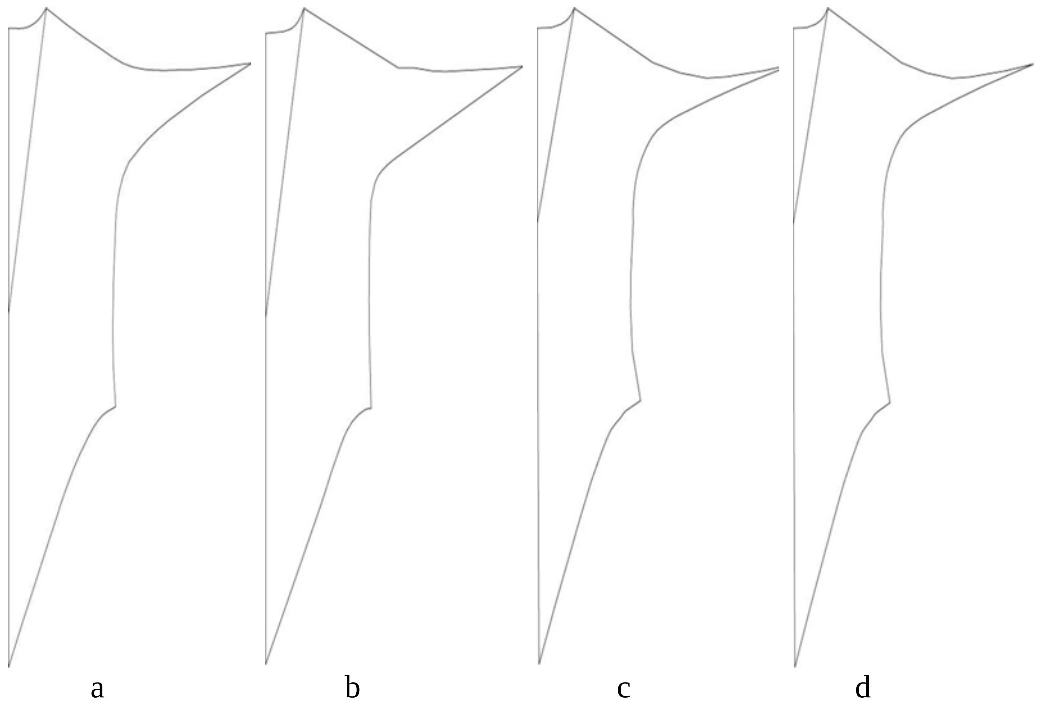
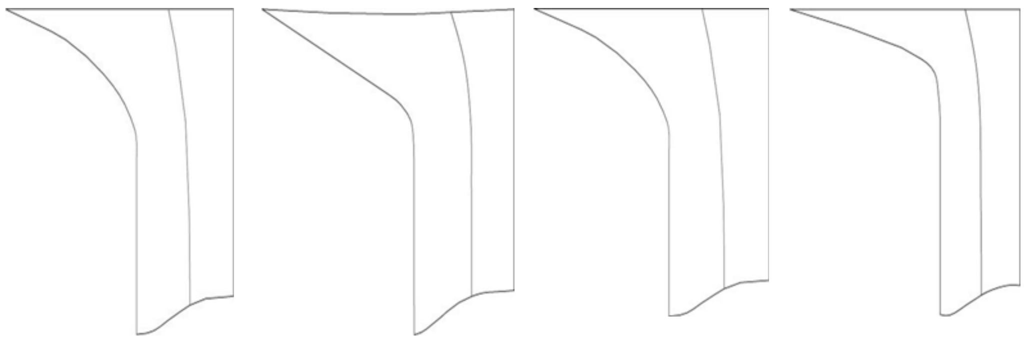
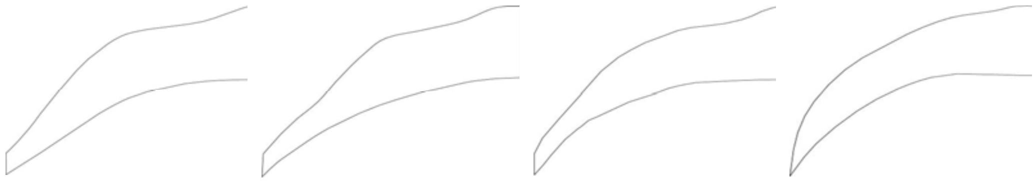


Figure 10-1 Dynamic patterns of front shirt with four fit designs: a) just-fit, b) 20% tight-fit, c) 40% tight-fit, and d) 60% tight-fit



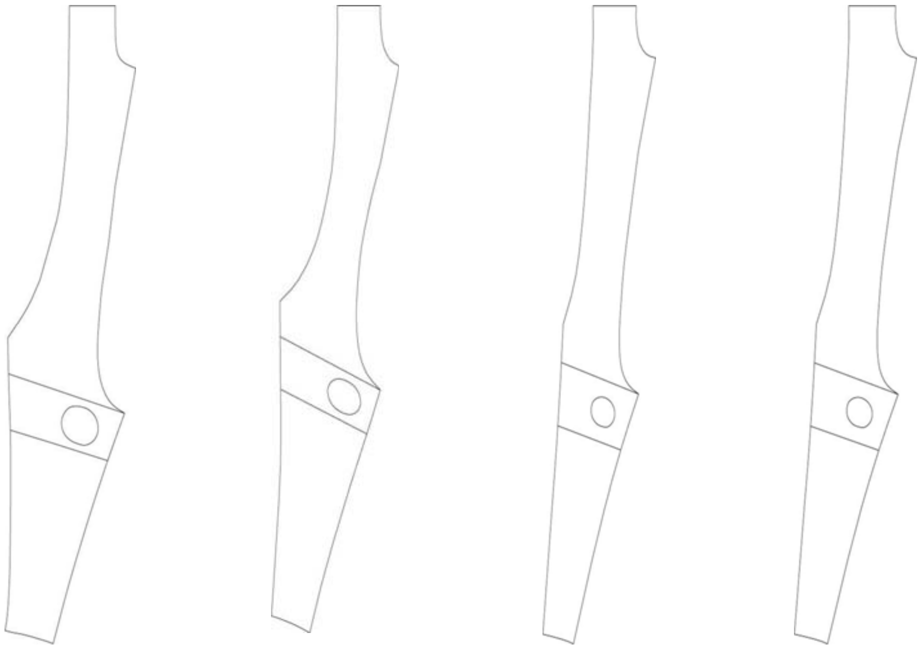
a b c d

Figure 10-2 Dynamic patterns of back shirt with four fit designs: a) just-fit, b) 20% tight-fit, c) 40% tight-fit, and d) 60% tight-fit



a b c d

Figure 10-3 Dynamic patterns of waist with four fit designs: a) just-fit, b) 20% tight-fit, c) 40% tight-fit, and d) 60% tight-fit



a b c d

Figure 10-4 Dynamic patterns of arm-shoulder sleeve with four fit designs: a) just-fit, b) 20% tight-fit, c) 40% tight-fit, and d) 60% tight-fit

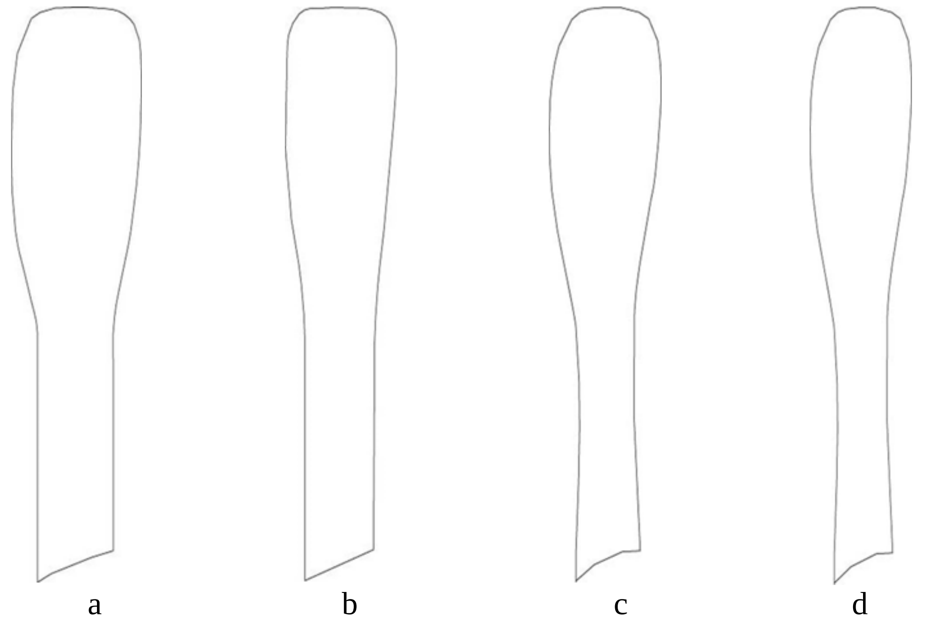


Figure 10-5 Dynamic patterns of side-shirt sleeve with four fit designs: a) just-fit, b) 20% tight-fit, c) 40% tight-fit, and d) 60% tight-fit

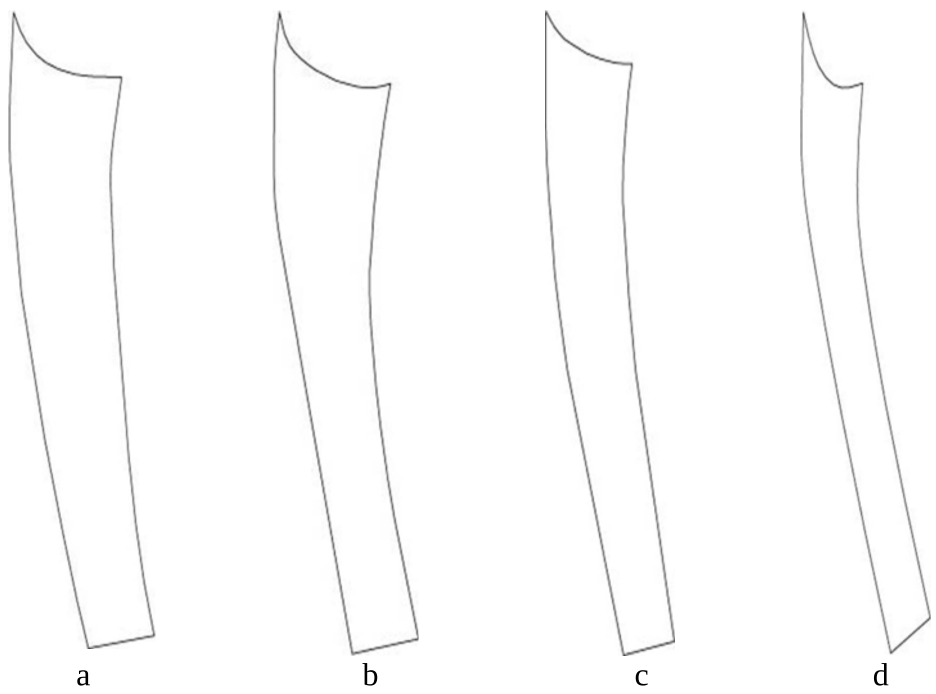


Figure 10-6 Dynamic patterns of inner sleeve with four fit designs: a) just-fit, b) 20% tight-fit, c) 40% tight-fit, and d) 60% tight-fit

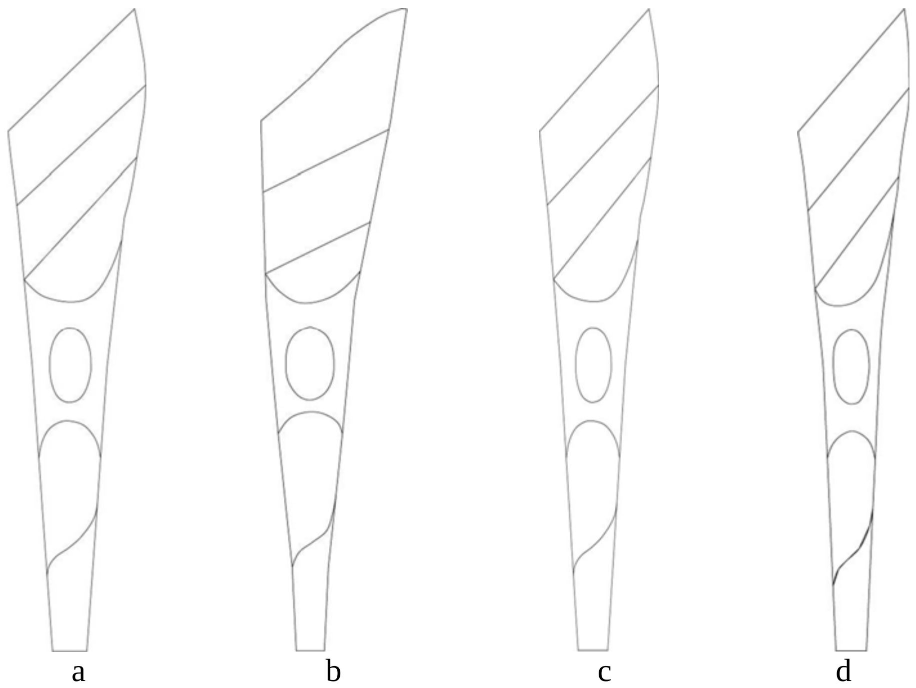


Figure 10-7 Dynamic patterns of front trousers with four fit designs: a) just-fit, b) 20% tight-fit, c) 40% tight-fit, and d) 60% tight-fit

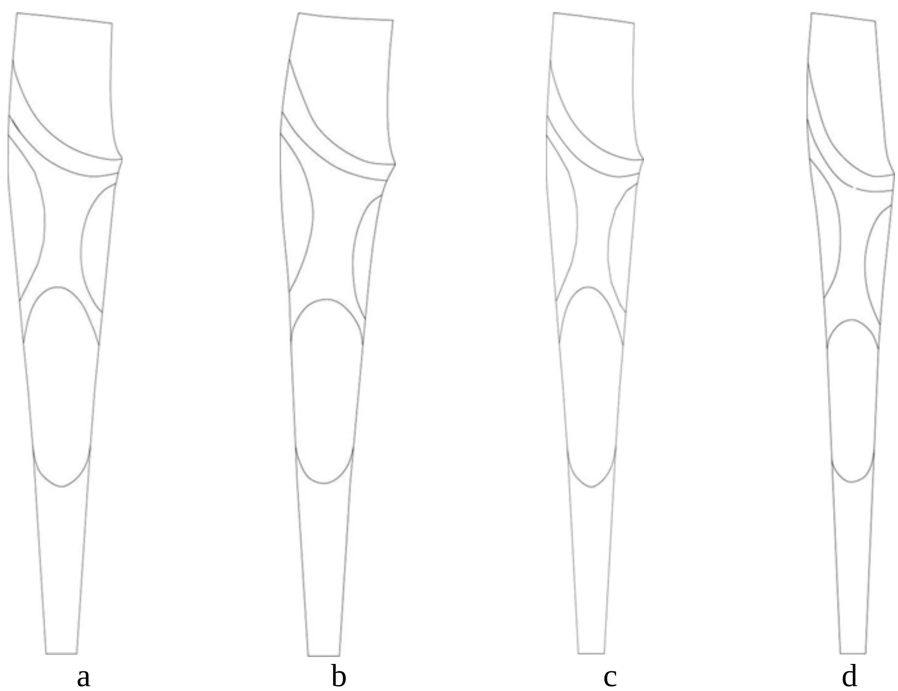


Figure 10-8 Dynamic patterns of back trousers with four fit designs: a) just-fit, b) 20% tight-fit, c) 40% tight-fit, and d) 60% tight-fit

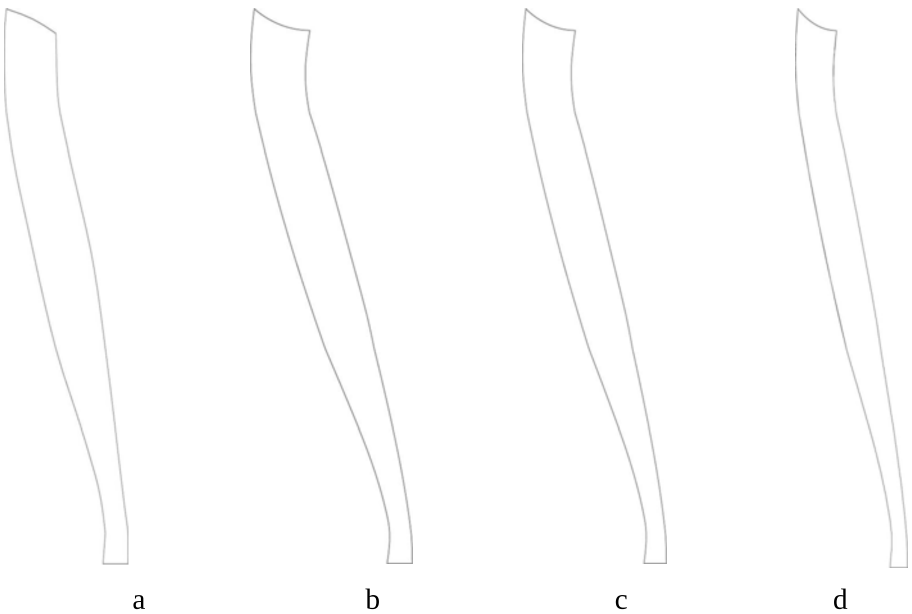


Figure 10-9 Dynamic patterns of side trousers with four fit designs: a) just-fit, b) 20% tight-fit, c) 40% tight-fit, and d) 60% tight-fit

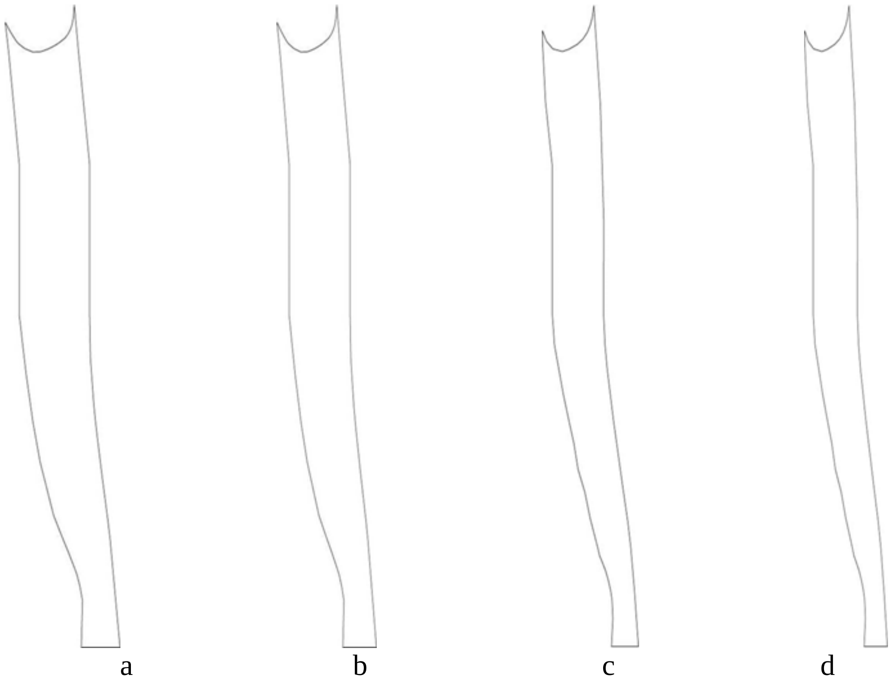


Figure 10-10 Dynamic patterns of inner trousers with four fit designs: a) just-fit, b) 20% tight-fit, c) 40% tight-fit, and d) 60% tight-fit

10.2.1.2 Application of elastic fabrics to dynamic patterns

In Chapter 9, the material properties of the four elastic knitted fabrics have been examined. To achieve a better thermo-physiological clothing comfort, fabrics with different structures were applied to the running wear patterns based on thermal-moisture distributions of the human body in running state (Yao et al, 2010). The applications of different fabrics (i.e., rib, plain, small mesh and big mesh) in the dynamic patterns are determined, as shown in Figure 10-11.

