

Optimization Design of Cycling Clothes' Patterns Based on Digital Clothing Pressures

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Abstract: Enormous research has focused on the analysis of garment wear-comfort using clothing pressure; however, optimization of clothing pressure based garment comfort has remained elusive. In this context, we propose a new method to optimize cycling clothes' patterns based on the difference of static-to-dynamic clothing pressure (DSDCP). Firstly, we mapped 53 measuring points on an upper cycling garment on which we measured garment pressures in both static and dynamic conditions. We then analyzed DSDCP to find the rightful garment patterns to adjust according to the analyzed results. A garment optimization degree (OD) is proposed to carry out a quantitative analysis for garment comfort optimization. Finally, two upper cycling garments were made according to the original patterns and optimized patterns. A comparative analysis through cyclist wear trials of the cycling garments to test the optimization effect was done. Results show that our proposed method improves dynamic wear comfort significantly. Moreover, the optimized upper cycling garment, offers additional improvement of dynamic wear comfort.

Keywords: Cycling clothes, Pattern optimization, Virtual try-on, Wear comfort, Digital clothing pressure

Introduction

Cycling is a very popular sport all over the world. Being a high-strength outdoor sport, athletes' motions generate much heat during cycling; therefore, cycling clothes should be not merely functional but also comfortable to wear. Currently, there are many kinds of cycling clothes on the sport wearing market; however, the quality is uneven. Two critical factors directly impacting the cycling clothes' quality are: fabric properties and design. The fabrics with excellent mechanical properties can provide comfort and protection to the wearer [1]. Therefore, the fine wear resistance [2], anti-ultraviolet radiation [3], waterproofing [4] among other functions, added to protective fabrics are developed to keep cyclists out of harm. Some excellent air permeability [5], moisture permeability [6] and other functions in fabrics are developed to enhance wear comfort. These high-performance fabrics are widely applied to sportswear design [7]. Many researchers believe that the fabric performance is the most important factor that influences wear comfort of cycling garments. This partly justifies the insignificant research about the optimization of design of cycling garment patterns. However, reasonable garment pattern design can also improve wear comfort and aesthetics significantly [8]. For example, the stand collar, tight-fitting style, raglan sleeve, and sealing zipper are applied in the cycling clothes design to keep out wind, reduce air resistance and move more freely.

Garment pattern making plays a crucial role in garment

design. For a form-fitting garment, a 3D-to-2D unfolding technology is generally applied to develop patterns of tight-fitting garments [9-14]. These garment patterns are optimized from the perspective of the stretch ability of elastomeric fabrics [15]. However, the vast of these research studies were conducted in static state of garments, while ignoring the dynamic state. The garment patterns developed by static state testing possess limited suitability in real application scenario. This is one of the reasons consumers always hardly choose fitting clothing. Wang *et al.* measured human bodies in the static state and 17 dynamic postures to establish a dynamic clothing wear ease for developing garment patterns [16]. However, the pattern optimization based on dynamic clothing pressure was not involved.

Cyclists wear biking jersey for cycling races; therefore, the dynamic wear comfort is important for the cyclists [17]. The optimization of garment patterns in dynamic conditions is an effective way to improve the clothing wear comfort and functionality. Garment pressure is one of the main factors influencing wear comfort [18-20]; especially for strait jackets [21-23]. Zheng *et al.* evaluated the wear comfort of the 3D seamless knitted bras and conventional wired bras from the aspect of clothing pressures [24]. Their research only analyzed the pressure wear comfort; however, the bra optimization design using clothing pressure was not involved. Zhang *et al.* pointed out that the numerical simulation of garment pressure distribution is critical for optimal design of apparel products [25]. Therefore, we proposed a method to optimize the design of garment patterns based on the difference of static-to-dynamic clothing pressures (DSDCP).

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The developed 3D virtual-reality technology is widely applied in clothing and textile products design [9,26-29]. Compared with traditional methods, these new methods have advantages of lower cost, time saving, improved efficiency, ease of access and higher accuracy [21,30,31]. Research showed that the numerical simulation method of clothing pressures can provide reliable prediction in terms of pressure comfort [21]. Some virtual try-on software, such as CLO 3D Modelist, OptiTex, Lectra 3D Prototype, are available on the market [32]. They normally include three main modules: 1) a 3D parametric mannequin module, 2) a fabric properties' module, and 3) a virtual pattern sewing module [32]. The 3D parametric mannequin module is applied to model a human body rapidly according to real body dimensions; the fabric properties module is used for adjust the virtual fabric according to real fabric properties; the virtual pattern sewing module is used to assemble patterns together. The combination of these three modules constitutes a virtual try-on system, permitting the simulation of the process of real garment making. In this context, the latest 3D technology was applied in our research, and all experiments were carried out in a virtual environment.