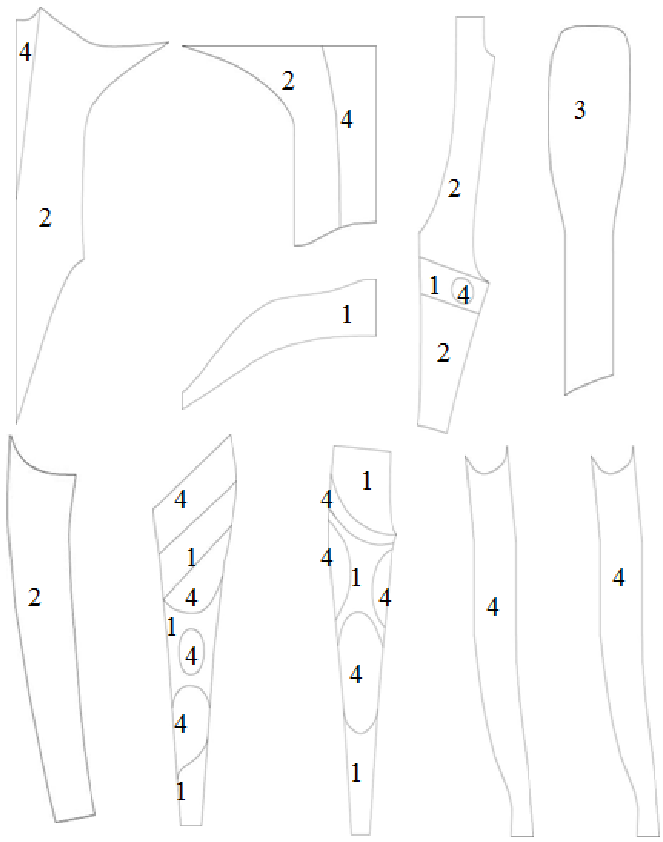
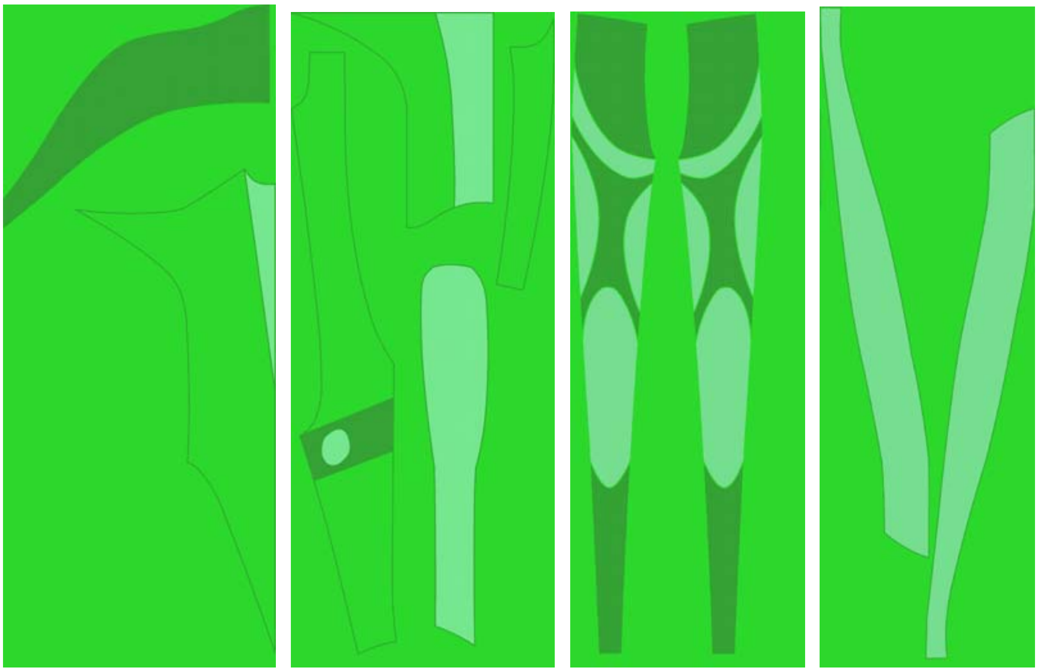


Figure 10-11 Application of elastic fabrics with four structures in dynamic patterns

1-elastic fabric with rib structure, 2-elastic fabric with plain structure,

3-elastic fabric with big mesh structure, 4-elastic fabric with small mesh structure

10.2.1.3 Design of knitting pattern



a b c d

Figure 10-12 Knitting patterns of one-piece running wear with different fit designs: a) front shirt and waist, b) back shirt, arm-shoulder sleeve, side-shirt sleeve as well as inner sleeve, c) front and back trousers, and d) side and inner trousers

Because the dynamic patterns of one-piece running wear with just-fit, 20% tight-fit, 40% tight-fit and 60% tight-fit need to be knitted and sewn as final samples, the corresponding knitting patterns can be constructed by the following steps:

Step 1: Based on plain elastic fabrics, the fabric density can be calculated: 21 strips/cm in the wale direction and 33 strips/cm in the course direction.

Step 2: The length in the wale and course of the original dynamic patterns of the one-piece running wear with different fit designs are re-calculated by formulas: a) length values in the wale direction of the knitting pattern = length in the wale direction of the dynamic pattern × 21 strips /cm, b) width values in the course direction of the knitting pattern = width values in the course direction of the dynamic pattern × 33 strips /cm. When all the length and width values are calculated, new knitting patterns can be re-constructed.

Step 3: When structure lines of all knitting pattern are determined, inner lines are drawn and different colours are used to mark different fabric structures on the patterns.

Finally, knitting patterns of one-piece running wear with different fit designs are constructed, as shown in Figure 10-13

10.2.1.4 Running wear sample development

After pattern pieces of one-piece running wear are knitted, the pieces of neck, sleeve and trousers cuff were added. A zip was then sewn using elastic sewing thread at the back centre line of the back shirt as opening. All pattern pieces were sewn together with elastic sewing thread and all cuffs were sewn with style of hem seam. Finally, samples of running wear were obtained, as shown in Figure 10-13.

a) front b) side c) back

Figure 10-13 Sample of one-piece running wear based on dynamic pattern method

In this study, four prototypes of running wear with dynamic patterns of 0%, 20%, 40% and 60% tight-fit designs were made for each subject based on his body size.

10.2.2 Subjective Evaluation of Running Wear Ergonomic Function

10.2.2.1 Subjects

The same subjects in former research works were recruited to take part in this study. Before conducting experiment, researchers introduced the procedure to all subjects and obtained their ethical approvals for participation in the wearing trial experiment.

10.2.2.2 Questionnaire design

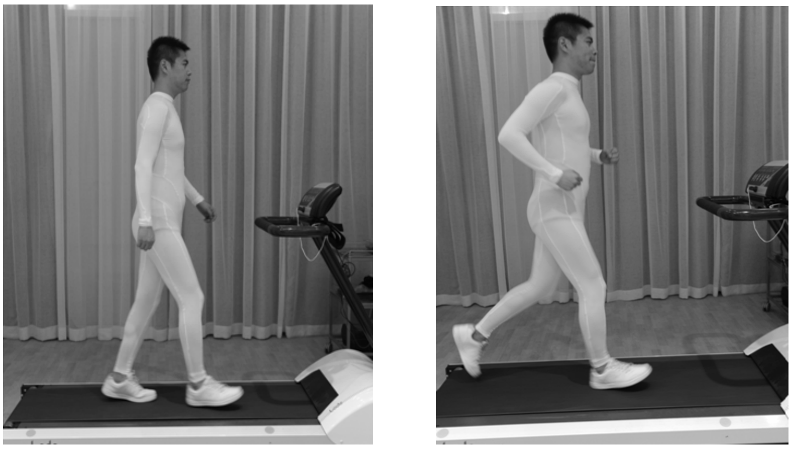
Subjective evaluation is a complex synthesis of many psychological and physiological responses of individuals. The physical properties of the product, the wearing habits and experiences of the subjects are important factors that influence subjects' responses (You et al., 2002). In order to correctly understand and quantify subjective sensations, questionnaire design is crucial in subjective evaluation method.

In this study, a questionnaire was designed and a copy of the questionnaire can be found in Appendix VII. The questionnaire includes three sections: *Section One* is the individual information. *Section Two* is subjective perception on ergonomic wearing comfort of running wear after walking. *Section Three* is subjective perception on ergonomic wearing comfort of running wear after running. In order to quantify subjective sensation correctly, magnitude estimation, a simple and effective method of psychophysical scaling (Marks, 1974) was used in this questionnaire for rating subjective perception There are various scales in magnitude estimation and the most commonly adopted ones are scale of 0-5, scale of 0-7 and scale 0-10 (Davis, 1985, Labat, 1987, Shim, 1994, Hwang, 1996) . In this questionnaire, subjects were asked to rate the senses of wearing pressure and the fetters of the running wear on a scale of 0-5 by answering corresponding questions.

10.2.2.3 Experiment protocol

Wear trial experiment was carried out in the clothing functional evaluation laboratory of The Hong Kong Polytechnic University, which has a controlled environment with regular room temperature of 24ºC, 65% relative humidity and wind speed less than 0.1 m/s. Each subject carried out a defined sequence of exercises and completed a questionnaire survey in the following way.

Firstly, each subject filled out *Section One* of the questionnaire and wore the prototype of the running wear with 0% tight-fit design. Next, he walked on the treadmill at 5 km/h for three minutes, as shown in Figure 10-14(a). After the walking exercise, the subject was required to complete *Section Two* of the questionnaire. Upon completion of this section of the questionnaire, the subject then performed three minutes of running on the treadmill at 10 km/h, as shown in Figure 10-14(b). After running, the subject would complete the last section, *Section Three* of the questionnaire. The evaluation for the running wear with 0% tight-fit design was then completed. The same experimental procedures were repeated on running wear with 20%, 40% and 60% tight-fit designs after 30 minutes break between evaluations.



(a) Walking (b) Running

Figure 10-14 Wearing trial experiment in subject evaluation of running wear ergonomic function: (a) walking and (b) running

10.2.2.4 Data collection and analysis

Subjects' subjective ratings on ergonomic wearing comfort of the running wear of different fit designs were recorded in EXCEL worksheet for data analysis. Statistical software of SPSS was used to analyse the collected data.

10.2.3 Objective Evaluation of Running Wear Ergonomic Function

Objective evaluation using pressure sensors to collect the clothing pressure is another important method to evaluate the ergonomic clothing function. In this study, pressure sensor method was also used in wearing trial experiment.

The same group of subjects participating in subjective evaluation also took part in this part of the experiment.

10.2.3.1 Determination of body positions for pressure measurement

In the literature on clothing pressure, 16 positions are often used to measure and understand clothing pressure for wearing comfort evaluation (Lin et al., 2010, Jin et al., 2008, Chen & Gan, 2005, You & Zhang, 2000). These positions include: a) front neck, back neck, shoulder, chest, scapular, front waist, back waist and hip on the torso; b) upper arm, elbow and forearm on the arms. c) front thigh, back thigh, knee, front calf and back calf on the legs, as shown in Figure 10-15. In this study, these 16 positions were selected to measure pressure of running wear with different fit designs.

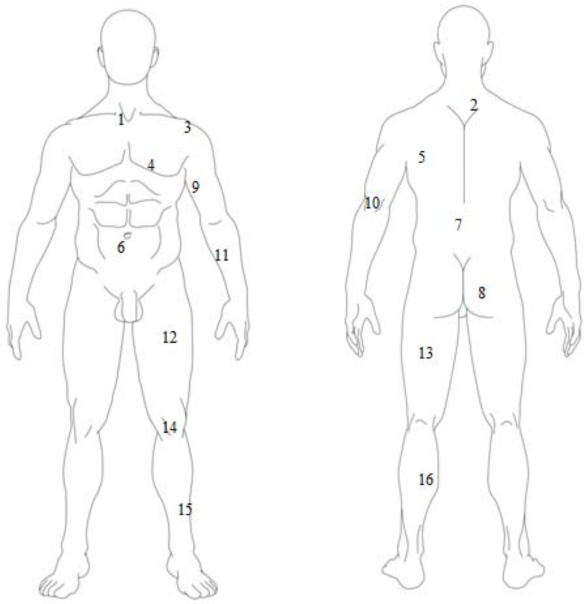


Figure 10-15 Pressure sensor locations on body skin: 1) front neck, 2) back neck, 3) shoulder, 4) chest, 5) scapular, 6) front waist, 7) back waist, 8) hip, 9) upper arm, 10) elbow, 11) forearm, 12) front thigh, 13) back thigh, 14) knee, 15) front calf, 16) back calf

10.2.3.2 Experiment instruments

The measurement system, consisting of host computer, data collector and pressure sensors (see Figure 10-16), was used to collect pressure data of running wear in static and running states. In this system, pressure sensors (FlexiForce interface pressure sensor-Tekscan, Inc, MA, USA) were fixed on skin with adhesive plaster, as shown in Figure 10-17. The data collector was used to collect digital signals from the sensors and store the data to host computer.

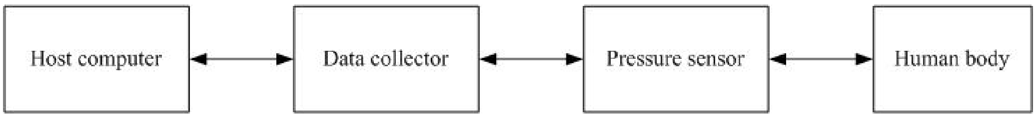


Figure 10-16 Measurement system of clothing pressure

Figure 10-17 Pressure sensor and fixation

10.2.3.3 Experiment protocol

The wearing trial experiment for objective evaluation were also carried out in the clothing functional evaluation laboratory of The Hong Kong Polytechnic University, In order to assess wearing comfort of pressure, each subject carried out a defined sequence of exercise as follows:

Before the experiment, 16 pressure sensors were fixed on the corresponding skin locations of each subject with adhesive plaster, as shown in Figure 10-17. After fixing pressure sensors, each subject was required to wear samples of one-piece running wear correctly. At the beginning of the experiment, each subject would keep the body relaxed and stand on the treadmill for three minutes. And then, he was required to run on a treadmill at a speed of 10 km/h for three minutes. After which, each subject stood on the treadmill again for another three minutes. In the whole rest-running-rest process, the pressure values of the 16 locations of human body were collected every 10 seconds.

10.2.2.4 Data collection and analysis

When each subject finished the required activities, the clothing pressure values of the running wear under investigation were recorded in the host computer. The data can be exported and analysed by standard data analysis software, e.g., SPSS.

10.3 Experimental Results

10.3.1 Subjective Sensations on Ergonomic Wearing Comfort of Running Wear with Different Fit Designs

10.3.1.1 One-piece running wear with just-fit design

The sensation data towards clothing pressure and the fetters of the running wear with just-fit design of the five subjects were recorded, and the mean values are shown in Table 10-1. It is indicated that all subjects consider running wear with just-fit design comfortable in terms of clothing pressure because all mean values are more than 4.00. Comparatively, subjects have higher ratings on the garment's wearing comfort in walking state than in running state. Among all body parts, shoulder, elbow, armpit, pelvis, crotch, knee and hip have higher ratings of comfort in terms of clothing pressure in walking state. In running state, shoulder, elbow, armpit and knee have higher ratings.

Moreover, the mean values of sensation towards the fetters of the clothing are close to 5.00, meaning do not feel any fetter from the clothing at all. It proves that the running wear with just-fit design provide sufficient freedom for body movement in walking and running. Among all body parts, shoulder, elbow, armpit, pelvis, crotch, knee and hip have better ratings on the freedom of movement in walking state. In running state, shoulder, elbow, knee and crotch have better ratings.

Table 10-1 Subjects' sensations on pressure and fetter of the running wear with just-fit design

Body parts	Clothing pressure				Clothing fetter			
	Walking		Running		Walking		Running	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Neck	4.40	0.55	4.20	0.45	4.40	0.55	4.20	0.45
Shoulder	4.80	0.45	4.60	0.55	4.60	0.45	4.60	0.55
Armpit	4.80	0.45	4.80	0.45	4.60	0.45	4.40	0.55
Elbow	4.80	0.45	4.60	0.55	4.60	0.45	4.60	0.45
Wrist	4.40	0.55	4.00	0.00	4.00	0.00	4.00	0.00
Navel	4.40	0.55	4.20	0.45	4.20	0.45	4.20	0.45
Pelvis	4.60	0.55	4.20	0.45	4.60	0.45	4.40	0.55
Hip	4.60	0.55	4.00	0.00	4.60	0.55	4.20	0.45
Crotch	4.80	0.45	4.40	0.55	4.80	0.45	4.60	0.55
Front thigh	4.20	0.45	4.00	0.00	4.20	0.45	4.20	0.45
Side thigh	4.40	0.55	4.00	0.00	4.40	0.55	4.40	0.55
Back thigh	4.40	0.55	4.00	0.00	4.20	0.45	4.20	0.45
Knee	5.00	0.00	4.80	0.45	4.80	0.45	5.00	0.00
Calf	4.40	0.55	4.00	0.00	4.40	0.55	4.40	0.55
Ankle	4.20	0.45	4.00	0.00	4.20	0.45	4.00	0.00

10.3.1.2 One-piece running wear with 20% tight-fit design

Table 10-2 Subjects' sensations on pressure and fetter of the running wear with 20% tight-fit design

Body parts	Clothing pressure				Clothing fetter			
	Walking		Running		Walking		Running	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Neck	4.00	0.00	3.60	0.55	4.20	0.45	4.00	0.00
Shoulder	3.60	0.55	3.80	0.45	4.60	0.55	4.60	0.55
Armpit	4.40	0.55	4.00	0.71	4.60	0.55	4.20	0.45
Elbow	4.00	0.00	4.00	0.71	4.40	0.55	4.20	0.45
Wrist	3.80	0.45	3.60	0.55	4.00	0.00	3.80	0.45
Navel	4.00	0.00	3.80	0.45	4.00	0.00	4.20	0.45
Pelvis	3.60	0.55	3.80	0.45	4.40	0.55	4.40	0.55
Hip	3.80	0.45	3.80	0.45	4.00	0.71	4.00	0.00
Crotch	4.20	0.45	4.00	0.00	4.60	0.55	4.60	0.55
Front thigh	3.60	0.55	3.40	0.55	4.00	0.00	4.00	0.00
Side thigh	4.00	0.00	3.60	0.55	4.00	0.00	4.00	0.00
Back thigh	3.60	0.55	3.40	0.55	4.00	0.00	4.00	0.00
Knee	4.40	0.55	4.00	0.00	4.60	0.55	4.60	0.55
Calf	3.60	0.55	3.60	0.55	4.20	0.45	4.00	0.00
Ankle	3.60	0.55	3.60	0.55	4.00	0.00	4.00	0.00

The sensation data towards wearing pressure comfort and the fetters of the running wear with 20% tight-fit design of the five subjects were recorded, and the mean values are shown in Table 10-2. It is found that all subjects consider the running wear with 20% tight-fit design comfortable in terms of clothing pressure because all mean values are more than 3.00. In walking state, neck, elbow, armpit, navel, crotch, knee and side thigh have higher ratings of clothing pressure comfort. In running state, elbow, armpit and crotch have better ratings.

Moreover, all mean values of the sensations towards the fetters of the clothing are more than 4.00 in both walking and running states. It proves that the clothing provides good freedom of movement. In walking state, the shoulder, armpit, crotch and knee have better ratings on the movement freedom. In running state, the shoulder, crotch and knee have better ratings.

10.3.1.3 One-piece running wear with 40% tight-fit design

The sensation data of towards wearing pressure comfort and the fetters of the running wear with 40% tight-fit design were recorded, and the mean values are shown in Table 10-3. As shown in the table, except the clothing pressure at the wrist (2.80/2.60) and ankle (2.80/2.40), the running wear with 40% tight-fit design provide satisfactory comfort in terms of clothing pressure, because the corresponding mean values are more than 3.00. In both walking and running states, the armpit, crotch and knee have better rating of clothing pressure comfort.

Moreover, all mean values of the sensation towards the fetters of the clothing are more than 3.40, meaning the running wear with 40% tight-fit design provides suitable freedom for movement in walking and running. In walking state, shoulder, armpit, crotch and knee have better ratings on the freedom of movement. The results are the same in running state.

Table 10-3 Subjects' sensations on pressure and fetter of the running wear with 40% tight-fit design

Body parts	Clothing pressure				Clothing fetter			
	Walking		Running		Walking		Running	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Neck	3.60	0.55	3.20	0.45	4.00	0.00	3.60	0.55
Shoulder	3.40	0.55	3.40	0.55	4.40	0.55	4.00	0.00
Armpit	4.00	0.71	3.80	0.45	4.40	0.55	4.00	0.00
Elbow	3.80	0.45	3.60	0.55	4.20	0.45	3.60	0.55
Wrist	2.80	0.45	2.60	0.45	4.00	0.00	3.60	0.55
Navel	3.80	0.45	3.60	0.55	4.00	0.00	3.80	0.45
Pelvis	3.80	0.45	3.40	0.55	4.20	0.45	3.80	0.45
Hip	3.60	0.55	3.60	0.55	3.80	0.45	3.80	0.45
Crotch	4.00	0.00	3.80	0.45	4.60	0.55	3.60	0.55
Front thigh	3.80	0.45	3.40	0.55	4.00	0.00	3.80	0.45
Side thigh	3.60	0.55	3.20	0.45	3.80	0.45	3.40	0.55
Back thigh	3.40	0.55	3.20	0.45	3.80	0.45	3.60	0.55
Knee	4.00	0.00	3.80	0.45	4.40	0.55	4.00	0.71
Calf	3.40	0.55	3.40	0.55	4.00	0.00	3.40	0.55
Ankle	2.80	0.45	2.40	0.55	3.80	0.45	3.60	0.55

10.3.1.4 One-piece running wear with 60% tight-fit design

Table 10-4 Subjects' sensations on pressure and fetter of the running wear with 60% tight-fit design

Body parts	Clothing pressure				Clothing fetter			
	Walking		Running		Walking		Running	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Neck	3.20	0.45	3.00	0.00	3.40	0.55	3.20	0.45
Shoulder	2.60	0.55	2.60	0.55	3.60	0.55	3.60	0.55
Armpit	2.80	0.45	2.40	0.55	3.60	0.55	3.60	0.55
Elbow	2.60	0.55	2.40	0.55	3.40	0.55	3.40	0.55
Wrist	2.40	0.55	2.60	0.55	3.20	0.45	3.20	0.45
Navel	2.60	0.55	2.60	0.55	3.40	0.55	3.40	0.55
Pelvis	2.80	0.45	2.40	0.55	3.40	0.55	3.20	0.45
Hip	2.80	0.71	2.60	0.55	3.40	0.55	3.40	0.55
Crotch	3.00	0.00	3.00	0.00	3.60	0.55	3.40	0.55
Front thigh	2.60	0.55	2.20	0.45	3.40	0.55	3.40	0.55
Side thigh	2.40	0.55	2.20	0.45	3.40	0.55	3.00	0.00
Back thigh	2.60	0.55	2.20	0.45	3.20	0.45	3.20	0.45
Knee	2.80	0.45	2.80	0.45	3.60	0.55	3.60	0.55
Calf	2.60	0.55	2.40	0.84	3.20	0.45	3.20	0.45
Ankle	2.60	0.55	2.60	0.55	3.20	0.45	3.20	0.45

The sensation data towards the wearing pressure comfort and the fetters of the running wear with 60% tight-fit design of the five subjects are recorded, and the mean values are shown in Table 10-4. It is shown that except the neck

(3.20/3.00) and the crotch (3.00/3.00), the running wear with 60% tight-fit design is not comfortable in terms of clothing pressure, because the corresponding mean values are below 3.00.

However, all mean values of sensation towards the fetters of the clothing are more than 3.20, meaning that the running wear with 60% tight-fit design provides sufficient freedom of movement. In walking state, shoulder, armpit, crotch and knee have better rating on the movement freedom. In running state, shoulder, armpit, and knee have better ratings.

10.3.2 Garment Pressure Results of Running Wear with Different Fit Designs

10.3.2.1 One-piece running wear with just-fit design

The maximum pressure values in the 16 locations of the running wear made of dynamic patterns with just-fit design are shown in Table 10-5. The data presented in the table is the mean value of the 5 subjects. It is indicated that in resting before running, the maximum pressure value (1.479 Kpa) appears in the shoulder area, and the second highest pressure is at hips (1.417 Kpa). The minimum pressure value is found in back waist (0.949 Kpa), and the second lowest pressure is in front waist (1.029 Kpa). When subjects run, pressures of 14 locations increase, except the back neck and the shoulder areas. Locations of chest (2.440 Kpa), hips (1.770 Kpa), elbow (2.527 Kpa) and knee (3.478 Kpa) have significant increases. In running state, knee has the maximum pressure value among the 16 locations, and the hips rank the second. When wearers finish running and back to rest state, the pressure values in all 16 locations decrease, which are smaller than the values before running exercise.

Table 10-5 Mean values of the maximum pressures in the 16 locations of one-piece running wear with just-fit design

Unit: Kpa

Body Parts	Rest before running		Running		Rest after running	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Front neck	1.163	0.007	1.296	0.271	1.143	0.005
Back neck	1.223	0.071	1.170	0.050	1.189	0.042
Shoulder	1.479	0.017	1.420	0.021	1.439	0.145
Chest	1.261	0.026	2.440	0.041	1.258	0.006
Scapular	1.203	0.143	1.332	0.016	1.172	0.053
Front waist	1.029	0.040	1.119	0.003	0.982	0.013
Back waist	0.949	0.016	0.960	0.011	0.947	0.013
Hips	1.417	0.194	1.770	0.011	1.360	0.087
Upper arm	1.215	0.064	1.421	0.007	1.214	0.012
Elbow	1.315	0.011	2.527	0.061	1.289	0.040
Forearm	1.156	0.098	1.321	0.065	1.148	0.042
Front thigh	1.142	.0342	1.889	0.021	1.140	0.222
Back thigh	1.224	0.013	1.651	0.042	1.207	0.006
Knee	1.363	0.141	3.478	0.143	1.362	0.050
Front calf	1.170	0.049	1.688	0.045	1.119	0.010
Back calf	1.222	0.050	1.453	0.010	1.200	0.006

10.3.2.2 One-piece running wear with 20% tight-fit design

The maximum pressure values in the 16 locations of the running wear made of dynamic patterns with 20% tight-fit design are shown in Table 10-6. It is indicated that the shoulder area has the maximum pressure value (1.400 Kpa) in rest before running, and the knee ranks the second (1.344 Kpa). The back waist has the minimum pressure value (0.949 Kpa) and the second is the front neck (0.991 Kpa). In running state, the knee area has the most significant increase, and the pressure value (3.385 Kpa) is the maximum among the 16 locations. In addition, the elbow area also has significant increase and its value is 2.290 Kpa. In rest after running, all values in the 16 locations resume to the values in rest before running. Among which, pressure values in 12 locations except scapular, front waist, upper arm and back calf are smaller than in rest before running state. Location of shoulder still had the maximum pressure value (1.370 Kpa) and back waist had the minimum pressure value (0.948 Kpa).

Table 10-6 Mean values of the maximum pressures in the 16 locations of one-piece running wear with 20% tight-fit design

Unit: Kpa

Body Parts	Rest before running		Running		Rest after running	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Front neck	0.991	0.024	1.154	0.008	0.989	0.013
Back neck	1.037	0.077	0.967	0.009	1.007	0.006
Shoulder	1.400	0.048	1.378	0.079	1.370	0.020
Chest	1.111	0.069	2.314	0.012	1.113	0.002
Scapular	1.136	0.053	1.256	0.072	1.110	0.007
Front waist	1.095	0.071	1.178	0.019	1.112	0.008
Back waist	0.949	0.015	0.962	0.007	0.946	0.0109
Hips	1.337	0.128	1.670	0.016	1.360	0.014
Upper arm	1.210	0.033	1.406	0.010	1.211	0.014
Elbow	1.293	0.023	2.290	0.006	1.278	0.002

Forearm	1.189	0.026	1.299	0.009	1.164	0.005
Front thigh	1.159	0.034	1.783	0.015	1.148	0.003
Back thigh	1.152	0.090	1.601	0.023	1.105	0.004
Knee	1.344	0.028	3.385	0.054	1.341	0.006
Front calf	1.097	0.051	1.567	0.020	1.113	0.011
Back calf	1.188	0.041	1.354	0.036	1.192	0.058

10.3.2.3 One-piece running wear with 40% tight-fit design

The maximum pressure values in the 16 locations of the running wear made of dynamic patterns with 40% tight-fit design are shown in Table 10-7. When subjects are at rest before running, all pressure values in the 16 locations are more than 1.00Kpa. Among which, the knee area has the maximum pressure (1.989 Kpa) and the hips rank the second (1.801 Kpa). Back waist has the minimum pressure (1.046 Kpa). When subjects run, all values in the 16 locations increase, especially in the locations of knee (3.819 Kpa), elbow (2.978 Kpa), hips (3.145), front thigh (2.676 Kpa) and chest (2.545 Kpa). Knee has the maximum pressure, and the pressure value in legs has significant increase. When subjects finish running, all pressure values in the 16 locations decrease which are smaller than the values of rest before running.

Table 10-7 Mean values of the maximum pressures in the 16 location of one-piece running wear with 40% tight-fit design

Unit: Kpa

Body Parts	Rest before running		Running		Rest after running	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Front neck	1.343	0.061	1.411	0.009	1.313	0.013

Back neck	1.330	0.078	1.384	0.012	1.323	0.009
Shoulder	1.561	0.014	1.589	0.011	1.558	0.006
Chest	1.340	0.035	2.545	0.050	1.410	0.011
Scapular	1.323	0.009	1.465	0.008	1.301	0.007
Front waist	1.095	0.025	1.224	0.011	1.021	0.021
Back waist	1.046	0.043	1.088	0.013	1.006	0.004
Hips	1.801	0.049	3.145	0.011	1.674	0.008
Upper arm	1.414	0.051	1.989	0.007	1.365	0.016
Elbow	1.764	0.008	2.978	0.066	1.751	0.014
Forearm	1.400	0.008	1.681	0.009	1.381	0.012
Front thigh	1.465	0.025	2.676	0.023	1.444	0.005
Back thigh	1.376	0.018	2.531	0.042	1.370	0.009
Knee	1.989	0.072	3.819	0.006	1.990	0.010
Front calf	1.436	0.062	2.442	0.005	1.366	0.005
Back calf	1.374	0.039	2.395	0.010	1.351	0.014

10.3.2.4 One-piece running wear with 60% tight-fit design

The maximum pressure values in the 16 locations of the running wear made of dynamic patterns with 60% tight-fit design are shown in Table 10-8. At rest before running, all values in the 16 locations are more than 1.120 Kpa. Knee has the maximum pressure (3.079 Kpa) and elbow ranks the second (2.657 Kpa). In running state, all values in the 16 locations increase. Among which, the values at arms and legs have significant increase in addition to knee, elbow, hips, chest. The knee area has the maximum pressure (4.417 Kpa). After running, all values in the 16 locations decrease which are smaller than the values at rest before running.

Table 10-8 Mean values of the maximum pressures in the 16 location of one-piece running wear with 60% tight-fit design

Unit: Kpa

Body Parts	Rest before running		Running		Rest after running	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Front neck	1.613	0.032	1.715	0.009	1.562	0.022
Back neck	1.630	0.025	1.656	0.012	1.613	0.015
Shoulder	2.133	0.038	2.346	0.032	2.132	0.047
Chest	1.742	0.016	3.061	0.037	1.727	0.135
Scapular	1.636	0.010	1.786	0.007	1.627	0.004
Front waist	1.558	0.039	1.644	0.013	1.545	0.004
Back waist	1.123	0.009	1.140	0.040	1.119	0.006
Hips	2.040	0.008	3.619	0.006	1.841	0.353
Upper arm	1.726	0.020	2.173	0.051	1.692	0.042
Elbow	2.657	0.011	4.058	0.036	2.557	0.005
Forearm	1.668	0.008	2.155	0.0036	1.664	0.023
Front thigh	1.710	0.008	2.863	0.002	1.668	0.006
Back thigh	1.710	0.050	2.644	0.008	1.673	0.020
Knee	3.079	0.063	4.417	0.135	2.896	0.011
Front calf	1.683	0.020	2.570	0.027	1.622	0.094
Back calf	1.644	0.055	2.464	0.160	1.643	0.007

10.4 Analyses and Discussions

10.4.1 Comparisons of Running Wear with Different Fit Designs on Subjective Sensations of the Ergonomic Wearing Comfort

- ***In walking state***

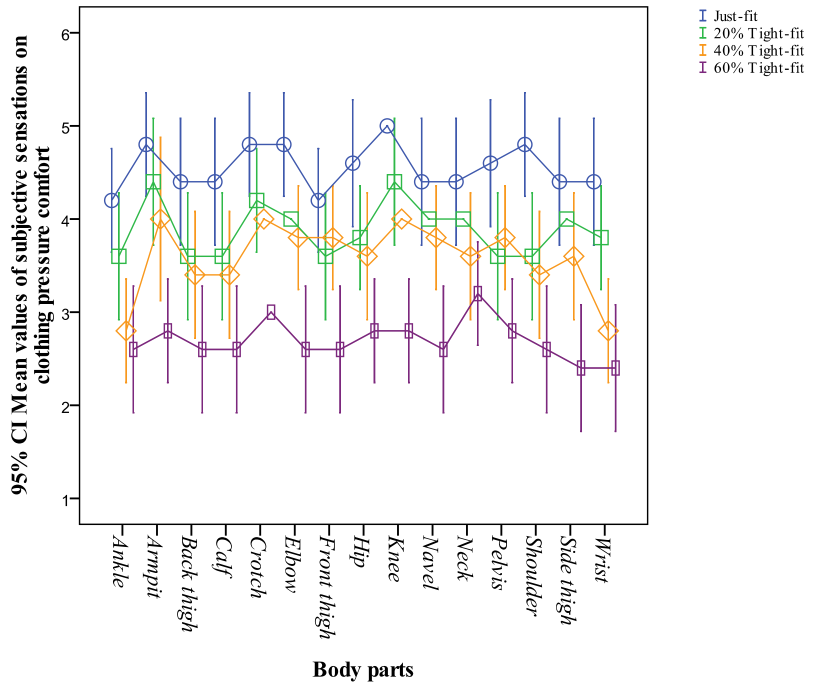


Figure 10-18 Mean values of subjective sensation towards clothing pressure comfort for running wear with different fit designs in the state of walking

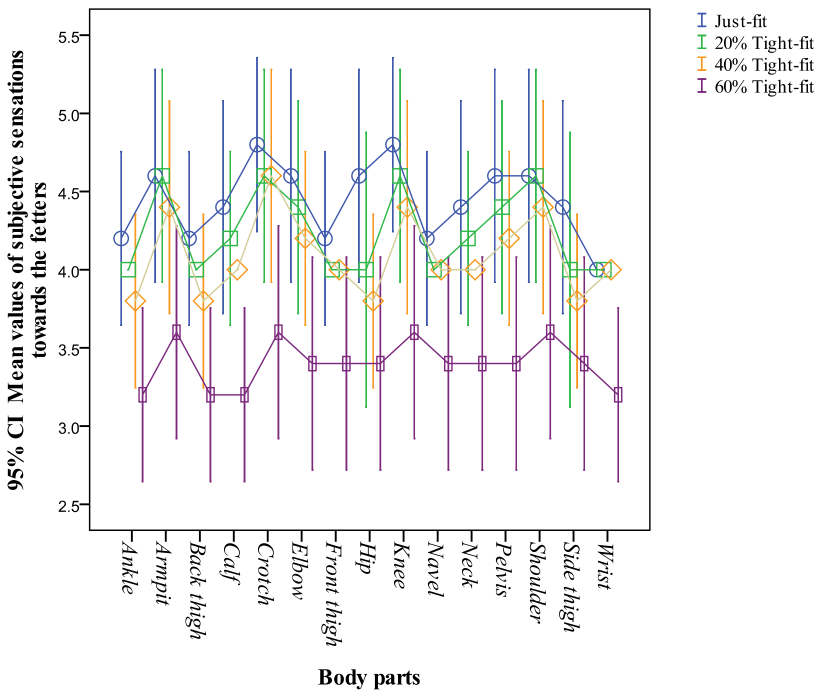


Figure 10-19 Mean values of subjective sensation towards the fetters of the running wear with different fit designs in the state of walking

Figures 10-18 and 10-19 compare the mean values of the subjective sensations on clothing pressure comfort and the fetters of the running wear with just-fit, 20% tight-fit, 40% tight-fit and 60% tight-fit designs in the state of walking. As shown in Figure 10-18, the running wear with just-fit design is the most comfortable garment in terms of clothing pressure because this fit design applied the maximum wearing ease. By reducing the wearing ease values, the ratings on comfort in terms of clothing pressure decrease. Except the wrist and the ankle, the running wear with 20% and 40% tight-fit designs are reasonably comfortable in terms of clothing pressure. For the running wear with 60% tight-fit design, subjects rate it as uncomfortable in most of the body parts except the neck.

Figure 10-19 shows that subjects are satisfied with the freedom of movements provided by the running wear with different fit designs developed based on the dynamic patterns. This proves that the dynamic patterns have good ergonomic functional design which can meet the physical requirements of the wearers for normal walking.

- ***In running state***

Figures 10-20 and 10-21 shows that the mean values of subjective sensations towards clothing pressure and the fetters of the running wear with just-fit, 20% tight-fit, 40% tight-fit and 60% tight-fit designs in the state of running. **Error! Reference source not found.** shows that running wear with just-fit, 20% and 40% tight-fit designs have similar performance as that in the walking state. For running wear with 60% tight-fit design, the clothing pressure is not comfortable to the subjects in all body parts except the neck and crotch.

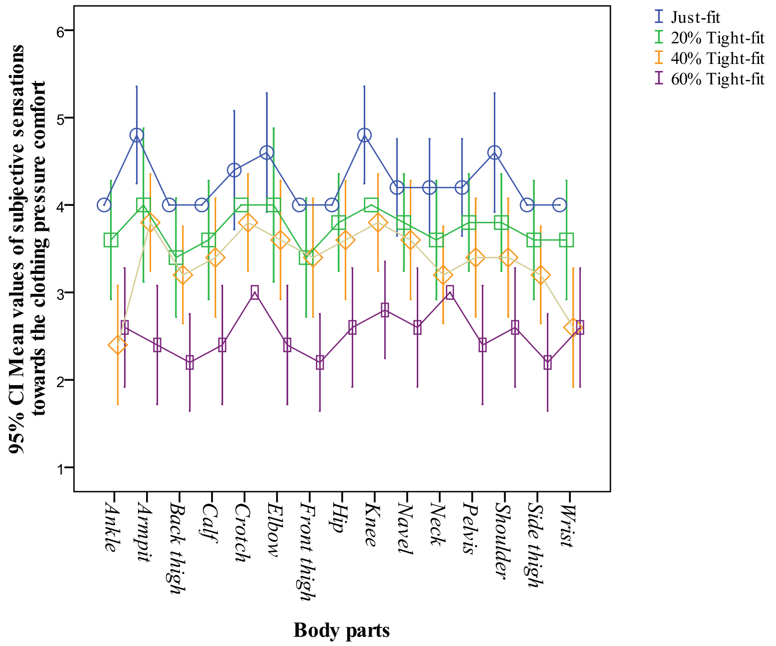


Figure 10-20 Mean values of subjective sensation towards the clothing pressure comfort of running wear with different fit designs in the state of running

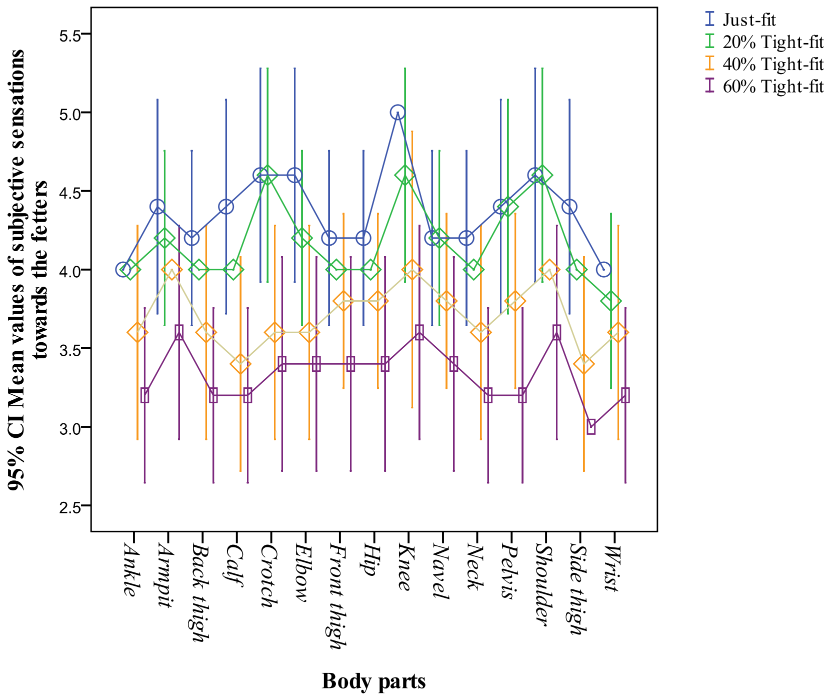


Figure 10-21 Mean values of subjective sensation towards the fetters of the running wear with different fit designs in the state of running

Figure 10-21 shows that the running wear with different fit designs developed based on the dynamic patterns can provide good freedom of movement to wearers. It further confirmed that the dynamic patterns have good ergonomic functional design which can meet the physical requirements of the wearers in the running state.

10.4.2 Comparisons of Running Wear with Different Fit Designs on Wearing Pressure Comfort

- ***In the stage of rest before running***

Figure 10-22 shows that the maximum pressure distributions of the 16 locations for running wear with just-fit, 20% tight-fit, 40% tight-fit and 60% tight-fit designs in the stage of rest before running. It can be shown that knee, elbow, hips and shoulder have larger pressures compared with other locations. In running wear with all four fit designs, knee has the maximum pressure value. In running wear with 20% and 60% tight-fit design, elbow also has high pressure value. In all running wear samples, back waist has the minimum value of pressure and the second lowest is the front waist. In addition, running wear with 60% tight-fit design has the largest pressures values in all 16 locations compared with other samples and the second is running wear with 40% tight-fit. The running wear with 20% tight-fit design has the smallest pressure values.

Previous studies reported that suitable clothing pressures for ergonomic comfort are between 1.96 to 3.92 Kpa (Song & Feng, 2006, Chen & Gan, 2005). Comparing the data in the tables of Section 10.3.2, it can be found that wearer would feel comfort except at the back waist when he wears running wear with 60% tight-fit design. For running wear with 40% tight-fit design, all locations has suitable pressure values except the front neck, back neck, shoulder, scapular, front and back waist, which the pressure values are under the preferred value. In running wear with just-fit and 20% tight-fit designs, wearer has no significant feeling on the clothing pressure. All in all, wearers have no excess tight feeling when wear the four kinds of running wear in rest stage.

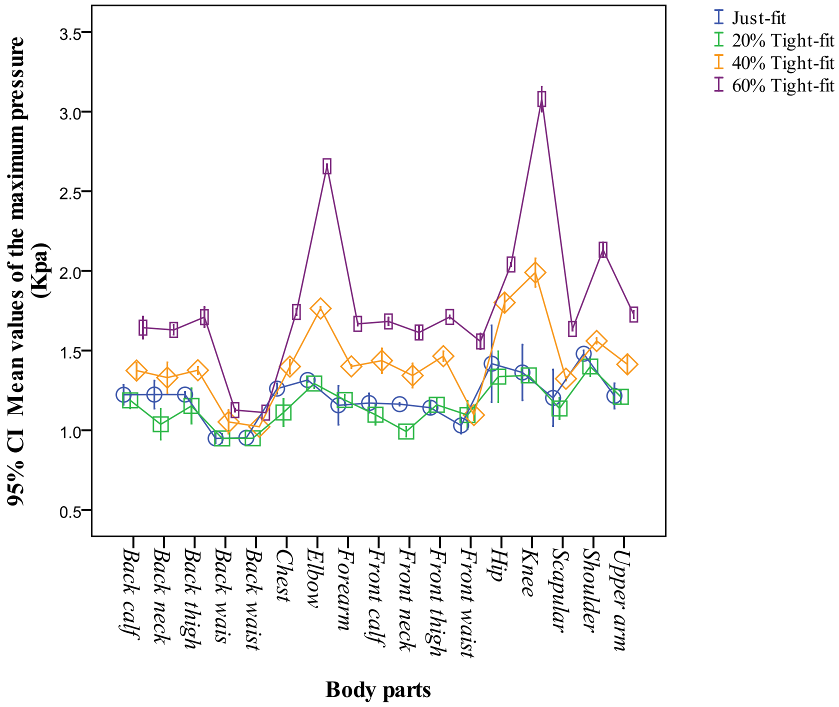


Figure 10-22 The maximum pressure of the running wear with different fit designs in the stage of rest before running

- ***In running state***

Figure 10-23 shows the maximum pressure distributions of the 16 locations in running wear with just-fit, 20% tight-fit, 40% tight-fit and 60% tight-fit designs in running state. It can be found that when wearing the running wear with 60% tight-fit design, people experience excess pressures at the locations of knee and elbow because its values are more than 4.00 Kpa, which would influence people's performance. When wearing running wear with just-fit and 20% tight-fit design, runner experiences comfortable clothing pressure at the locations of chest, elbow, hips, front thigh, back thigh, knee as well as front calf. However, other locations are too loose to wearer because he does not experience the desired clothing pressure. When wearing running wear with 40% tight-fit design, wearer feels comfortable at most locations except the front neck, back neck, scapular, front waist and back waist. By comparing the results of the four fit designs, it can be summarised that running wear with 20% to 40% tight-fit designs are good tight-fit levels for providing people good ergonomic comfort. However, smaller pressure values of front and back waist in running wear with 20-40% tight-fit design indicate tight-fit level needs to be increased to keep the waist straight in running. Therefore, 40% tight-fit design may be a better choice in this regard.