The main purpose of this research work is to optimize the patterns of cycling clothes. In section 2, we introduce the development of optimization of cycling jersey's patterns, and the measurement of clothing pressure in static and dynamic conditions. In section 3, we analyze the wear comfort of the optimized patterns. Finally, we present some conclusions and possible further works in section 4.

General Scheme of Garment Pattern Optimization

The general scheme of the clothing pressure based

optimization of garment patterns is described in Figure 1. It consists of following steps:

- 1) Arrangement of some equidistant points on the garment pattern of front, back, sleeve and collar pieces.
- 2) Trying on the patterns in static condition and dynamic conditions.
- 3) Measurement of static and dynamic clothing pressures.
- 4) Comparison of point-to-point of each measuring point's static and dynamic condition to locate the high pressure points.
- 5) Optimization of patterns by minimizing the dynamic clothing pressure.
- 6) Validation of the optimized patterns using different fabrics.
- 7) Making two cycling clothes according to original patterns and optimized patterns. Evaluation and validation of optimized patterns through a real cycling experiment.

Experimental

Clothing Pressure Measurement

The best cycling garment design should meet two conditions in static or dynamic state; garment ease allowance and garment pressure. The former should ideally be zero at all parts of the garment while the later should be as minimum as possible. However, in reality ease allowance and garment pressure are negatively correlated within a certain range. Therefore, it is very difficult for a garment design to meet these two requirements simultaneously.

Pattern makers usually design garment patterns considering the static condition, whereas dynamic conditions are rarely considered. Therefore, the resulting garment has excellent comfort in static state but lacks in dynamic comfort for

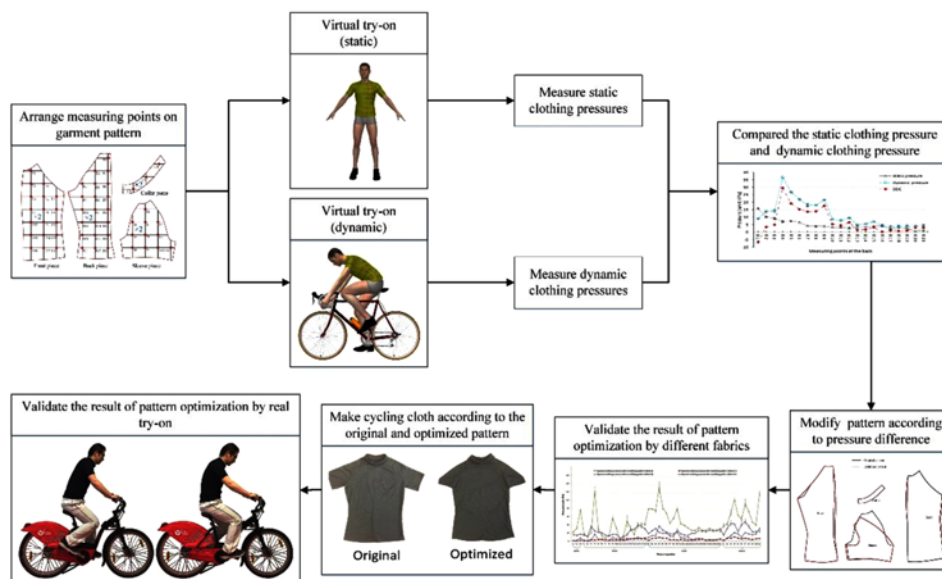


Figure 1. General scheme of garment pattern optimization based on clothing pressure.