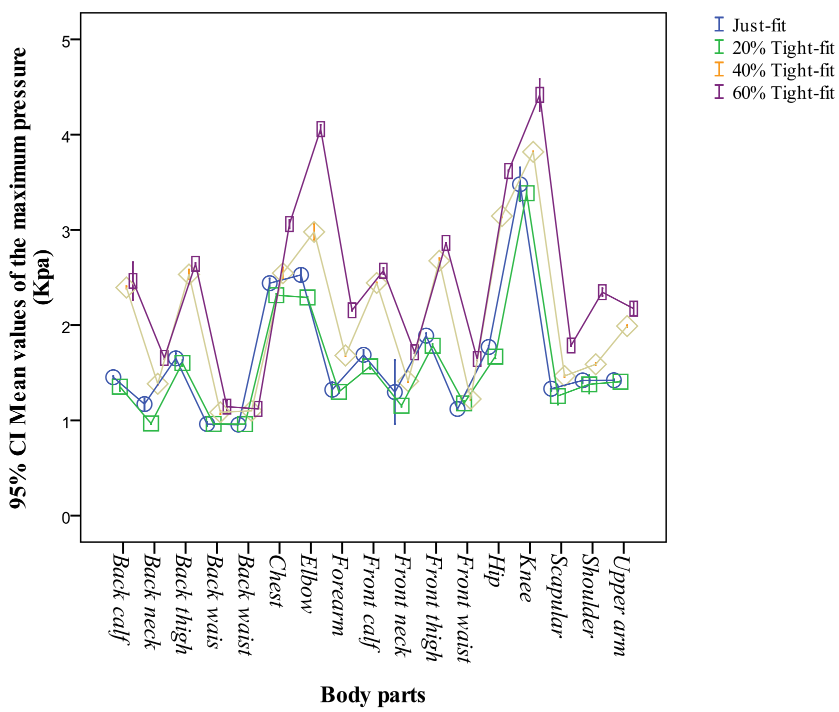


Figure 10-23 The maximum pressure of the running wear with different fit designs in running state

- ***In the stage of rest after running***

Figure 10-24 shows that the maximum pressure distributions of all the 16 locations in running wear with just-fit, 20% tight-fit, 40% tight-fit and 60% tight-fit designs in the stage of rest after running. It can be found that all values of the 16 locations in running wear with different fit designs decrease and its values are similar to that in the stage of rest before running. Running wear with 60% tight-fit design still has the largest values of clothing pressure and running wear with 20% tight-fit design has the smallest pressure values except at the location of back waist.

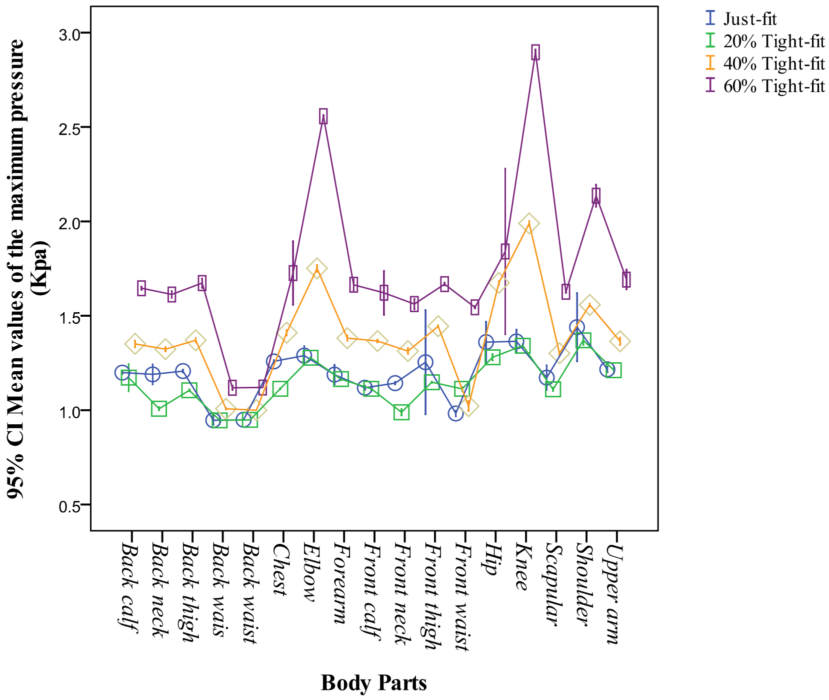


Figure 10-24 The maximum pressure of the running wear with different fit designs in the stage of rest after running

10.4.3 Dynamic Pattern Construction System

The experimental results have proved that the running wear made of dynamic patterns provide good ergonomic wearing comfort, especially the running wear with 20% to 40% tight-fit design. Therefore, dynamic pattern construction method is an effective approach for high performance running wear clothing pattern design, and the method is summarised in Figure 10-25.

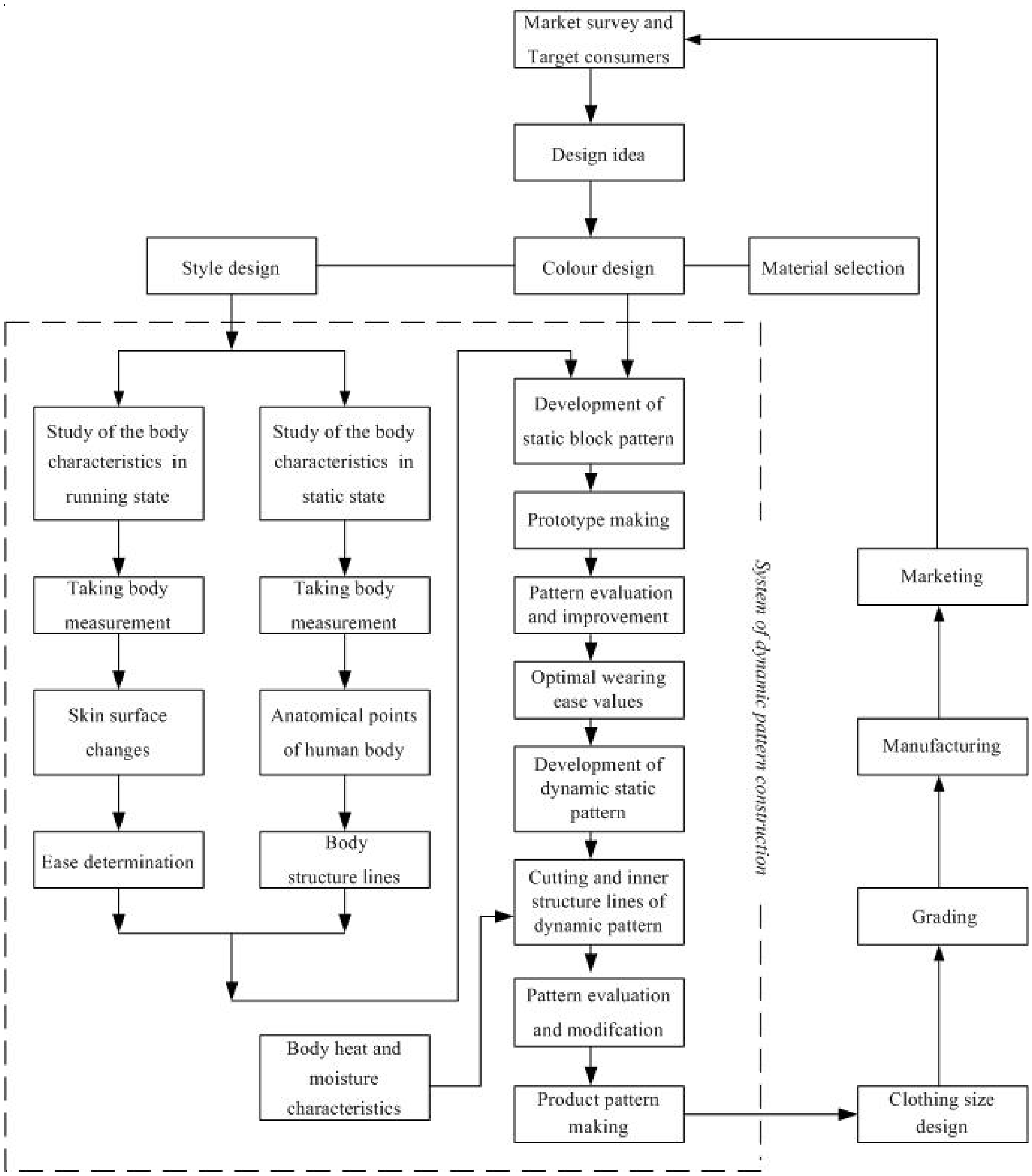


Figure 10-25 Dynamic pattern construction method for running wear

10.5 Conclusions

By wearing trial experiments, the performance of ergonomic clothing function for the running wear made of dynamic patterns with different fit designs have been evaluated subjectively by questionnaire survey and objectively by collecting clothing pressure data with pressure sensor. A number of conclusions can be drawn.

Firstly, the results of the questionnaire survey reveal that running wear with 20% and 40% tight-fit designs are appropriate tight-fit design for good clothing pressure comfort. It is also proved that all four kinds of running wear with dynamic patterns provide good movement freedom for walking and running.

Secondly, the clothing pressures at the 16 locations of the running wear with just-fit, 20%, 40% and 60% tight-fit designs indicate that knee has the biggest clothing pressures in running and back waist has the smallest values.

Thirdly, the objective clothing pressure data revels that running wear with 20% and 40% tight-fit designs can exert comfortable clothing pressure to wearers in running.

Fourthly, experimental results of both the subjective and objective evaluations have proved that running wear with 20% to 40% tight-fit design is the most suitable tight-fit design for running wear made of dynamic patterns, which good ergonomic wearing comfort is guaranteed.

Finally, a systematic system for dynamic pattern construction have been concluded.

CHAPTER 11 CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

11.1 Conclusions

In this thesis, a new systematic pattern engineering approach, called the dynamic pattern construction, has been developed for high-performance tight-fit running wear pattern design. The method integrates knowledge from multiple disciplines, including anthropometry study in static and dynamic running states, static and dynamic block pattern designs, physical and physiological analyses of the human body in running state, textile material property investigation, and evaluation of clothing function.

Well-designed running wear are essential for runners' health, which should provide excellent ergonomic wearing comfort，thermo-physiological wearing comfort, skin sensorial comfort as well as psychological comfort. Among the many influential factors of garment's functional performance, pattern construction and fit design are the two most important factors. However, traditional pattern construction methods are developed based on the body's geometric characteristics and measurements in static state, which are not suitable for high-performance sportswear design. There are limited studies regarding the impacts of fit design on sportswear functional performance. The purpose of this research is to fill the knowledge gap and develop a systematic pattern construction method for high-performance running wear. By conducting a series of theoretical study and experimental investigation, the purposed objectives of the study have been achieved and summarised as follows:

(i) To develop fitted block patterns based on body measurements in static state, and scientifically evaluate fit performance of the fitted block patterns.

In Chapters 3 and 4, the objective has been achieved by well-planned experimental investigation and newly proposed pattern development and evaluation methods. Body measurements have been collected by the 3D body scanning technique, which provides precise size information for static block development. Moreover, the anatomical points and body structure lines acquired on scanned body surfaces can provide good references to construct the framework of static block patterns. A new approach, by reflection method, has been developed to construct static block patterns with just-fit design. A new objective fit evolution method has also been introduced to analyse the fit of the static block patterns by integrating 3D body scanning and reverse engineering techniques.

(ii) To conduct anthropometric survey on human body in static state, dynamic postures and running progress, so as to systematically analyse the changes of body measurement in dynamic movements.

The objective has been investigated in Chapters 5 and 6. Body measurements in motion states are traditionally difficult to obtain, and new methods have been proposed in this project for the evaluation of body dimensional changes. First of all, traditional manual method with measuring tape and gonimeter has been used to collect body measurements in various dynamic postures. Next, body motion capture system has been proposed for measuring body sizes in motion state. The experimental results supported the use of these new methods. It is found that there are significant changes in body measurements when performing different dynamic postures and in running progress. The findings are summarised as follows:

- Among 30 body measurement, 24 key measurements have been identified to describe human body characteristics in static state.
- It has been found that the wrist, ankle and neck base girths remain unchanged in different dynamic postures, while the elbow girth, across back width and outside arm length vary significantly. Twenty-one out of the 24 key measurements are influenced by dynamic postures except the neck base girth, ankle girth and crotch depth.
- It has been found that the neck base girth, wrist girth and ankle girth measurements do not change in running. Eleven body measurements, including chest girth, waist girth, calf girth, across shoulder width, across back width, across chest width, front waist length, back waist length, the 7^{th} cervical to waist length, underarm to waist length and inside arm length, have smaller changes in running state than in dynamic postures. The other 16 body measurements have larger changes in running state as compared to in dynamic postures. Among which, the elbow has the largest changes in running state.

Based on the changes of body measurement in dynamic postures and running state, wearing ease values for running wear design can be determined.

(iii) To develop a scientific understanding of the physical characteristics of the human body in running motion

This objective has been investigated in Chapter 7. A method has been developed to measure the skin surface changes of the human body in running state.

The relationship among physical characteristics of the human body in running state and pattern structure design has been analysed, and the results are summarised as follows:

- When a person runs, different parts of the body skin change differently. A distribution map on the skin surface change has been developed.
- According to the distribution maps of the body skin surface changes and with reference to the literature on body heat and moisture distribution, structure lines and internal lines of the running wear have been designed.

(iv) To establish a new method to construct dynamic block pattern based on fitted block patterns, optimised wearing ease, and analysis result of physical- body characteristics in running state.

Based on the literature review in Chapter 2 and research findings obtained in Chapters 3, 4, 5, 6 and 7, dynamic pattern construction method for one-piece running wear with just-fit design have been proposed and explained in Chapter 8. Ten pattern components are included: front shirt, back shirt, waist, arm-shoulder sleeve, side-shirt sleeve, inner sleeve, front trousers, back trousers, side trousers and inner trousers. The dynamic pattern construction procedures are summarised as follows:

- Collecting body measurements in static state, dynamic posture and running state.
- Analysing body geometric feature and determining anatomical points and body structure lines.
- Constructing static block patterns with just-fit design. Modifying and improving the patterns based on fit assessment.

- Designing the optimal wearing ease values based on the changes of body measurement in dynamic postures and running state.
- Incorporating desired wearing ease values to the corresponding positions of the static block patterns and constructing dynamic block patterns.
- Understanding physical characteristics of the human body in running state. Determining the structure lines of dynamic patterns and internal lines of each piece based on skin surface change and body heat distributions.
- Constructing dynamic patterns of the running wear with just-fit design according to the acquired dynamic block patterns and preferred structure lines design.

(v) To study the mechanical and physical properties of elastic fabrics, and understand the relationship between material properties and garment fit.

This objective has been investigated in Chapter 9 by well-planned experimental work. A number of material properties, including basic, mechanical and physical properties of fabrics under different stretching levels, have been tested so as to give systematic comparison on the properties of four widely used elastic knitted fabrics. Based on the testing results and body physiological requirements in running state, the application of elastic fabrics in final dynamic patterns of the running wear has been determined. The major findings are summarised as follows:

- Tensile energy (WT), tensile strain (EMT), shearing (G), bending rigidity (B) as well as double stretching capacity (X-F) are indices that are highly correlated to the clothing shape and deformation. Air resistance, thermal conductivity, thermal insulation, water vapour permeability and overall moisture management capacity are key indices that are highly correlated to the performance of running wear on thermoregulation.

- The four elastic knitted fabrics exhibit different changing characteristics on physical properties at different levels of stretching. Materials being stretched 20-40% are suitable for tight-fit design of high-performance sportswear, which provides good thermoregulation and ensures clothing comfort.
- Based on the material properties of elastic knitted fabrics, the application of the four fabrics to different parts of the running wear have been suggested: rib knitted fabric is suitable for back waist, neck, wrist, ankle, parts of limb, around joints, as well as hips; big mesh fabric is suitable for centre front chest, back chest and armhole; small mesh knitted fabric is suitable for thigh (inner and outer), calf (front), knee joint (back) and elbow joint (inner); and plain knitted fabric is suitable for shoulder areas and the other remaining parts.

(vi) To evaluate the performance of tight-fit running wear in terms of ergonomic wearing comfort by subjective and objective methods.

This objective has been investigated in Chapter 10. Subjective evaluation by wearing trial using questionnaire survey and objective evaluation by measuring clothing pressure with pressure sensor have been used to evaluate the functional performance of the running wear. The results of the questionnaire survey has indicated that the running wear developed using dynamic patterns provide good ergonomic wearing comfort to wearers in terms of both clothing pressure and freedom of body movement for walking and running. Except the 60% tight-fit design, running wear with just-fit, 20% and 40% tight-fit designs are comfortable in terms of clothing pressure. The results of objective evaluation by clothing pressure measurement using pressure sensor has revealed that running wear with different tight-fit designs exert different clothing pressures on the body skin. Among the four tight-fit designs, running wear with 20% to 40% tight-fit design can provide comfortable clothing pressure and at the same time fulfil the freedom requirement of human body in running state. All research results prove that running wear developed based on the proposed dynamic patterns has good performance on ergonomic wearing comfort and the 40% tight-fit design is regarded as the best tight-fit design for running wear

(vii) To propose a scientific system to generate functional dynamic patterns for tight-fit running wear.

A scientific dynamic pattern construction method has been developed by integrating all the methodologies proposed in different chapters. To construct dynamic patterns, static block patterns with just-fit design are first constructed based on physical characteristics of the human body in static state. The fit of the resulted patterns are evaluated for fit improvement. The changes of body measurements in dynamic postures and running state and the optimal wearing ease values are decided. The dynamic block patterns are generated by incorporating the optimal eases to the fitted static block patterns. By analysing skin surface changes and integrating heat-moisture characteristics of the body in running state, the cutting lines and internal structure lines of each pattern piece are determined. With dynamic block patterns, preferred cutting line and internal structure line designs, dynamic patterns of running wear are constructed. The resulted running wear has been evaluated by subjective and objective methods through wearing trial experiments. It has been shown that running wear developed by the proposed dynamic patterns can meet physical body requirements of the runner in running state. Finally, dynamic patterns of running wear with different fit designs have been compared.

The research findings in this study enhance the knowledge of pattern engineering technology for functional tight-fit running wear and propose a new systematic dynamic pattern construction method. The proposed method is applicable not only for the pattern design of high-performance running wear, but also for the design of other high-performance sportswear or products, such as protective apparels, fitness garments and underwear. The research findings are valuable to sportswear designers, product developers, fabric and garment manufacturers, and those organizations dealing with sports products.

11.2 Recommendations for Future Work

A systematic pattern construction method for dynamic patterns of high-performance running wear has been developed in this thesis. The activities where further research can hopefully expand the results obtained in this thesis are outlined as follows:

(1) Increase the sample sizes of experiment for physical characteristics investigation in static and running states. By collecting more data of human subject's physical characteristics, it can improve the accuracy and practicability of the dynamic pattern construction method.

(2) The investigation of body measurement changes in running state using the body motion capture system needs to be further improved. Smaller size markers should be fixed on the body skin in order to improve the accuracy of data acquisition, so as the accuracy of derived wearing ease values in dynamic patterns.

(3) The thermal-physiological characteristics of the body in running, under different environment conditions, should be investigated by carefully planned experiments. The findings can be used to fine tune the internal structural line design and application of different fabric materials. The overall performance of the thermal-physiological comfort should be evaluated by wearing trial experiments.

(4) In addition to running exercise, physical-physiological characteristics of human body in different sports, such as tennis and cycling, are needed to be measured and analysed. By acquiring more data, the dynamic pattern construction method can be applied for the development of different high-performance sportswear.

APPENDICES

APPENDIX I. SWATCHES OF THE FOUR ELASTIC KNITTED FABRICS

I-1 Rib knitted fabric swatch (10cm × 10cm)

Fibre content: 98% Nylon and 2% Elastomeric yarn
Stich numbers (Warp/Weft): 80/60

I-2 Plain knitted fabric swatch (10cm × 10cm)

Fibre content: 98% Nylon and 2% Elastomeric yarn
Stich numbers (Warp/Weft): 70/70

I-3 Big mesh knitted fabric swatch (10cm × 10cm)

Fibre content: 98% Nylon and 2% Elastomeric yarn
Stich numbers (Warp/Weft): 100/100

I-4 Small mesh knitted fabric swatch (10cm × 10cm)

Fibre content: 98% Nylon and 2% Elastomeric yarn
Stich numbers (Warp/Weft): 84/70

APPENDIX II. RAW DATA FOR BODY MEASUREMENTS OF THE FIVE SUBJECTS IN STATIC STATE (CHAPTER 3)

Table II-1 Measuring results of five subjects on stature, weight and BMI

	Subject				
	1	2	3	4	5
Stature (cm)	170.00	172.00	175.00	174.00	175.00
Weight (kg)	65.00	65.00	65.00	69.00	68.00
BMI	22.49	21.97	21.22	22.79	22.20

Table II-2 Measuring results of five subjects on girth measurements

Unit: cm

Items	Subject				
	1	2	3	4	5
Neck Base Girth	40.17	39.32	40.01	40.35	39.78
Chest Girth	97.67	93.96	96.82	95.95	97.98
Armscye Girth	38.91	39.68	42.76	42.01	44.15
Waist Girth	77.65	79.49	78.63	81.68	78.47
Hip Girth	93.65	94.36	98.85	98.66	94.22
Upper Arm Girth	24.97	27.24	28.49	27.98	26.67
Elbow Girth	24.55	24.81	24.61	24.52	24.82
Forearm Girth	24.47	25.48	25.46	24.64	24.56
Wrist Girth	15.80	16.58	16.39	16.14	15.79
Thigh Girth	55.87	52.87	57.67	56.58	52.60
Mid-thigh Girth	43.98	46.74	45.13	49.66	45.37
Knee Girth	36.36	38.28	36.03	38.77	36.16
Calf Girth	36.72	39.03	35.34	38.12	36.28
Minimum Leg Girth	21.55	23.46	21.13	22.63	21.77
Ankle Girth	24.56	26.93	24.26	25.31	25.01

Table II-3 Measuring results of five subjects on height measurements

Unit: cm

Items	Subject				
	1	2	3	4	5
Front Neck Base Height	140.89	140.02	141.31	140.11	143.07
Side Neck Height	144.14	144.02	147.31	146.11	147.07
Back Neck Height	143.39	143.77	146.81	145.86	146.32
Long Shoulder Height	138.14	139.14	140.81	139.74	141.82
Armscye Height	128.93	129.22	130.99	129.92	130.87

Across Back Height	132.03	132.05	132.70	132.44	133.55
Across Front Height	134.63	134.22	135.49	134.82	135.77
Chest Height	128.39	129.02	130.31	129.86	130.82
Chest Point Height	122.89	123.52	126.56	125.86	126.82
Waist Height	96.89	97.02	102.56	98.36	102.32
Hip Height	82.89	83.52	87.56	84.36	86.32
Crotch Height	77.39	77.52	82.56	78.36	82.32
Max-Thigh Height	77.09	71.32	82.66	78.46	82.02
Mid-Thigh Height	63.89	60.27	61.31	60.86	60.33
Knee Height	45.39	46.02	48.06	47.36	46.33
Calf Height	31.39	32.52	33.06	32.86	33.83
Minimum Leg Height	11.63	12.63	12.00	12.50	12.75
Ankle Height Outside	7.13	8.25	7.25	8.00	7.63
Crown Height	10.57	10.71	10.98	10.83	12.63

Table II-4 Measuring results of five subjects on depth and length measurements

Unit: cm

Items	Subject				
	1	2	3	4	5
Front Neck Depth	6.25	6.00	5.75	6.00	6.75
Back Neck Depth	1.25	1.25	1.50	1.75	1.25
Back Waist Length	49.04	49.90	49.70	50.86	50.35
Front Waist Length	44.77	44.86	45.58	46.19	46.10
Outside Leg Length	101.56	102.41	103.61	103.05	102.60
Underarm Length	45.10	45.02	46.29	45.02	44.07
Central Arm Length	53.74	55.08	56.27	55.12	53.69
Back Neck To Elbow	56.59	52.20	54.82	53.71	53.71
Total Crotch Length	58.17	61.66	72.65	64.17	68.83
Shoulder Length	12.81	12.61	13.32	12.93	12.16
Shoulder Slope	5.17	4.52	5.58	5.29	4.97

Table II-5 Measuring results of five subjects on width measurements

Unit: cm

Items	Subject				
	1	2	3	4	5
Across Shoulder Width	39.09	40.59	40.55	40.08	40.94
Across Back Width	38.04	39.45	39.38	39.22	39.43
Across Chest Width	37.16	38.80	38.33	38.41	38.87
Chest Point to Chest Point Width	19.73	17.23	22.62	20.51	14.95
Neck Width	11.84	12.12	12.50	12.65	13.01

APPENDIX III. RAW DATA FOR OBJECTIVE FIT EVALUATION OF STATIC BLOCK PATTERNS WITH JUST-FIT DESIGN (CHAPTER 4)

Table III-1 Changing values of body measurements with manual method and 3D body scanning system

Unit: cm

	subject				
	1	2	3	4	5
Chest	2.88	3.77	3.36	2.70	1.30
Waist	0.60	0.19	1.29	2.67	0.08
Hips	0.53	0.27	0.10	0.01	2.05
Neck_Base	-2.12	-0.01	-0.45	-0.70	-0.15
Upper_Arm	0.97	1.21	3.66	0.39	0.52
Elbow	0.74	0.88	1.50	1.05	0.68
Wrist	0.73	2.08	0.98	0.00	1.70
Mid- Thigh	0.64	1.32	0.82	0.02	0.46
Knee	0.92	1.73	0.91	0.93	0.99
Calf	1.50	0.55	0.46	0.65	0.74
Ankle	1.03	2.09	2.57	1.25	2.26

Table III-2 Changing values of body cross-section areas with 3D body scanning system and Rapidform software

Unit: cm^2

	Subjects				
	1	2	3	4	5
Chest	27.87	65.19	25.06	50.25	26.35
Waist	38.26	20.70	37.63	46.76	39.78
Hips	38.35	9.69	58.79	27.31	22.79
Neck Base	-4.66	-5.96	-1.40	-5.51	-3.02
Upper Arm	11.59	4.77	3.39	6.88	3.37
Elbow	5.01	2.54	5.54	4.27	7.11
Wrist	2.52	3.55	6.23	5.24	3.84
Mid-Thigh	12.03	1.60	6.77	14.83	12.29
Knee	11.70	2.14	7.41	5.59	7.46
Calf	8.41	3.87	4.58	3.62	3.94
Ankle	16.82	11.17	8.57	17.32	14.55

Table III-3 Changing values of body cross-section thickness with 3D body scanning system and Rapidform software

Unit: cm

	subjects				
	1	2	3	4	5
Chest	0.31	0.62	0.14	0.26	0.02
Waist	1.41	1.1	1.78	0.96	1.52
Hips	0.99	0.85	0.73	0.22	0.59
Neck Base	-0.04	-0.08	0.1	0.15	0.14
Upper Arm	0.28	0.22	0.49	-0.02	0.2
Elbow	0.13	0.34	0.56	-0.02	0.44
Wrist	0.51	0.54	1.07	-0.07	0.41
Mid -Thigh	-0.02	0.32	0.22	0.24	0.5
Knee	-0.02	0.32	0.27	0.15	0.26
Calf	-0.05	0.25	0.35	0.31	0.34
Ankle	0.35	0.46	0.15	-0.06	0.46

Table III-4 Changing values of body cross-section width with 3D body scanning system and Rapidform software

Unit: cm

	Subjects				
	1	2	3	4	5
Chest	1.68	3.09	1.99	2.88	2.09
Waist	0.14	0.38	0.99	0.1	0.04
Hips	0.87	0.18	0.45	0.05	0.48
Neck Base	-0.35	-0.42	-0.38	-0.24	-0.07
Upper Arm	0.89	0.8	-0.02	1.06	0.28
Elbow	0.97	0.33	0.21	0.09	0.51
Wrist	1.29	0.67	0.46	-0.44	0.42
Mid-Thigh	0.41	0.63	0.68	0.59	0.09
Knee	0.34	0.39	0.61	0.38	0.38
Calf	0.3	0.12	0.24	0.19	0.34
Ankle	0.91	0.81	0.33	-0.76	0.98

APPENDIX IV. RAW DATA FOR BODY MEASUREMENTS IN DYNAMIC POSTURES (CHAPTER 5)

Table IV-1 Changes of body measurement in dynamic postures of elbow and shoulder joints (1)

Unit: cm

postures	Neck base girth	Bust girth	Waist girth	Armscye girth	Upper-arm girth	Elbow girth	Across shoulder width	Across back width
a	0.0	3.0	4.0	-3.0	-1.0	-2.0	-4.0	3.0
a	0.0	2.0	0.0	-4.0	-1.0	0.0	-12.0	1.0
a	0.0	3.0	3.0	-8.0	-1.0	-1.0	-15.0	1.0
a	0.0	3.0	0.0	-2.0	0.0	0.0	-19.0	4.0
a	0.0	1.0	0.0	-1.0	0.0	0.0	-20.0	2.0
a	0.0	5.0	2.0	-3.0	-1.0	-1.0	-3.0	10.0
a	0.0	3.0	3.0	0.0	0.0	-1.0	-7.0	1.0
a	0.0	6.0	1.0	-5.0	-0.5	0.0	-14.0	10.0
a	0.0	2.5	5.0	-5.0	-0.5	0.0	-2.0	7.0
a	0.0	0.0	3.0	-6.0	-1.5	0.0	-2.0	9.0
b	0.0	0.0	2.0	4.0	1.0	0.0	-2.0	-4.0
b	0.0	1.0	0.0	4.0	1.0	0.0	-8.0	-9.0
b	0.0	-1.0	0.0	8.0	1.0	0.0	-1.0	-1.0
b	0.0	0.0	2.0	7.0	0.0	0.0	-1.0	-2.0
b	0.0	0.0	0.0	6.0	1.0	3.0	-1.0	-2.0
b	0.0	0.0	1.0	5.0	1.0	0.0	-1.0	-2.0
b	0.0	-2.0	1.0	4.0	2.0	0.0	0.0	-4.0
b	0.0	4.0	2.0	1.0	0.0	0.5	0.0	-1.0
b	0.0	0.0	2.0	1.0	0.0	0.0	-2.0	-1.0
b	0.0	-3.0	1.0	0.0	0.0	0.5	0.0	-2.0
c	0.0	0.0	2.0	0.0	1.0	0.0	1.0	2.0
c	0.0	-1.0	0.0	3.0	0.0	0.0	1.0	0.0
c	0.0	-1.0	0.0	1.0	1.0	1.0	1.0	0.0
c	0.0	0.0	0.0	5.0	0.0	0.0	0.0	0.0
c	0.0	2.0	0.0	2.0	1.0	3.0	2.0	3.0
c	0.0	-2.0	2.0	1.0	1.0	1.0	1.0	4.0
c	0.0	0.0	1.0	3.0	2.0	1.0	1.0	1.0
c	0.0	0.0	2.0	3.0	0.5	1.0	2.0	2.0
c	0.0	0.0	0.0	0.0	0.0	0.0	2.0	3.0
c	0.0	-4.0	1.0	2.0	0.5	0.5	1.0	0.0
d	0.0	-1.0	1.0	1.0	1.0	1.0	1.0	0.0
d	0.0	3.0	0.0	0.0	0.0	0.0	0.0	1.0
d	0.0	-1.0	0.0	0.0	0.0	0.0	0.0	0.0

d	0.0	-1.0	0.0	0.0	0.0	0.0	0.0	0.0
d	0.0	-1.0	1.0	0.0	0.0	1.0	0.0	1.0
d	0.0	-1.0	1.0	1.0	0.0	1.0	0.0	1.0
d	0.0	0.0	2.0	0.0	0.0	1.0	1.0	1.0
d	0.0	-1.0	0.0	0.0	0.0	0.5	1.0	3.0
d	0.0	-1.0	0.0	0.0	0.0	0.0	0.0	1.0
d	0.0	-4.0	2.0	0.0	0.5	1.0	0.0	0.0

Table IV-2 Changes of body measurement in dynamic postures of elbow and shoulder joints (2)

Unit: cm

postures	Across front width	Back waist length	Front waist length	7th-cervical to waist length	Under armhole point to waist length	Standard arm length	Hip girth	Thigh girth
a	-5.0	4.0	-8.0	4.0	6.0	2.0	0.0	0.0
a	-13.0	5.0	-1.0	4.0	11.0	1.0	5.0	1.0
a	-13.0	6.0	-4.0	5.0	11.0	3.0	0.0	0.0
a	-8.0	4.0	-1.0	5.0	10.0	6.0	1.0	0.0
a	-12.0	4.0	-3.0	4.0	9.0	1.0	1.0	0.0
a	-6.0	6.0	-7.0	5.0	4.0	6.0	0.0	0.5
a	-1.0	4.0	-4.0	6.0	5.0	2.0	5.0	0.0
a	-8.0	6.0	-6.0	5.0	7.0	0.0	1.0	0.0
a	-7.0	4.0	-6.0	4.0	2.0	6.0	4.0	0.0
a	-10.0	4.0	-6.0	4.0	3.0	5.0	2.0	0.0
b	3.0	-1.0	2.0	0.0	5.0	-8.0	-3.0	0.0
b	4.0	-2.0	5.0	-4.0	1.0	-6.0	0.0	0.0
b	9.0	-2.0	2.0	-1.0	4.0	-3.0	-1.0	0.0
b	1.0	-1.0	0.0	-1.0	1.0	-2.0	0.0	0.0
b	1.0	-2.0	2.0	-1.0	4.0	-7.0	0.0	0.0
b	3.0	-1.0	5.0	0.0	3.0	0.0	-1.0	0.5
b	1.0	-1.0	4.0	-1.0	2.0	-10.0	0.0	0.0
b	0.0	-1.0	0.0	-1.0	2.0	0.0	0.0	0.0
b	5.0	2.0	2.0	-1.0	2.0	-1.0	0.0	0.0
b	2.0	0.0	3.0	-1.0	1.0	-3.0	0.0	0.0
c	2.0	0.0	1.0	1.0	1.0	1.0	0.0	0.0
c	2.0	8.0	4.0	6.0	6.0	2.0	1.0	0.0
c	1.0	5.0	2.0	6.0	6.0	1.0	0.0	0.0
c	2.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
c	0.0	8.0	2.0	10.0	10.0	0.0	0.0	0.0
c	0.0	4.0	4.0	6.0	6.0	3.0	0.0	0.5
c	0.0	5.0	5.0	3.0	3.0	0.0	0.0	0.0

c	0.0	5.0	0.0	3.0	3.0	1.0	1.0	0.0
c	0.0	5.0	0.0	3.0	1.0	1.0	2.0	0.0
c	1.5	3.0	3.0	5.0	5.0	0.0	0.0	0.0
d	0.0	0.0	1.0	0.0	1.0	2.0	0.0	0.0
d	2.0	1.0	2.0	0.0	1.0	0.0	1.0	0.0
d	2.0	1.0	1.0	0.0	2.0	0.0	0.0	0.0
d	2.0	1.0	0.0	1.0	1.0	0.0	0.0	0.0
d	0.0	0.0	1.0	3.0	3.0	1.0	0.0	0.0
d	2.0	2.0	1.0	1.0	2.0	2.0	0.0	0.5
d	0.0	1.0	0.0	1.0	1.0	0.0	0.0	0.0
d	0.0	0.0	1.0	2.0	1.0	0.0	1.0	0.0
d	0.0	3.0	0.0	0.5	1.0	0.0	2.0	0.0
d	1.0	0.0	2.0	4.0	2.0	0.0	1.0	0.0

Table IV-3 Changes of body measurement in dynamic postures of elbow and shoulder joints (3)

Unit: cm

postures	Knee girth	Calf girth	Ankle girth	Total crotch length	Crotch Depth	Outside leg length	Front leg length	Back leg length
a	0.0	0.0	0.0	1.0	2.0	0.0	-7.0	3.0
a	3.0	0.0	0.0	0.0	0.0	0.0	-13.0	9.0
a	1.0	-1.0	0.0	2.0	0.0	2.0	-11.0	9.0
a	0.0	0.0	0.0	0.0	1.0	1.0	-8.0	0.0
a	0.0	0.0	0.0	0.0	1.0	0.0	-8.0	6.0
a	0.0	0.0	0.0	0.0	0.0	1.0	-8.0	8.0
a	0.0	0.0	0.0	0.0	0.0	5.0	-2.0	4.0
a	1.0	-0.5	0.0	3.0	1.0	0.0	-11.0	6.0
a	0.0	0.0	0.0	0.0	0.0	0.0	-13.0	5.0
a	0.0	0.0	0.0	0.0	1.0	1.0	-14.0	10.0
b	0.0	0.0	0.0	0.0	2.0	1.0	0.0	-4.0
b	0.0	0.0	0.0	0.0	0.0	0.0	2.0	-9.0
b	1.0	-1.0	0.0	1.0	0.0	0.0	3.0	-3.0
b	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
b	0.0	0.0	0.0	2.0	0.0	0.0	2.0	-6.0
b	0.0	0.0	0.0	0.0	2.0	1.0	4.0	-6.0
b	0.0	0.0	0.0	0.0	0.0	2.0	1.0	-2.0
b	0.0	0.0	0.0	2.0	1.0	0.0	0.0	0.0
b	0.0	0.0	0.0	3.0	1.0	2.0	1.0	-3.0
b	0.0	0.0	0.0	0.0	0.0	3.0	3.0	-5.0
c	0.0	0.0	0.0	3.0	0.0	0.0	1.0	0.0
c	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0
c	1.0	-1.0	0.0	1.0	0.0	0.0	9.0	1.0
c	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

c	0.0	0.0	0.0	0.0	0.0	4.0	0.0	0.0
c	0.0	0.0	0.0	0.0	0.0	2.0	3.0	1.0
c	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0
c	0.0	-0.5	0.0	3.0	0.0	5.0	3.0	1.0
c	0.0	0.0	0.0	0.0	0.0	2.0	1.0	1.0
c	0.0	0.0	0.0	0.0	0.0	3.0	3.0	3.0
d	0.0	0.0	0.0	3.0	0.0	0.0	1.0	0.0
d	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
d	1.0	-1.0	0.0	0.0	0.0	0.0	9.0	0.0
d	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
d	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
d	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
d	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0
d	0.0	-0.5	0.0	2.0	0.0	0.0	1.0	0.0
d	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
d	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table IV-4 Changes of body measurement in waist movements (1)

Unit: cm

postures	Neck base girth	Bust girth	Waist girth	Armscye girth	Upper-arm girth	Elbow girth	Across shoulder width	Across back width
e	0.0	0.0	0.0	3.0	1.0	2.0	1.0	1.0
e	0.0	0.0	0.0	3.0	1.0	2.0	1.0	1.0
e	0.0	-1.0	0.0	2.5	1.0	2.0	1.0	1.0
e	0.0	-1.0	0.0	4.0	1.0	2.0	1.0	1.0
e	0.0	0.0	0.0	4.0	1.0	2.0	1.0	1.0
e	0.0	0.0	0.0	2.0	1.0	2.0	1.0	1.0
e	0.0	0.0	0.0	3.0	1.0	2.0	1.0	1.0
e	0.0	-1.0	0.0	2.5	2.0	3.0	1.0	1.0
e	0.0	-1.5	0.0	2.0	1.5	2.0	1.0	1.0
e	0.0	-1.0	-1.0	2.0	1.0	2.0	1.0	1.0
f	0.0	1.0	0.0	4.0	3.0	5.5	1.0	-2.0
f	0.0	2.0	0.0	6.0	3.0	8.0	1.0	-3.0
f	0.0	1.0	0.0	4.0	3.0	8.0	0.0	-3.0
f	0.0	0.0	0.0	4.0	3.0	6.0	1.0	-1.0
f	0.0	0.0	0.0	7.0	4.0	9.0	0.0	0.0
f	0.0	0.0	0.0	2.0	3.0	6.0	1.0	0.0
f	0.0	1.0	0.0	5.0	1.0	4.0	6.0	-1.0
f	0.0	0.0	0.0	4.0	3.5	7.5	1.0	0.0
f	0.0	0.0	0.0	5.5	2.5	8.5	0.0	-1.0
f	0.0	1.0	0.0	3.0	2.0	8.5	1.0	-1.0
g	0.0	0.0	2.0	-2.0	-1.0	-2.0	0.0	0.0
g	0.0	0.0	1.0	-5.0	-1.0	0.0	-3.0	7.0

g	0.0	0.0	0.0	-6.0	-1.0	0.0	-8.0	2.0
g	0.0	2.0	0.0	-3.0	1.0	-1.0	-2.0	6.0
g	0.0	2.0	0.0	0.0	1.0	0.0	-5.0	6.0
g	0.0	4.0	1.0	-1.0	0.0	0.0	-4.0	4.0
g	0.0	1.0	1.0	0.0	0.0	-1.0	-5.0	1.0
g	0.0	0.0	0.0	-2.0	-0.5	-0.5	-9.0	7.0
g	0.0	3.0	1.0	-3.0	-1.0	0.0	-8.0	6.0
g	0.0	1.0	1.0	-3.0	-1.0	-0.5	-4.0	7.0
h	0.0	0.0	1.0	5.0	1.0	0.0	-3.0	-7.0
h	0.0	0.0	1.0	6.0	2.0	1.0	-3.0	-11.0
h	0.0	-1.0	0.0	3.0	1.0	0.0	-4.0	-5.0
h	0.0	-2.0	0.0	3.0	1.0	0.0	-4.0	-2.0
h	0.0	-1.0	0.0	7.0	2.0	1.0	-7.5	-1.0
h	0.0	-2.0	1.0	2.0	1.0	1.0	-4.0	-4.0
h	0.0	-2.0	1.0	3.0	1.0	0.0	-1.0	-2.0
h	0.0	0.0	0.0	4.0	0.0	0.5	-9.0	-3.0
h	0.0	-1.0	0.0	2.0	1.0	0.5	-4.0	-5.0
h	0.0	-4.0	1.0	0.0	0.0	1.0	-2.0	-2.0
i	0.0	0.0	1.0	-6.0	-1.0	-2.0	-4.0	-5.0
i	0.0	-2.0	1.0	-6.0	-2.0	0.0	-9.0	-5.0
i	0.0	-1.0	0.0	-9.0	-2.0	-1.0	-10.0	-3.0
i	0.0	0.0	0.0	-3.0	-1.0	-1.0	-5.0	-2.0
i	0.0	-1.0	0.0	-2.0	0.0	0.0	-18.0	-3.0
i	0.0	-1.0	1.0	-2.0	-1.0	0.0	-4.0	-2.0
i	0.0	-1.0	1.0	-2.0	-1.0	-1.0	-1.0	-4.0
i	0.0	-1.0	0.0	-2.0	0.0	0.0	-2.0	-5.0
i	0.0	0.0	0.0	-4.0	-1.5	-0.5	-13.0	-5.0
i	0.0	-3.0	1.0	-7.0	-0.5	-0.5	-9.0	-5.0
j	0.0	-1.0	0.0	-4.0	-2.0	-2.0	-13.0	-3.0
j	0.0	-2.0	-1.0	-4.0	-2.0	0.0	-19.0	-3.0
j	0.0	-1.0	-1.0	-8.0	-1.0	-1.0	-20.0	-1.0
j	0.0	0.0	-1.0	-3.0	-1.0	-1.0	-20.0	-1.0
j	0.0	-1.0	-2.0	0.0	0.0	0.0	-18.0	-3.0
j	0.0	0.0	0.0	-3.0	-1.0	0.0	-6.0	-4.0
j	0.0	-2.0	-1.0	-2.0	0.0	-1.0	-7.0	-5.0
j	0.0	-1.0	0.0	-5.5	-1.0	-0.5	-16.5	-5.0
j	0.0	-1.0	0.0	-4.0	-1.5	-0.5	-17.0	-4.0
j	0.0	-3.0	0.0	-4.0	-1.0	-0.5	-21.0	0.0
k	0.0	0.0	0.0	4.0	1.0	0.0	6.0	5.0
k	0.0	1.0	0.0	4.0	2.0	0.0	3.0	7.0
k	0.0	1.0	0.0	1.0	1.0	0.0	4.0	8.0
k	0.0	0.0	0.0	1.0	0.0	0.0	1.0	9.0
k	0.0	4.0	0.0	0.0	0.0	1.0	1.0	4.0
k	0.0	2.0	1.0	1.0	1.0	0.0	3.0	4.0

k	0.0	0.0	1.0	2.0	1.0	0.0	2.0	5.0
k	0.0	2.0	1.5	1.5	1.0	2.0	2.0	8.0
k	0.0	3.0	1.0	0.0	0.5	0.0	3.0	4.0
k	0.0	0.0	0.0	1.5	0.5	1.0	0.0	6.0
l	0.0	0.0	0.0	6.0	1.0	0.0	-1.0	-14.0
l	0.0	0.0	0.0	2.0	2.0	0.0	-3.0	-9.0
l	0.0	-1.0	0.0	1.0	0.0	0.0	-1.0	-2.0
l	0.0	-1.0	1.0	1.0	0.0	0.0	-3.0	-5.0
l	0.0	-2.0	0.0	9.0	2.0	1.0	-12.0	-17.0
l	0.0	-1.0	0.0	6.0	1.0	0.0	-4.0	-6.0
l	0.0	0.0	1.0	4.0	2.0	0.0	-2.0	-4.0
l	0.0	0.0	0.0	2.0	1.5	2.0	-3.0	-5.0
l	0.0	-1.0	0.0	4.0	0.5	1.5	-4.0	-6.0
l	0.0	0.0	0.0	2.0	0.0	0.0	0.0	-6.0