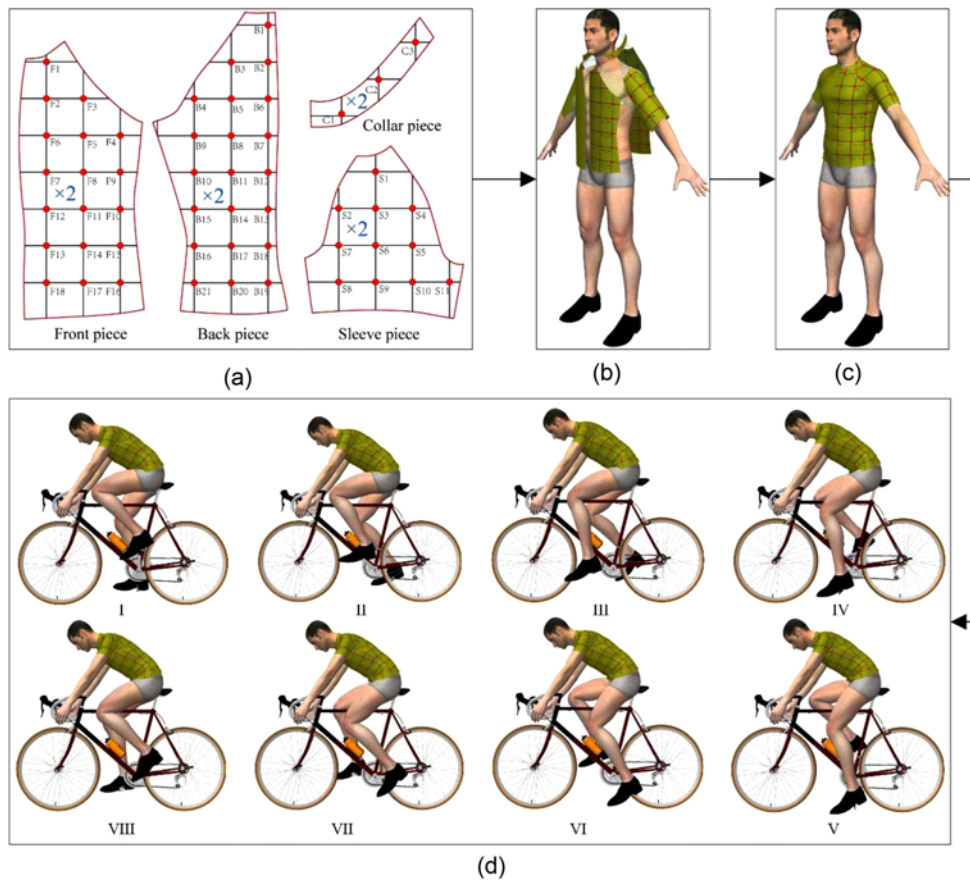


Figure 2. Flowchart of the measurement of static and dynamic clothing pressures.

Table 1. Fabric mechanical properties for virtual try-on and the measurement of clothing pressures

Fabric type	Fabric mechanical properties											
	BST	BSP	BRT	BRP	ST	SW	BT	BP	SH	DE	ID	FC
Fabric A	80	80	80	80	27	27	38	38	9	27	1	3
Fabric B	35	35	35	35	50	50	60	60	25	60	20	20

Note: BST is buckling stiffness-weft; BSP is buckling stiffness-warp; BRT is buckling ratio-weft; BRP is buckling ratio-warp; ST is stretch-weft; SW is stretch-warp; BT is bending-weft; BP is bending-warp; SH is shear; DE is density; ID is internal damping; FC is friction coefficient. The values of fabric mechanical properties in the Table are relative values and the relative values range is [1-99].

dynamic state. In reality, the pattern should be adjusted according to the requirement of dynamic wear comfort also. As shown in Figure 2(a), the cycling clothes pattern have a good wear comfort and fit in static condition, however, the fitting at dynamic condition is unknown. In order to analyze the garment pressure in static and dynamic states, we conducted the experiment using fabric A (properties are given in Table 1) and the validation was conducted using fabric B. Some fabric properties significantly influencing clothing pressures and wear comfort were measured. The buckling stiffness-weft, buckling stiffness-warp, buckling ratio-weft and buckling ratio-warp of fabric A are significantly stronger than that of fabric B; the stretch-weft, stretch-warp,

bending-weft, bending-warp, shear, density, internal damping and friction coefficient of fabric A are obviously smaller than that of fabric B (Table 1). These two fabrics with extreme different properties validate better whether our proposed method is suited for different fabrics.