Table IV-5 Changes of body measurement in waist movement (2)

Unit: cm

postures	Across front width	Back waist length	Front waist length	7th-cervical to waist length	Under armhole point to waist length	Standard arm length	Hip girth	Thigh girth
e	1.5	1.0	0.0	0.0	0.0	2.5	0.0	0.0
e	1.0	1.0	1.0	0.0	0.0	3.0	0.0	0.0
e	1.0	1.0	0.0	0.0	0.0	2.5	0.0	0.0
e	1.0	1.0	0.0	0.0	0.0	2.0	0.0	0.0
e	1.0	1.0	1.0	0.0	0.0	4.0	0.0	0.0
e	1.0	1.0	1.0	0.0	0.0	2.0	0.0	0.0
e	1.0	1.0	0.0	0.0	0.0	2.0	0.0	0.0
e	1.0	1.0	0.0	0.0	0.0	3.0	0.0	0.0
e	1.0	1.0	1.0	0.0	0.0	4.0	0.0	0.0
e	1.0	1.5	0.0	0.0	0.0	2.0	0.0	0.0
f	5.0	1.0	0.0	0.0	0.0	6.0	0.0	0.0
f	1.0	0.0	2.0	0.0	1.0	0.0	0.0	0.0
f	1.0	1.0	1.0	0.0	0.0	7.0	0.0	0.0
f	1.0	0.0	1.0	0.0	0.0	8.0	0.0	0.0
f	0.0	1.0	1.0	0.0	1.0	7.0	0.0	0.0
f	0.0	0.0	0.0	0.0	0.0	12.0	0.0	0.0
f	1.0	1.0	1.0	0.0	0.0	2.0	0.0	0.0
f	1.0	2.0	0.0	0.0	0.0	6.0	0.0	0.0
f	1.0	1.0	0.0	0.0	0.0	5.0	0.0	0.0
f	1.5	1.0	1.0	0.0	0.0	5.0	0.0	0.0
g	-4.0	1.0	0.0	0.0	2.0	2.0	0.0	0.0
g	-6.0	0.0	1.0	0.0	2.0	0.0	0.0	0.0
g	-5.0	0.0	2.0	0.0	2.0	4.0	0.0	0.0

g	-5.0	1.0	0.0	0.0	2.0	6.0	0.0	0.0
g	-5.0	1.0	2.0	0.0	3.0	4.0	0.0	0.0
g	-5.0	1.0	1.0	0.0	0.0	8.0	0.0	0.0
g	-8.0	1.0	0.0	1.0	1.0	1.0	0.0	0.0
g	-7.0	0.0	0.0	2.0	5.0	5.0	0.0	0.0
g	-9.0	1.0	1.0	0.0	2.0	4.0	0.0	0.0
g	-7.0	1.0	2.0	0.0	2.0	3.0	0.0	0.0
h	6.0	0.0	1.0	0.0	2.0	0.0	0.0	0.0
h	4.0	-2.0	2.0	-1.0	3.0	-6.0	0.0	0.0
h	2.0	-1.0	2.0	0.0	4.0	-4.0	0.0	0.0
h	2.0	0.0	1.0	-1.0	1.0	-1.0	0.0	0.0
h	3.0	-1.0	2.5	-3.0	4.0	-4.0	0.0	0.0
h	1.0	-1.0	0.0	0.0	0.0	-3.0	0.0	0.0
h	2.0	-1.0	0.0	-1.0	1.0	-5.0	0.0	0.0
h	6.0	-1.0	1.0	-1.0	4.0	-1.0	0.0	0.0
h	2.0	0.0	1.0	0.0	0.0	-1.0	0.0	0.0
h	1.0	-1.0	0.0	-1.0	1.0	-5.0	0.0	0.0
i	2.0	0.0	0.0	0.0	3.0	-6.0	0.0	0.0
i	0.0	2.0	2.0	0.0	4.0	-5.0	0.0	0.0
i	0.0	2.0	2.0	0.0	4.0	0.0	0.0	0.0
i	0.0	0.0	1.0	1.0	1.0	-1.0	0.0	0.0
i	1.0	2.0	6.5	0.0	10.0	3.0	0.0	0.0
i	1.0	1.0	1.0	0.0	2.0	-2.0	0.0	0.0
i	1.0	0.0	0.0	0.0	1.0	-5.0	0.0	0.0
i	1.0	4.0	1.0	3.0	5.5	-1.0	0.0	0.0
i	1.0	3.0	1.0	0.0	1.5	-1.0	0.0	0.0
i	1.0	3.0	1.0	1.5	3.0	-1.0	0.0	0.0
j	-6.0	0.0	1.0	1.0	8.0	0.0	0.0	0.0
j	-13.0	1.0	5.0	1.0	10.0	0.0	0.0	0.0
j	-6.0	3.0	14.0	0.0	10.0	3.0	0.0	0.0
j	-7.0	1.0	1.0	1.0	6.0	6.0	0.0	0.0
j	-1.0	2.0	6.5	0.0	10.0	3.0	0.0	0.0
j	0.0	1.0	3.0	0.0	8.0	2.0	0.0	0.0
j	-8.0	0.0	3.0	1.0	6.0	0.0	0.0	0.0
j	-6.0	0.0	2.0	0.0	10.0	5.0	0.0	0.0
j	-13.0	0.0	3.0	0.0	8.0	3.0	0.0	0.0
j	-15.0	1.0	5.0	1.0	8.0	3.0	0.0	0.0
k	-4.0	0.0	-4.0	0.0	1.0	2.0	0.0	0.0
k	-6.0	1.0	-2.0	0.0	1.0	1.0	0.0	0.0
k	-6.0	1.0	-2.0	1.0	2.0	1.0	0.0	0.0
k	-7.0	2.0	-1.0	1.0	0.0	4.0	0.0	0.0
k	-6.0	1.0	-2.0	1.0	0.0	4.0	0.0	0.0
k	-7.0	1.0	-1.0	0.0	0.0	6.0	0.0	0.0
k	-8.0	0.0	-2.0	0.0	1.0	0.0	0.0	0.0

k	-8.0	2.0	-3.0	1.0	2.0	3.0	0.0	0.0
k	-13.0	0.0	-1.0	0.0	1.0	3.0	0.0	0.0
k	-9.0	1.0	0.0	0.0	1.0	2.0	0.0	0.0
l	3.0	-2.0	3.0	0.0	1.0	-3.0	0.0	0.0
l	4.0	-1.0	4.0	0.0	1.0	-6.0	0.0	0.0
l	2.0	-1.0	3.0	-1.0	2.0	-1.0	0.0	0.0
l	7.0	-2.0	1.0	-1.0	0.0	0.0	0.0	0.0
l	4.0	-1.0	3.0	0.0	0.0	0.0	0.0	0.0
l	6.0	0.0	3.0	0.0	0.0	-2.0	0.0	0.0
l	2.0	0.0	0.0	-1.0	0.0	-4.0	0.0	0.0
l	1.0	-1.0	2.0	-1.0	1.0	-1.0	0.0	0.0
l	2.0	-2.0	1.0	0.0	1.0	1.0	0.0	0.0
l	3.0	-2.5	3.0	-2.0	1.0	-1.0	0.0	0.0

Table IV-6 Changes of body measurement in waist movement (3)

Unit: cm

postures	Knee girth	Calf girth	Ankle girth	Total crotch length	Crotch Depth	Inside leg length	Front leg length	Back leg length
e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
f	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
f	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
f	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
f	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
f	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
f	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
f	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
f	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
f	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
f	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
g	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
g	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
g	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
g	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

g	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
g	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
g	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
g	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
g	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
g	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
h	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
h	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
h	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
h	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
h	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
h	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
h	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
h	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
h	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
h	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
i	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
i	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
i	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
i	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
i	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
i	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
i	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
i	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
i	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
i	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
j	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
j	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
j	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
j	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
j	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
j	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
j	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
j	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
j	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
j	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
k	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
k	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
k	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
k	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
k	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
k	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
k	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
k	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

k	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
k	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
l	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
l	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
l	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
l	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
l	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
l	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
l	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
l	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
l	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
l	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table IV-7 Changes of body measurement in dynamic postures of hip and knee joints (1)

Unit: cm

postures	Neck base girth	chest girth	Waist girth	Armscye girth	Upper-arm girth	Elbow girth	Across shoulder width	Across back width
m	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0
m	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
m	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
m	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
m	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
m	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
m	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
m	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
m	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
m	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0
n	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0
n	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
n	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
n	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
n	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
n	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
n	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
n	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
n	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
n	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
o	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0
o	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
o	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
o	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
o	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

o	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
o	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
o	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
o	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
o	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
p	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0
p	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
p	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
p	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
p	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
p	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
p	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
p	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
p	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
p	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
q	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0
q	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
q	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
q	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
q	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
q	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
q	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
q	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
q	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
q	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0

Table IV-8 Changes of body measurement in dynamic postures of hip and knee joints (2)

Unit: cm

postures	Across front width	Back waist length	Front waist length	7th-cervical to waist length	Under armhole point to waist length	Standard arm length	Hip girth	Thigh girth
m	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
m	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0
m	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0
m	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0
m	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0
m	0.0	0.0	0.0	0.0	0.0	0.0	3.0	1.0
m	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
m	0.0	0.0	0.0	0.0	0.0	0.0	5.0	1.0
m	0.0	0.0	0.0	0.0	0.0	0.0	6.0	0.0
m	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0
n	0.0	0.0	0.0	0.0	0.0	0.0	4.0	1.0

n	0.0	0.0	0.0	0.0	0.0	0.0	5.0	4.0
n	0.0	0.0	0.0	0.0	0.0	0.0	3.0	2.0
n	0.0	0.0	0.0	0.0	0.0	0.0	9.0	2.0
n	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0
n	0.0	0.0	0.0	0.0	0.0	0.0	5.0	2.0
n	0.0	0.0	0.0	0.0	0.0	0.0	4.0	1.0
n	0.0	0.0	0.0	0.0	0.0	0.0	5.0	2.0
n	0.0	0.0	0.0	0.0	0.0	0.0	9.0	1.0
n	0.0	0.0	0.0	0.0	0.0	0.0	4.0	2.0
o	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0
o	0.0	0.0	0.0	0.0	0.0	0.0	5.0	4.0
o	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0
o	0.0	0.0	0.0	0.0	0.0	0.0	9.0	1.0
o	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0
o	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0
o	0.0	0.0	0.0	0.0	0.0	0.0	4.0	1.0
o	0.0	0.0	0.0	0.0	0.0	0.0	5.0	1.0
o	0.0	0.0	0.0	0.0	0.0	0.0	9.0	1.0
o	0.0	0.0	0.0	0.0	0.0	0.0	4.0	3.0
p	0.0	0.0	0.0	0.0	0.0	0.0	1.0	-1.0
p	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
p	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0
p	0.0	0.0	0.0	0.0	0.0	0.0	2.0	-1.0
p	0.0	0.0	0.0	0.0	0.0	0.0	1.0	-1.0
p	0.0	0.0	0.0	0.0	0.0	0.0	2.0	-2.0
p	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-3.0
p	0.0	0.0	0.0	0.0	0.0	0.0	1.0	-1.0
p	0.0	0.0	0.0	0.0	0.0	0.0	4.0	-1.0
p	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-2.0
q	0.0	0.0	0.0	0.0	0.0	0.0	-1.0	1.0
q	0.0	0.0	0.0	0.0	0.0	0.0	-1.0	1.0
q	0.0	0.0	0.0	0.0	0.0	0.0	-2.0	1.0
q	0.0	0.0	0.0	0.0	0.0	0.0	-1.0	1.0
q	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
q	0.0	0.0	0.0	0.0	0.0	0.0	-1.0	1.0
q	0.0	0.0	0.0	0.0	0.0	0.0	-1.0	1.0
q	0.0	0.0	0.0	0.0	0.0	0.0	-3.0	1.0
q	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
q	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0

Table IV-9 Changes of body measurement in dynamic postures of hip and knee joints (3)

Unit: cm

postures	Knee girth	Calf girth	Ankle girth	Total crotch length	Crotch Depth	Inside leg length	Front leg length	Back leg length
m	2.0	5.0	0.0	7.0	2.0	-2.0	-10.0	4.0
m	6.0	0.0	0.0	0.0	0.0	0.0	-7.0	7.0
m	2.0	0.0	0.0	1.0	0.0	-1.0	-7.0	5.0
m	3.0	1.0	0.0	1.0	0.0	-3.0	-8.0	1.0
m	0.0	0.0	0.0	2.0	0.0	-1.0	-7.0	6.0
m	1.0	2.0	0.0	1.0	1.0	-1.0	-8.0	5.0
m	2.0	1.0	0.0	0.0	0.0	-1.0	-7.0	8.0
m	4.0	0.0	0.0	1.0	1.0	-2.0	-7.0	7.0
m	2.0	1.0	0.0	2.0	0.0	-1.0	-10.0	6.0
m	4.0	0.5	0.0	1.0	1.0	-1.0	-8.0	2.0
n	3.0	5.0	0.0	8.0	2.0	-3.0	-2.0	2.0
n	9.0	0.0	0.0	1.0	0.0	0.0	-12.0	5.0
n	4.0	0.0	0.0	0.0	0.0	-2.0	-9.0	7.0
n	8.0	2.0	0.0	2.0	1.0	0.0	-2.0	6.0
n	3.0	0.0	0.0	2.0	1.0	0.0	-6.0	4.0
n	1.0	1.0	0.0	0.0	0.0	-4.0	-2.0	6.0
n	3.0	0.0	0.0	0.0	0.0	0.0	-8.0	5.0
n	8.0	0.5	0.0	0.0	2.5	-4.0	-5.0	8.0
n	5.0	1.0	0.0	3.0	0.0	-2.0	-12.0	6.0
n	5.0	0.5	0.0	1.0	1.0	-2.0	-11.0	6.0
o	0.0	0.0	0.0	7.0	2.0	0.5	3.0	-4.0
o	-1.0	-1.0	0.0	0.0	0.0	0.5	1.0	-2.0
o	0.0	-2.0	0.0	0.0	0.0	0.5	3.0	-2.0
o	0.0	0.0	0.0	2.0	1.0	1.0	1.0	-2.0
o	-1.0	-4.0	0.0	2.0	1.0	1.0	1.0	-2.0
o	0.0	-1.0	0.0	0.0	0.0	1.0	5.0	-2.0
o	-1.0	0.0	0.0	1.0	1.0	1.0	1.0	-1.0
o	-2.0	-1.5	0.0	0.0	3.5	2.0	5.0	-2.0
o	-2.0	0.0	0.0	3.0	0.5	0.5	5.0	-3.0
o	-1.0	-4.5	0.0	1.0	1.0	1.0	4.0	-2.0
p	-1.0	0.0	0.0	3.0	1.0	2.0	0.0	0.0
p	0.0	-1.0	0.0	0.0	0.0	0.5	1.0	0.0
p	-1.0	-1.0	0.0	0.0	2.0	0.5	2.0	0.0
p	-1.0	0.0	0.0	0.0	0.0	1.0	2.0	4.0
p	-1.0	-1.0	0.0	0.0	1.0	0.5	1.0	3.0
p	-1.0	1.0	0.0	0.0	2.0	1.0	2.0	0.0
p	-1.0	0.0	0.0	0.0	0.0	1.0	3.0	2.0
p	-0.5	-0.5	0.0	0.0	3.0	0.5	2.0	3.0

p	-2.0	0.0	0.0	1.0	1.0	0.5	2.0	2.0
p	-0.5	0.0	1.0	0.0	1.0	0.5	0.0	0.0
q	1.0	0.0	0.0	3.0	2.0	-2.0	-1.0	0.0
q	3.0	-1.0	0.0	1.0	0.0	-2.0	-1.0	4.0
q	2.0	0.0	0.0	2.0	0.0	-1.0	-1.0	0.0
q	1.0	0.0	0.0	1.0	1.0	0.0	-1.0	10.0
q	2.0	0.0	0.0	2.0	1.0	0.0	-3.0	2.0
q	0.0	-1.0	0.0	0.0	0.0	-1.0	-1.0	2.0
q	1.0	-1.0	0.0	0.0	0.0	-2.0	-3.0	3.0
q	1.5	-0.5	0.0	1.0	0.0	-1.0	-1.5	2.0
q	1.0	0.0	0.0	2.0	0.0	-1.0	-1.0	4.0
q	0.5	0.0	0.0	0.0	2.0	0.0	-1.0	1.0

APPENDIX V. RAW DATA FOR ANTHROPOMETRY OF HUMAN BODY IN RUNNING STATE (CHAPTER 6)

Table V-1 Maximum changes of body measurement in running state

Unit: cm

	Subjects				
	1	2	3	4	5
Neck Base Girth	0.00	0.00	0.00	0.00	0.00
Chest Girth	3.80	2.50	2.80	1.70	2.45
Waist Girth	1.00	2.50	1.00	2.00	1.45
Hip Girth	6.80	5.20	6.60	4.70	5.80
Armscye Girth	5.50	4.50	3.80	5.50	4.50
Upper Arm Girth	3.00	2.60	3.50	3.50	3.80
Elbow Girth	8.80	6.00	6.15	7.80	8.85
Forearm Girth	0.00	1.00	1.00	0.50	1.50
Wrist Girth	0.00	0.00	0.00	0.00	0.00
Thigh Girth	3.00	4.00	2.80	3.80	3.50
Mid-Thigh Girth	2.00	2.20	1.90	3.30	3.20
Knee Girth	6.60	5.50	7.00	6.60	7.00
Calf Girth	1.60	0.50	1.00	1.60	1.40
Ankle Girth	0.00	0.00	0.00	0.00	0.00
Across Shoulder Width	1.80	3.20	0.50	1.80	0.50
Across Chest Width	1.50	2.00	2.80	2.00	2.80
Across Back Width	2.50	2.50	2.00	2.20	2.00
Front Waist Length	1.20	1.00	1.20	1.10	1.00
Back Waist Length	1.50	1.40	1.72	1.18	1.25
7th-Cervical to Waist	1.00	1.00	1.20	1.00	1.10
Underarm to Waist	0.80	0.70	1.10	0.50	1.00
Total Crotch Length	2.20	1.60	1.80	1.35	2.20
Crotch Depth	1.20	1.00	1.00	1.00	1.50
Central Arm Length	5.50	6.60	6.50	4.80	4.50
Inside Arm Length	2.50	2.50	3.80	4.50	4.00
Outside Arm Length	4.00	4.40	3.50	3.00	2.80
Inside Leg Length	1.00	1.60	0.50	1.50	0.70
Outside Leg Length	4.80	2.50	3.50	3.30	3.00
Front Leg Length	2.30	3.00	1.80	3.10	2.66
Back Leg Length	5.50	5.80	5.10	6.00	6.20

APPENDIX VI. RAW DATA FOR FABRIC PROPERTY INVESTIGATION AND ITS APPLICATION IN FUNCTIONAL PATTERN DESIGN (CHAPTER 9)

Table VI-1 Thicknesses of the four elastic knitted fabrics

Unit: mm

Times	Rib	Plain	Big mesh	Small mesh
1	1.22	0.71	0.94	0.76
2	1.23	0.70	0.95	0.75
3	1.21	0.71	0.93	0.77
4	1.21	0.70	0.94	0.78
5	1.22	0.71	0.96	0.77

Table VI-2 Weights of the four elastic knitted fabrics

Unit: g/m^2

Times	Rib	Plain	Big mesh	Small mesh
1	293.30	214.452	209.850	192.475
2	294.65	209.725	207.875	195.700
3	299.33	214.125	206.475	188.900
4	301.53	213.150	204.050	192.225
5	295.83	211.950	206.125	192.525

Table VI-3 Physical properties of elastic knitted fabrics at 0% stretching level

Fabrics	Stretching	Air resistance (Kpa.s/m)	Water vapour permeability (g/m^2.24h)	OMMC	Contact angle (°)	Thermal insulation-dry (Clo)	Thermal insulation (Clo)	Thermal conductivity (W. cm/K)
Rib	0%	0.846	513.093	0.330	0.000	0.108	0.069	0.062
Rib	0%	0.827	732.484	0.358	0.000	0.114	0.066	0.063
Rib	0%	0.904	714.791	0.347	0.000	0.128	0.084	0.062
Rib	0%	0.841	672.328	0.386	0.000	0.109	0.079	0.062
Rib	0%	0.847	594.480	0.373	0.000	0.126	0.046	0.059
Plain	0%	0.817	445.860	0.441	0.000	0.282	0.077	0.064
Plain	0%	0.799	498.938	0.455	0.000	0.305	0.068	0.063
Plain	0%	0.845	467.091	0.320	0.000	0.295	0.065	0.060
Plain	0%	0.886	527.247	0.375	0.000	0.288	0.072	0.059
Plain	0%	0.832	442.321	0.261	0.000	0.299	0.077	0.058
Big mesh	0%	0.443	751.238	0.579	0.000	0.137	0.053	0.057
Big mesh	0%	0.447	639.420	0.648	0.000	0.132	0.063	0.057

Big mesh	0%	0.441	713.730	0.586	0.000	0.141	0.065	0.058
Big mesh	0%	0.411	641.543	0.555	0.000	0.139	0.055	0.061
Big mesh	0%	0.403	697.098	0.556	0.000	0.149	0.055	0.059
Small mesh	0%	0.483	598.018	0.312	0.000	0.267	0.050	0.059
Small mesh	0%	0.422	566.171	0.461	0.000	0.263	0.042	0.057
Small mesh	0%	0.446	559.094	0.467	0.000	0.274	0.048	0.058
Small mesh	0%	0.451	590.941	0.510	0.000	0.263	0.042	0.058
Small mesh	0%	0.469	576.787	0.277	0.000	0.274	0.043	0.056

Table VI-4 Physical properties of elastic knitted fabrics at 20% stretching level

Fabrics	Stretching	Air resistance (Kpa.s/m)	Water vapour permeability (g/m².24h)	OMMC	Contact angle (°)	Thermal insulation-dry (Clo)	Thermal insulation (Clo)	Thermal conductivity (W. cm/K)
Rib	20%	0.147	736.023	0.265	0.000	0.291	0.027	0.052
Rib	20%	0.148	774.947	0.358	0.000	0.282	0.030	0.052
Rib	20%	0.148	693.560	0.468	0.000	0.275	0.029	0.053
Rib	20%	0.151	831.564	0.385	0.000	0.278	0.031	0.052
Rib	20%	0.147	767.870	0.348	0.000	0.284	0.031	0.052
Plain	20%	0.149	519.462	0.275	0.000	0.300	0.023	0.051
Plain	20%	0.143	535.740	0.314	0.000	0.285	0.026	0.053
Plain	20%	0.142	575.372	0.331	0.000	0.292	0.026	0.052
Plain	20%	0.140	421.090	0.335	0.000	0.297	0.023	0.051
Plain	20%	0.144	486.553	0.301	0.000	0.301	0.025	0.051
Big mesh	20%	0.108	817.410	0.508	0.000	0.223	0.023	0.040
Big mesh	20%	0.086	803.255	0.390	0.000	0.221	0.023	0.041
Big mesh	20%	0.077	803.255	0.412	0.000	0.206	0.023	0.042
Big mesh	20%	0.089	718.330	0.377	0.000	0.190	0.023	0.042
Big mesh	20%	0.079	728.946	0.343	0.000	0.208	0.023	0.042
Small mesh	20%	0.119	686.483	0.306	0.000	0.282	0.025	0.052
Small mesh	20%	0.108	566.171	0.283	0.000	0.286	0.026	0.051
Small mesh	20%	0.103	675.867	0.271	0.000	0.289	0.026	0.050
Small mesh	20%	0.109	636.943	0.288	0.000	0.289	0.027	0.050
Small mesh	20%	0.110	548.478	0.345	0.000	0.288	0.025	0.050

Table VI-5 Physical properties of elastic knitted fabrics at 40% stretching level

Fabrics	Stretching	Air resistance (Kpa.s/m)	Water vapour permeability (g/m².24h)	OMMC	Contact angle (°)	Thermal insulation-dry (Clo)	Thermal insulation (Clo)	Thermal conductivity (W. cm/K)
Rib	40%	0.059	718.330	0.627	0.000	0.228	0.023	0.038
Rib	40%	0.041	736.023	0.571	0.000	0.229	0.022	0.039
Rib	40%	0.032	831.564	0.657	0.000	0.223	0.026	0.043
Rib	40%	0.040	859.873	0.462	0.000	0.195	0.024	0.041

Rib	40%	0.037	785.563	0.661	0.000	0.219	0.024	0.041
Plain	40%	0.018	552.017	0.463	0.000	0.231	0.025	0.036
Plain	40%	0.016	525.478	0.489	0.000	0.225	0.024	0.034
Plain	40%	0.025	647.912	0.469	0.000	0.237	0.024	0.034
Plain	40%	0.020	628.096	0.571	0.000	0.238	0.024	0.033
Plain	40%	0.018	471.691	0.470	0.000	0.229	0.024	0.033
Big mesh	40%	0.016	704.176	0.591	0.000	0.188	0.023	0.026
Big mesh	40%	0.017	721.868	0.767	0.000	0.193	0.022	0.027
Big mesh	40%	0.008	994.338	0.584	0.000	0.190	0.020	0.027
Big mesh	40%	0.009	902.335	0.590	0.000	0.188	0.021	0.028
Big mesh	40%	0.011	881.104	0.542	0.000	0.191	0.022	0.027
Small mesh	40%	0.008	725.407	0.310	0.000	0.248	0.026	0.038
Small mesh	40%	0.012	668.790	0.474	0.000	0.248	0.022	0.038
Small mesh	40%	0.014	644.020	0.305	0.000	0.255	0.022	0.038
Small mesh	40%	0.012	651.097	0.460	0.000	0.245	0.023	0.037
Small mesh	40%	0.010	601.557	0.303	0.000	0.249	0.023	0.038

Table VI-6 Physical properties of elastic knitted fabrics at 60% stretching level

Fabrics	Stretching	Air resistance (Kpa.s/m)	Water vapour permeability (g/m².24h)	OMMC	Contact angle (°)	Thermal insulation-dry (Clo)	Thermal insulation (Clo)	Thermal conductivity (W. cm/K)
Rib	60%	0.004	905.874	0.677	0.000	0.218	0.021	0.036
Rib	60%	0.005	820.948	0.701	0.000	0.202	0.022	0.038
Rib	60%	0.004	912.951	0.678	0.000	0.220	0.023	0.043
Rib	60%	0.003	866.950	0.763	0.000	0.192	0.022	0.040
Rib	60%	0.005	810.333	0.755	0.000	0.210	0.023	0.041
Plain	60%	0.002	635.881	0.742	0.000	0.228	0.023	0.036
Plain	60%	0.003	577.849	0.651	0.000	0.220	0.022	0.034
Plain	60%	0.004	718.330	0.768	0.000	0.230	0.023	0.032
Plain	60%	0.002	515.570	0.691	0.000	0.227	0.024	0.033
Plain	60%	0.001	600.495	0.707	0.000	0.215	0.023	0.033
Big mesh	60%	0.003	920.028	0.775	0.000	0.173	0.021	0.026
Big mesh	60%	0.001	948.337	0.693	0.000	0.188	0.020	0.027
Big mesh	60%	0.002	973.107	0.681	0.000	0.171	0.019	0.027
Big mesh	60%	0.001	912.951	0.695	0.000	0.166	0.021	0.027
Big mesh	60%	0.001	930.644	0.719	0.000	0.185	0.022	0.027
Small mesh	60%	0.002	941.260	0.694	0.000	0.222	0.023	0.038
Small mesh	60%	0.002	1022.647	0.695	0.000	0.231	0.022	0.037
Small mesh	60%	0.003	912.951	0.708	0.000	0.243	0.020	0.037
Small mesh	60%	0.002	941.260	0.619	0.000	0.232	0.022	0.036
Small mesh	60%	0.002	863.411	0.709	0.000	0.239	0.022	0.037

Table VI-7 Mechanical properties of elastic knitted fabrics in the wale direction(1)

Fabrics	LT	WT (gf.cm/cm²)	RT (%)	EMT (%)	B (gf.cm²/cm)	2HB (gf.cm/cm)	G (gf/cm.deg)	2HG (gf/cm)	2HG5 (gf/cm)
rib	1.098	10.210	59.120	37.970	0.073	0.146	0.940	4.070	3.820
rib	1.139	11.980	54.010	42.900	0.051	0.117	0.960	4.100	3.830
rib	1.163	11.820	54.390	41.480	0.049	0.119	0.970	3.920	3.870
rib	1.141	11.760	54.670	42.070	0.042	0.151	1.060	4.100	3.830
rib	1.129	12.090	55.430	43.720	0.081	0.142	0.930	4.070	3.820
plain	1.087	18.330	56.150	68.810	0.026	0.078	0.680	2.380	2.650
plain	1.071	17.680	57.100	67.390	0.030	0.077	0.690	2.360	2.680
plain	1.082	17.460	56.450	65.880	0.018	0.069	0.640	1.990	1.990
plain	1.071	18.890	56.120	72.030	0.012	0.074	0.630	2.210	2.450
Plain	1.073	18.030	56.630	68.610	0.024	0.057	0.590	1.790	1.820
BM	1.091	25.210	50.620	94.330	0.019	0.072	0.480	1.380	1.350
BM	1.084	25.090	54.690	94.430	0.034	0.085	0.380	1.500	1.350
BM	1.099	25.360	55.410	94.180	0.027	0.075	0.440	1.470	1.400
BM	1.093	25.260	56.170	94.380	0.027	0.083	0.480	1.400	1.350
BM	1.024	23.620	54.770	94.140	0.028	0.071	0.410	1.350	1.300
SM	1.070	22.660	59.430	86.420	0.018	0.101	0.490	1.430	1.250
SM	1.086	24.230	55.910	91.010	0.020	0.055	0.400	1.400	1.230
SM	1.063	23.230	57.130	89.210	0.038	0.108	0.570	1.400	1.300
SM	1.092	22.360	52.410	83.590	0.015	0.061	0.530	1.370	1.320
SM	1.064	21.760	52.520	83.450	0.030	0.062	0.400	1.330	1.160

Table VI-8 Mechanical properties of elastic knitted fabrics in the wale direction (2)

Fabrics	LC	WC (gf.cm/cm²)	RC (%)	MIU	MMD	SMD (um)
rib	0.409	0.384	40.890	0.431	0.014	3.765
rib	0.455	0.366	39.890	0.442	0.014	3.555
rib	0.492	0.337	40.360	0.426	0.015	4.125
rib	0.321	0.396	38.890	0.492	0.017	3.635
rib	0.479	0.363	39.950	0.447	0.015	4.335
plain	0.445	0.217	41.010	0.485	0.014	2.920
plain	0.424	0.208	41.350	0.455	0.014	3.205
plain	0.461	0.203	43.350	0.442	0.013	3.030
plain	0.441	0.193	41.450	0.488	0.014	2.980
Plain	0.306	0.205	40.000	0.454	0.014	3.290
BM	0.454	0.354	38.700	0.448	0.014	5.975
BM	0.471	0.339	39.230	0.429	0.012	5.970
BM	0.474	0.341	38.120	0.424	0.011	5.725
BM	0.370	0.339	38.350	0.492	0.015	5.815
BM	0.440	0.327	37.310	0.449	0.014	5.900
SM	0.269	0.286	34.270	0.433	0.013	5.165

SM	0.246	0.313	37.380	0.415	0.014	6.070
SM	0.410	0.275	38.910	0.414	0.013	5.135
SM	0.470	0.269	38.660	0.444	0.014	4.955
SM	0.399	0.283	39.220	0.425	0.012	4.210

Table VI-9 Mechanical properties of elastic knitted fabrics in the course direction (1)

Times	LT	WT(gf.cm/cm²)	RT (%)	EMT (%)	B (gf.cm²/cm)	2HB (gf.cm/cm)
rib	1.132	14.430	54.760	52.020	0.046	0.118
rib	1.122	14.680	54.610	53.390	0.070	0.133
rib	1.119	14.900	53.680	54.310	0.061	0.164
rib	1.116	15.090	54.030	55.190	0.082	0.187
rib	1.121	14.880	54.410	54.170	0.073	0.150
plain	1.122	17.990	49.670	65.440	0.023	0.062
plain	1.119	17.190	51.880	62.710	0.020	0.060
plain	1.119	16.910	51.910	61.680	0.031	0.102
plain	1.123	19.050	48.660	69.250	0.026	0.079
Plain	1.102	17.680	49.890	65.490	0.017	0.066
BM	1.075	23.130	50.170	87.840	0.013	0.049
BM	1.073	23.770	51.200	90.430	0.014	0.049
BM	1.083	22.830	52.620	86.080	0.018	0.041
BM	1.092	22.360	52.410	83.590	0.023	0.064
BM	1.064	21.760	52.520	83.450	0.020	0.047
SM	1.033	20.130	57.060	79.540	0.019	0.050
SM	1.102	21.640	52.900	80.130	0.017	0.059
SM	1.079	21.760	52.340	82.280	0.026	0.044
SM	1.097	21.700	52.480	80.720	0.039	0.057
SM	1.096	22.270	51.580	82.910	0.034	0.056

Table VI-10 Mechanical properties of elastic knitted fabrics in the course direction (2)

Times	G (gf/cm.deg)	2HG (gf/cm)	2HG5 (gf/cm)	MIU	MMD	SMD (um)
rib	0.850	3.530	3.580	0.482	0.019	13.410
rib	0.890	3.950	3.870	0.453	0.018	11.070
rib	0.900	3.970	4.020	0.432	0.017	11.820
rib	0.940	3.800	4.020	0.449	0.017	8.705
rib	0.910	3.610	3.780	0.411	0.020	9.325
plain	0.690	1.910	1.840	0.354	0.013	3.200
plain	0.700	2.010	1.910	0.383	0.013	2.980
plain	0.730	2.040	1.910	0.383	0.012	2.935
plain	0.640	1.990	1.810	0.440	0.013	2.210
Plain	0.650	2.040	1.890	0.387	0.012	2.530
BM	0.480	1.720	1.720	0.467	0.010	4.040

BM	0.430	1.330	1.320	0.437	0.009	4.515
BM	0.620	1.520	1.550	0.428	0.009	4.160
BM	0.570	1.500	1.500	0.520	0.011	3.925
BM	0.470	1.520	1.470	0.449	0.009	3.395
SM	0.490	1.570	1.550	0.521	0.012	2.670
SM	0.480	1.550	1.520	0.444	0.010	2.815
SM	0.510	1.470	1.450	0.431	0.009	2.745
SM	0.460	1.520	1.470	0.541	0.011	2.495
SM	0.500	1.420	1.450	0.465	0.011	2.390

APPENDIX VII. QUESTIONNAIRE FOR THE EVALUATION OF RUNNING WEAR ERGONOMIC FUNCTION BY WEARING TRIAL EXPERIMENT (CHAPTER 10)

We are a research team of the Institute of Textiles and Clothing, The Hong Kong Polytechnic University. Currently, we are conducting a research relating to high-performance sportswear development. You are invited to have wearing trial evaluation on a number of running wear products. This questionnaire has three sections, please complete relevant section after each required exercise. The data collected in this study will be only used for academic research. Thank you very much for the cooperation.

Style of fit design:__________

Venue:___________________ Date: ____________________

SECTION ONE : Complete <u>before the exercise</u>

Name: __________________ Age: __________________

Height:__________________ Weight:_________________

<u>Please complete the following questions according to the body parts in Figure 1</u>

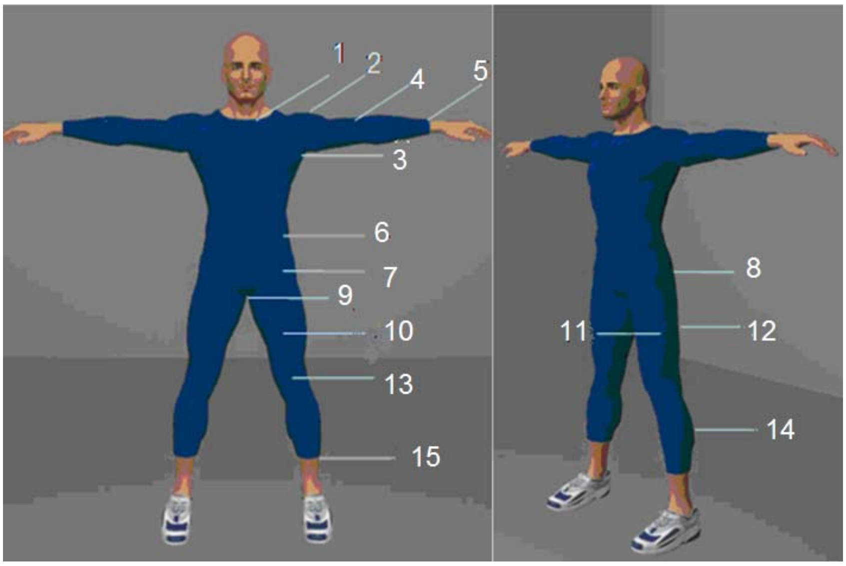


Figure 1 Illustrations of body parts

1- Neck, 2- Shoulder, 3- Armpit, 4- Elbow, 5-Wrist, 6-Navel, 7- Pelvis, 8- Hip, 9- Crotch, 10- Front thigh, 11- Back thigh Ankle, 12- Side thigh -, 13- Knee, 14-Calf, 15- Calf

SECTION TWO: Complete <u>after walking</u> on the treadmill for 3 minutes

Please choose your degree of perceptions on the following aspects.

Body Parts	Subjective Sensation		
Neck	Extremely uncomfortable clothing pressure	0 1 2 3 4 5	Extremely comfortable clothing pressure
	Excessive fetter	0 1 2 3 4 5	Zero fetter
Shoulder	Extremely uncomfortable clothing pressure	0 1 2 3 4 5	Extremely comfortable clothing pressure
	Excessive fetter	0 1 2 3 4 5	Zero fetter
Armpit	Extremely uncomfortable clothing pressure	0 1 2 3 4 5	Extremely comfortable clothing pressure
	Excessive fetter	0 1 2 3 4 5	Zero fetter
Elbow	Extremely uncomfortable clothing pressure	0 1 2 3 4 5	Extremely comfortable clothing pressure
	Excessive fetter	0 1 2 3 4 5	Zero fetter
Wrist	Extremely uncomfortable clothing pressure	0 1 2 3 4 5	Extremely comfortable clothing pressure
	Excessive fetter	0 1 2 3 4 5	Zero fetter
Navel	Extremely uncomfortable clothing pressure	0 1 2 3 4 5	Extremely comfortable clothing pressure
	Excessive fetter	0 1 2 3 4 5	Zero fetter
Pelvis	Extremely uncomfortable clothing pressure	0 1 2 3 4 5	Extremely comfortable clothing pressure
	Excessive fetter	0 1 2 3 4 5	Zero fetter
Hip	Extremely uncomfortable clothing pressure	0 1 2 3 4 5	Extremely comfortable clothing pressure
	Excessive fetter	0 1 2 3 4 5	Zero fetter
Crotch	Extremely uncomfortable		Extremely comfortable

	clothing pressure	0 1 2 3 4 5	clothing pressure
	Excessive fetter	0 1 2 3 4 5	Zero fetter
Front thigh	Extremely uncomfortable clothing pressure	0 1 2 3 4 5	Extremely comfortable clothing pressure
	Excessive fetter	0 1 2 3 4 5	Zero fetter
Side thigh	Extremely uncomfortable clothing pressure	0 1 2 3 4 5	Extremely comfortable clothing pressure
	Excessive fetter	0 1 2 3 4 5	Zero fetter
Back thigh	Extremely uncomfortable clothing pressure	0 1 2 3 4 5	Extremely comfortable clothing pressure
	Excessive fetter	0 1 2 3 4 5	Zero fetter
Knee	Extremely uncomfortable clothing pressure	0 1 2 3 4 5	Extremely comfortable clothing pressure
	Excessive fetter	0 1 2 3 4 5	Zero fetter
Calf	Extremely uncomfortable clothing pressure	0 1 2 3 4 5	Extremely comfortable clothing pressure
	Excessive fetter	0 1 2 3 4 5	Zero fetter
Ankle	Extremely uncomfortable clothing pressure	0 1 2 3 4 5	Extremely comfortable clothing pressure
	Excessive fetter	0 1 2 3 4 5	Zero fetter

SECTION THREE : Complete after running on the treadmill for 3 minutes

Please choose your degree of perceptions on the following aspects

Body Parts	Subjective Sensation		
Neck	Extremely uncomfortable clothing pressure	0 1 2 3 4 5	Extremely comfortable clothing pressure
	Excessive fetter	0 1 2 3 4 5	Zero fetter
Shoulder	Extremely uncomfortable clothing pressure	0 1 2 3 4 5	Extremely comfortable clothing pressure
	Excessive fetter	0 1 2 3 4 5	Zero fetter
Armpit	Extremely uncomfortable clothing pressure	0 1 2 3 4 5	Extremely comfortable clothing pressure
	Excessive fetter	0 1 2 3 4 5	Zero fetter
Elbow	Extremely uncomfortable clothing pressure	0 1 2 3 4 5	Extremely comfortable clothing pressure
	Excessive fetter	0 1 2 3 4 5	Zero fetter
Wrist	Extremely uncomfortable clothing pressure	0 1 2 3 4 5	Extremely comfortable clothing pressure
	Excessive fetter	0 1 2 3 4 5	Zero fetter
Navel	Extremely uncomfortable clothing pressure	0 1 2 3 4 5	Extremely comfortable clothing pressure
	Excessive fetter	0 1 2 3 4 5	Zero fetter
Pelvis	Extremely uncomfortable clothing pressure	0 1 2 3 4 5	Extremely comfortable clothing pressure
	Excessive fetter	0 1 2 3 4 5	Zero fetter
Hip	Extremely uncomfortable clothing pressure	0 1 2 3 4 5	Extremely comfortable clothing pressure
	Excessive fetter	0 1 2 3 4 5	Zero fetter

Crotch	Extremely uncomfortable clothing pressure	0 1 2 3 4 5	Extremely comfortable clothing pressure
	Excessive fetter	0 1 2 3 4 5	Zero fetter
Front thigh	Extremely uncomfortable clothing pressure	0 1 2 3 4 5	Extremely comfortable clothing pressure
	Excessive fetter	0 1 2 3 4 5	Zero fetter
Side thigh	Extremely uncomfortable clothing pressure	0 1 2 3 4 5	Extremely comfortable clothing pressure
	Excessive fetter	0 1 2 3 4 5	Zero fetter
Back thigh	Extremely uncomfortable clothing pressure	0 1 2 3 4 5	Extremely comfortable clothing pressure
	Excessive fetter	0 1 2 3 4 5	Zero fetter
Knee	Extremely uncomfortable clothing pressure	0 1 2 3 4 5	Extremely comfortable clothing pressure
	Excessive fetter	0 1 2 3 4 5	Zero fetter
Calf	Extremely uncomfortable clothing pressure	0 1 2 3 4 5	Extremely comfortable clothing pressure
	Excessive fetter	0 1 2 3 4 5	Zero fetter
Ankle	Extremely uncomfortable clothing pressure	0 1 2 3 4 5	Extremely comfortable clothing pressure
	Excessive fetter	0 1 2 3 4 5	Zero fetter

Thank you for your time!

-End-

APPENDIX VIII. RAW DATA OF SUBJECTS SENSATION FOR SUBJECTIVE FUNCTIONAL EVALUATION OF RUNNING WEAR WITH DIFFERENT FIT DESIGNS (CHAPTER 10)

Table VIII-1 Values of five subjects' perceptions on clothing pressure comfort of running wear with different fit design in the state of walking

Body parts	Just-fit design					20% tight-fit design					40% tight-fit design					60% tight-fit design				
	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5
Neck	4.00	4.00	5.00	4.00	5.00	4.00	4.00	4.00	4.00	4.00	4.00	3.00	4.00	3.00	4.00	3.00	3.00	3.00	3.00	4.00
Shoulder	4.00	5.00	5.00	5.00	5.00	4.00	3.00	4.00	4.00	3.00	4.00	3.00	4.00	3.00	3.00	2.00	3.00	2.00	3.00	3.00
Armpit	5.00	4.00	5.00	5.00	5.00	4.00	4.00	5.00	4.00	5.00	4.00	3.00	4.00	4.00	5.00	3.00	3.00	3.00	3.00	2.00
Elbow	5.00	4.00	5.00	5.00	5.00	4.00	4.00	4.00	4.00	4.00	4.00	3.00	4.00	4.00	4.00	3.00	3.00	2.00	3.00	2.00
Wrist	4.00	4.00	5.00	5.00	4.00	4.00	4.00	4.00	3.00	4.00	2.00	3.00	3.00	3.00	3.00	3.00	2.00	2.00	3.00	2.00
Navel	5.00	4.00	4.00	5.00	4.00	4.00	4.00	4.00	4.00	4.00	3.00	4.00	4.00	4.00	4.00	3.00	2.00	3.00	3.00	2.00
Pelvis	4.00	5.00	4.00	5.00	5.00	4.00	3.00	4.00	4.00	3.00	3.00	4.00	4.00	4.00	4.00	3.00	2.00	3.00	3.00	3.00
Hip	4.00	5.00	5.00	4.00	5.00	4.00	3.00	4.00	4.00	4.00	4.00	3.00	3.00	4.00	4.00	2.00	3.00	3.00	3.00	3.00
Crotch	4.00	5.00	5.00	5.00	5.00	4.00	4.00	4.00	4.00	5.00	4.00	4.00	4.00	4.00	4.00	3.00	3.00	3.00	3.00	3.00
Front thigh	4.00	4.00	5.00	4.00	4.00	3.00	4.00	4.00	3.00	4.00	3.00	4.00	4.00	4.00	4.00	3.00	3.00	2.00	3.00	2.00
Side thigh	4.00	4.00	5.00	4.00	5.00	4.00	4.00	4.00	4.00	4.00	3.00	4.00	3.00	4.00	4.00	3.00	2.00	3.00	2.00	2.00
Back thigh	4.00	5.00	5.00	4.00	4.00	3.00	4.00	4.00	3.00	4.00	3.00	4.00	4.00	3.00	3.00	3.00	2.00	3.00	2.00	3.00
Knee	5.00	5.00	5.00	5.00	5.00	4.00	4.00	5.00	4.00	5.00	4.00	4.00	4.00	4.00	4.00	3.00	3.00	3.00	3.00	2.00
Calf	4.00	4.00	5.00	4.00	5.00	3.00	3.00	4.00	4.00	4.00	3.00	3.00	3.00	4.00	4.00	3.00	3.00	3.00	2.00	2.00
Ankle	4.00	5.00	4.00	4.00	4.00	4.00	3.00	4.00	3.00	4.00	2.00	3.00	3.00	3.00	3.00	2.00	3.00	3.00	3.00	2.00

Table VIII-2 Values of five subjects' perceptions on clothing fetter of running wear with different fit design in the state of walking

Body parts	Just-fit design					20% tight-fit design					40% tight-fit design					60% tight-fit design				
	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5
Neck	4.00	5.00	5.00	4.00	4.00	4.00	4.00	5.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	3.00	3.00	3.00	4.00
Shoulder	5.00	5.00	5.00	4.00	4.00	5.00	4.00	5.00	4.00	5.00	4.00	4.00	5.00	4.00	5.00	4.00	3.00	4.00	4.00	3.00
Armpit	5.00	4.00	5.00	5.00	4.00	5.00	4.00	5.00	4.00	5.00	4.00	4.00	5.00	4.00	5.00	4.00	4.00	3.00	4.00	3.00
Elbow	4.00	4.00	5.00	5.00	5.00	4.00	4.00	4.00	5.00	5.00	4.00	4.00	4.00	4.00	5.00	3.00	3.00	4.00	4.00	3.00
Wrist	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	3.00	4.00	3.00	3.00	3.00
Navel	4.00	4.00	4.00	5.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	3.00	3.00	3.00
Pelvis	5.00	4.00	5.00	4.00	5.00	5.00	4.00	4.00	4.00	5.00	4.00	4.00	4.00	4.00	5.00	4.00	4.00	3.00	3.00	3.00
Hip	4.00	5.00	4.00	5.00	5.00	4.00	5.00	4.00	3.00	4.00	4.00	4.00	4.00	3.00	4.00	4.00	3.00	3.00	3.00	4.00
Crotch	5.00	5.00	4.00	5.00	5.00	5.00	4.00	4.00	5.00	5.00	4.00	5.00	5.00	4.00	5.00	3.00	4.00	4.00	3.00	4.00
Front thigh	5.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	3.00	4.00	3.00	3.00
Side thigh	5.00	4.00	4.00	5.00	4.00	4.00	4.00	3.00	5.00	4.00	4.00	4.00	4.00	4.00	3.00	4.00	3.00	3.00	3.00	4.00
Back thigh	5.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	3.00	4.00	4.00	4.00	4.00	3.00	3.00	3.00	3.00	4.00
Knee	5.00	5.00	4.00	5.00	5.00	5.00	5.00	4.00	5.00	4.00	4.00	5.00	4.00	4.00	5.00	3.00	3.00	4.00	4.00	4.00
Calf	5.00	4.00	5.00	4.00	4.00	4.00	4.00	5.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	3.00	3.00	3.00	3.00
Ankle	4.00	4.00	5.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	3.00	4.00	4.00	4.00	3.00	3.00	3.00	3.00

Table VIII-3 Values of five subjects' perceptions on clothing pressure comfort of running wear with different fit design in the state of running

Body parts	Just-fit design					20% tight-fit design					40% tight-fit design					60% tight-fit design				
	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5
Neck	4.00	4.00	5.00	4.00	4.00	3.00	4.00	3.00	4.00	4.00	3.00	3.00	3.00	3.00	4.00	3.00	3.00	3.00	3.00	3.00
Shoulder	4.00	5.00	5.00	5.00	4.00	4.00	4.00	4.00	3.00	4.00	3.00	3.00	4.00	3.00	4.00	3.00	3.00	2.00	3.00	2.00
Armpit	4.00	5.00	5.00	5.00	5.00	4.00	3.00	4.00	4.00	5.00	4.00	3.00	4.00	4.00	4.00	3.00	3.00	2.00	2.00	2.00
Elbow	4.00	4.00	5.00	5.00	5.00	4.00	4.00	5.00	4.00	3.00	4.00	4.00	3.00	4.00	3.00	2.00	2.00	3.00	2.00	3.00
Wrist	4.00	4.00	4.00	4.00	4.00	4.00	3.00	4.00	4.00	3.00	2.00	3.00	3.00	2.00	3.00	2.00	3.00	3.00	2.00	3.00
Navel	4.00	4.00	4.00	5.00	4.00	4.00	4.00	3.00	4.00	4.00	4.00	4.00	3.00	3.00	4.00	3.00	2.00	3.00	3.00	2.00
Pelvis	4.00	4.00	4.00	4.00	5.00	4.00	3.00	4.00	4.00	4.00	4.00	3.00	4.00	3.00	3.00	2.00	3.00	2.00	2.00	3.00
Hip	4.00	4.00	4.00	4.00	4.00	4.00	3.00	4.00	4.00	4.00	4.00	3.00	3.00	4.00	4.00	3.00	3.00	3.00	2.00	2.00
Crotch	4.00	4.00	4.00	5.00	5.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	3.00	4.00	4.00	3.00	3.00	3.00	3.00	3.00
Front thigh	4.00	4.00	4.00	4.00	4.00	4.00	3.00	3.00	4.00	3.00	4.00	4.00	3.00	3.00	3.00	2.00	2.00	3.00	2.00	2.00
Side thigh	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	3.00	3.00	4.00	3.00	3.00	3.00	3.00	2.00	3.00	2.00	2.00	2.00
Back thigh	4.00	4.00	4.00	4.00	4.00	4.00	3.00	4.00	3.00	3.00	4.00	3.00	3.00	3.00	3.00	2.00	2.00	3.00	2.00	2.00
Knee	4.00	5.00	5.00	5.00	5.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	3.00	4.00	4.00	2.00	3.00	3.00	3.00	3.00
Calf	4.00	4.00	4.00	4.00	4.00	4.00	3.00	3.00	4.00	4.00	4.00	3.00	3.00	3.00	4.00	2.00	3.00	2.00	2.00	3.00
Ankle	4.00	4.00	4.00	4.00	4.00	4.00	3.00	4.00	3.00	4.00	2.00	3.00	2.00	3.00	2.00	2.00	3.00	3.00	3.00	2.00

Table VIII-4 Values of five subjects’ perceptions on clothing fetter of running wear with different fit design in the state of running

Body parts	Just-fit design					20% tight-fit design					40% tight-fit design					60% tight-fit design				
	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5
Neck	4.00	5.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	3.00	3.00	4.00	4.00	4.00	3.00	3.00	3.00	3.00
Shoulder	5.00	4.00	5.00	4.00	5.00	4.00	4.00	5.00	5.00	5.00	4.00	4.00	4.00	4.00	4.00	3.00	3.00	4.00	4.00	4.00
Armpit	5.00	4.00	4.00	4.00	5.00	5.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	3.00	3.00	4.00	4.00	4.00
Elbow	4.00	5.00	5.00	4.00	5.00	4.00	4.00	4.00	4.00	5.00	3.00	4.00	3.00	4.00	4.00	3.00	3.00	3.00	4.00	4.00
Wrist	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	3.00	4.00	4.00	3.00	4.00	3.00	4.00	3.00	3.00	4.00	3.00	3.00
Navel	4.00	4.00	4.00	5.00	4.00	4.00	4.00	4.00	5.00	4.00	4.00	3.00	4.00	4.00	4.00	4.00	3.00	4.00	3.00	3.00
Pelvis	5.00	4.00	4.00	4.00	5.00	5.00	4.00	4.00	4.00	5.00	4.00	4.00	4.00	4.00	3.00	3.00	3.00	4.00	3.00	3.00
Hip	4.00	4.00	4.00	4.00	5.00	4.00	4.00	4.00	4.00	4.00	4.00	3.00	4.00	4.00	4.00	4.00	3.00	3.00	3.00	4.00
Crotch	5.00	4.00	4.00	5.00	5.00	5.00	4.00	4.00	5.00	5.00	3.00	4.00	4.00	4.00	3.00	3.00	4.00	3.00	4.00	3.00
Front thigh	5.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	3.00	4.00	4.00	3.00	4.00	3.00	3.00
Side thigh	5.00	4.00	4.00	5.00	4.00	4.00	4.00	4.00	4.00	4.00	3.00	4.00	3.00	3.00	4.00	3.00	3.00	3.00	3.00	3.00
Back thigh	4.00	4.00	4.00	5.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	3.00	4.00	3.00	4.00	4.00	3.00	3.00	3.00	3.00
Knee	5.00	5.00	5.00	5.00	5.00	5.00	4.00	5.00	4.00	5.00	5.00	4.00	4.00	4.00	3.00	3.00	4.00	4.00	4.00	3.00
Calf	4.00	4.00	5.00	5.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	3.00	3.00	3.00	4.00	3.00	3.00	3.00	3.00	4.00
Ankle	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	3.00	4.00	3.00	4.00	3.00	3.00	4.00	3.00	3.00

APPENDIX IX. RAW DATA OF CLOTHING PRESSURE FOR OBJECTIVE FUNCTIONAL EVALUATION OF RUNNING WEAR WITH DIFFERENT FIT DESIGNS (CHAPTER 10)

Table IX-1 Mean values of the maximum clothing pressure in the state of rest before running

Unit: Kpa

	Rest before running									
	Just-fit					20% Tight-fit				
Body parts	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5
Front neck	1.161	1.173	1.165	1.153	1.163	0.997	1.000	0.970	1.025	0.965
Back neck	1.224	1.224	1.125	1.325	1.220	1.012	1.000	1.110	0.942	1.123
Shoulder	1.475	1.455	1.499	1.480	1.490	1.388	1.366	1.478	1.358	1.410
Chest	1.265	1.224	1.284	1.286	1.246	1.118	1.100	1.211	1.018	1.109
Scapular	1.204	1.200	1.405	1.001	1.205	1.105	1.077	1.210	1.120	1.170
Front waist	1.011	1.021	1.001	1.015	1.100	1.088	1.100	1.188	0.988	1.110
Back waist	0.953	0.933	0.974	0.950	0.938	0.950	0.930	0.940	0.970	0.955
Hip	1.355	1.555	1.655	1.155	1.367	1.278	1.266	1.305	1.270	1.564
Upper arm	1.223	1.203	1.225	1.303	1.123	1.198	1.200	1.166	1.234	1.250
Elbow	1.315	1.301	1.320	1.331	1.311	1.289	1.287	1.330	1.268	1.290
Forearm	1.212	1.222	1.000	1.230	1.118	1.189	1.168	1.210	1.219	1.160
Front thigh	1.188	1.120	1.125	1.167	1.108	1.155	1.140	1.170	1.120	1.210
Back thigh	1.224	1.240	1.233	1.214	1.208	1.116	1.100	1.111	1.123	1.312
Knee	1.365	1.350	1.370	1.563	1.165	1.344	1.324	1.364	1.377	1.310
Front calf	1.207	1.200	1.118	1.210	1.116	1.117	1.110	1.119	1.134	1.007
Back calf	1.216	1.210	1.217	1.304	1.165	1.201	1.118	1.211	1.190	1.220
	40% Tight-fit					60% Tight-fit				
Body parts	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5
Front neck	1.300	1.450	1.333	1.310	1.322	1.567	1.656	1.610	1.621	1.611
Back neck	1.300	1.366	1.430	1.220	1.333	1.600	1.653	1.610	1.655	1.632
Shoulder	1.576	1.542	1.550	1.570	1.565	2.180	2.165	2.100	2.095	2.125
Chest	1.339	1.425	1.400	1.421	1.411	1.750	1.763	1.722	1.730	1.743
Scapular	1.325	1.336	1.312	1.320	1.324	1.630	1.640	1.625	1.650	1.635
Front waist	1.079	1.110	1.068	1.130	1.089	1.555	1.500	1.610	1.567	1.556
Back waist	1.022	1.100	1.011	1.083	1.012	1.110	1.132	1.130	1.120	1.122
Hip	1.765	1.789	1.887	1.775	1.788	2.047	2.031	2.035	2.050	2.039
Upper arm	1.338	1.477	1.412	1.435	1.408	1.710	1.734	1.755	1.710	1.722
Elbow	1.756	1.778	1.760	1.761	1.764	2.645	2.666	2.650	2.670	2.655

Forearm	1.400	1.389	1.410	1.404	1.399	1.665	1.657	1.680	1.670	1.667
Front thigh	1.445	1.466	1.450	1.507	1.456	1.705	1.701	1.721	1.715	1.710
Back thigh	1.366	1.386	1.400	1.352	1.376	1.678	1.707	1.680	1.798	1.688
Knee	2.000	2.080	1.880	1.978	2.011	3.020	3.100	3.171	3.021	3.081
Front calf	1.341	1.461	1.421	1.507	1.451	1.665	1.665	1.707	1.700	1.677
Back calf	1.355	1.324	1.420	1.408	1.364	1.667	1.700	1.552	1.650	1.651

Table IX-2 Mean values of the maximum clothing pressure in running state

Unit: Kpa

	Running									
	Just-fit					20% Tight-fit				
Body parts	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5
Front neck	1.177	1.166	1.780	1.201	1.158	1.155	1.166	1.145	1.150	1.156
Back neck	1.200	1.207	1.212	1.115	1.117	0.968	0.970	0.980	0.961	0.958
Shoulder	1.422	1.420	1.390	1.450	1.418	1.378	1.380	1.375	1.268	1.490
Chest	2.425	2.415	2.410	2.510	2.441	2.313	2.315	2.310	2.333	2.300
Scapular	1.322	1.320	1.356	1.343	1.320	1.255	1.250	1.257	1.360	1.156
Front waist	1.118	1.120	1.116	1.124	1.119	1.171	1.180	1.165	1.210	1.166
Back waist	0.955	0.952	0.980	0.954	0.960	0.961	0.956	0.970	0.970	0.955
Hip	1.768	1.756	1.786	1.770	1.772	1.669	1.690	1.650	1.679	1.657
Upper arm	1.422	1.420	1.425	1.410	1.430	1.406	1.410	1.409	1.415	1.389
Elbow	2.534	2.555	2.510	2.600	2.435	2.289	2.290	2.286	2.287	2.300
Forearm	1.327	1.320	1.325	1.410	1.227	1.304	1.310	1.286	1.300	1.296
Front thigh	1.888	1.900	1.865	1.874	1.918	1.788	1.785	1.758	1.790	1.795
Back thigh	1.654	1.652	1.650	1.710	1.590	1.601	1.600	1.567	1.631	1.610
Knee	3.511	3.510	3.522	3.613	3.234	3.404	3.415	3.289	3.406	3.410
Front calf	1.667	1.670	1.656	1.767	1.680	1.566	1.565	1.560	1.600	1.545
Back calf	1.446	1.456	1.466	1.440	1.455	1.345	1.346	1.410	1.310	1.359
	40% Tight-fit					60% Tight-fit				
Body parts	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5
Front neck	1.400	1.415	1.425	1.408	1.410	1.710	1.730	1.705	1.716	1.715
Back neck	1.385	1.380	1.400	1.367	1.388	1.650	1.645	1.675	1.660	1.651
Shoulder	1.578	1.600	1.580	1.599	1.588	2.300	2.390	2.350	2.347	2.345
Chest	2.566	2.570	2.565	2.456	2.567	3.000	3.068	3.101	3.075	3.061
Scapular	1.469	1.460	1.456	1.476	1.466	1.775	1.785	1.790	1.792	1.788
Front waist	1.220	1.210	1.230	1.240	1.222	1.640	1.660	1.648	1.625	1.645
Back waist	1.100	1.099	1.070	1.080	1.089	1.120	1.115	1.129	1.210	1.124
Hip	3.134	3.164	3.145	3.140	3.144	3.610	3.621	3.625	3.618	3.619
Upper arm	1.980	1.990	2.000	1.988	1.989	2.185	2.190	2.220	2.085	2.187
Elbow	3.051	3.022	2.899	2.918	3.000	4.100	4.000	4.055	4.065	4.068
Forearm	1.667	1.690	1.680	1.685	1.684	2.150	2.160	2.157	2.155	2.155
Front thigh	2.668	2.670	2.658	2.715	2.667	2.865	2.860	2.865	2.863	2.862

Back thigh	2.545	2.550	2.456	2.550	2.556	2.655	2.634	2.645	2.640	2.644
Knee	3.820	3.810	3.826	3.820	3.818	4.410	4.425	4.230	4.610	4.411
Front calf	2.440	2.450	2.439	2.440	2.443	2.560	2.548	2.570	2.616	2.558
Back calf	2.390	2.385	2.410	2.400	2.389	2.500	2.670	2.223	2.458	2.469

Table IX-3 Mean values of the maximum clothing pressure in the state of rest after running

Unit: Kpa

	Rest after running									
	Just-fit					20% Tight-fit				
Body parts	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5
Front neck	1.145	1.140	1.151	1.137	1.142	0.988	0.990	0.980	1.010	0.975
Back neck	1.202	1.200	1.115	1.220	1.210	1.009	1.000	1.010	1.015	1.002
Shoulder	1.434	1.444	1.430	1.240	1.651	1.385	1.380	1.386	1.340	1.360
Chest	1.261	1.250	1.260	1.265	1.254	1.112	1.110	1.115	1.114	1.115
Scapular	1.202	1.200	1.113	1.227	1.118	1.107	1.100	1.110	1.115	1.119
Front waist	0.989	0.980	1.000	0.968	0.975	1.110	1.100	1.120	1.116	1.118
Back waist	0.949	0.950	0.955	0.925	0.956	0.948	0.950	0.960	0.944	0.930
Hip	1.344	1.340	1.444	1.234	1.440	1.280	1.285	1.300	1.267	1.268
Upper arm	1.215	1.200	1.210	1.225	1.230	1.211	1.210	1.200	1.234	1.202
Elbow	1.300	1.300	1.218	1.315	1.312	1.277	1.275	1.280	1.276	1.279
Forearm	1.210	1.200	1.230	1.180	1.121	1.168	1.165	1.170	1.160	1.159
Front thigh	1.155	1.150	1.160	1.153	1.651	1.148	1.145	1.150	1.151	1.145
Back thigh	1.211	1.200	1.215	1.201	1.208	1.106	1.100	1.110	1.105	1.105
Knee	1.349	1.350	1.330	1.452	1.340	1.346	1.340	1.350	1.336	1.335
Front calf	1.118	1.120	1.131	1.108	1.116	1.110	1.100	1.115	1.111	1.130
Back calf	1.201	1.200	1.205	1.199	1.189	1.211	1.212	1.220	1.110	1.108
	40% Tight-fit					60% Tight-fit				
Body parts	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5
Front neck	1.300	1.308	1.321	1.331	1.305	1.550	1.560	1.545	1.600	1.556
Back neck	1.320	1.335	1.310	1.325	1.325	1.620	1.587	1.615	1.620	1.621
Shoulder	1.560	1.550	1.555	1.565	1.558	2.115	2.220	2.110	2.118	2.117
Chest	1.400	1.410	1.405	1.428	1.408	1.670	1.657	1.968	1.670	1.668
Scapular	1.300	1.310	1.290	1.305	1.300	1.630	1.625	1.620	1.631	1.628
Front waist	1.000	1.010	1.023	1.055	1.017	1.540	1.550	1.548	1.541	1.544
Back waist	1.000	1.005	1.010	1.008	1.005	1.120	1.108	1.121	1.125	1.120
Hip	1.670	1.668	1.687	1.670	1.677	2.000	1.988	1.210	2.008	1.998
Upper arm	1.389	1.344	1.360	1.365	1.366	1.680	1.675	1.660	1.766	1.678
Elbow	1.750	1.770	1.730	1.755	1.751	2.556	2.560	2.550	2.562	2.558
Forearm	1.380	1.400	1.368	1.378	1.381	1.655	1.640	1.670	1.701	1.655
Front thigh	1.445	1.440	1.450	1.440	1.447	1.670	1.665	1.660	1.675	1.668

Back thigh	1.370	1.380	1.356	1.374	1.371	1.670	1.675	1.700	1.645	1.676
Knee	1.990	2.007	1.980	1.985	1.986	2.900	2.880	2.895	2.910	2.897
Front calf	1.360	1.371	1.360	1.370	1.369	1.670	1.665	1.455	1.651	1.668
Back calf	1.350	1.330	1.370	1.355	1.351	1.650	1.640	1.640	1.655	1.644

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