The clothing pressures were measured by the software *CLO 3D Modelist* in the following steps (Note: In this research, the unit of digital clothing pressures is Virtual kPa, which is different from the unit of real pressure kPa.):

Step 1. Measuring the dimensions of the real human body (height, waist girth, bust girth, shoulder width, arm length, armhole girth and neck girth), and then adjusting the parametric model according to the measured dimensions.

Step 2. Measuring pressure at points F1, F2, F3 ... F18 distributed in the front piece; B1, B2, B3 ... B21 distributed on the back piece; C1, C2, C3 distributed on the collar piece; and the S1, S2, S3 ... S11 distributed on the sleeve piece (Figure 2(a)).

Step 3. The front piece, back piece, collar piece and sleeve piece were assembled together around the upper body of the avatar by 3D virtual try on technology (Figure 2(b)). The measuring points were then attached to the skin surfaces (Figure 2(c)).

Step 4. The static clothing pressures were measured according to the arranged points in Figure 2(a) in the static standing posture. We took measurements three times, and took their average for accuracy (Figure 2(c)).

Step 5. A cycling loop was divided into eight main states: dynamic I (0°), dynamic II (45°), dynamic III (90°), dynamic IV (135°), dynamic V (180°), dynamic VI (225°), dynamic VII (270°) and dynamic VIII (315°) (Figure 2(d)). The pressures in these eight states were measured respectively according to the mapped points in Figure 2(a). Each measuring point has eight dynamic clothing pressure values; we took the average of these eight values.

Analysis of Clothing Pressure on the Collar and Optimization of the Collar’s Pattern

The collar is an important part in cycling clothes’ design. The cycling garment’s collar is usually designed to be a stand collar which is not only beautiful and comfortable but also functional. The stand collar helps in reducing air resistance, and its ease allowance is usually set to less than zero for keeping out wind. However, negative garment ease allowance leads to high clothing pressure, thus effecting head blood supply. This effect is unobservable for short time and low-intensity exercise, but it is obvious for long time and high-intensity cycling. The advantage with the collar of cycling clothes is that the ease allowance and pressure are both zero whether in static states or dynamic states. Further study on the neck’s garment pressure would be necessary.

As shown in Figure 3, DDSCP are negative at point C1 and C2, and positive at point C3; this phenomenon indicates that pressure wear comfort at point C1 and C2 improved but

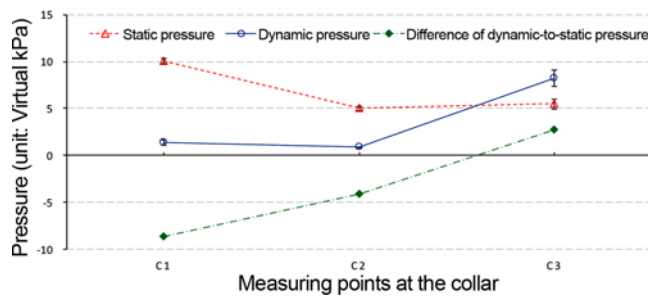


Figure 3. Comparison of static and dynamic clothing pressure at the collar.

deteriorated at point C3 during cycling. The dynamic clothing pressure at point C1 and C2 are close to zero (Figure 3); this phenomenon indicates that the pressure wear comfort is good during cycling, and the patterns in the two parts need no further optimization. The dynamic clothing pressure at C3 does not increase significantly compared to static clothing pressure; this indicates that the wear comfort is acceptable during cycling. In addition, the neck hole length is not changed in the pattern making process if possible; therefore, we did not modify the collar pattern.

Analysis of Clothing Pressure on the Front and Optimization of the Front’s Pattern

The front pieces of cycling clothes face the wind directly. The fabric with excellent wind resistance is usually adopted for the front pieces. In addition, the left front piece and right front piece are usually connected to each other by a zipper to stop wind. The body leans forward during cycling (Figure 2(d)); this results in many folds around the armhole of the front, and it influences wear comfort. While many people tend to think that the pressure on the whole front decreases significantly, our research shows that the garment pressure on certain parts of the front has increased significantly.

As shown in Figure 4, compared to static clothing pressure, dynamic clothing pressures increased at points F1, F2, F3, F11, F5, F6, F7 and F8. These points correspond to the upper front piece; therefore, we reduced ease allowance by 1 cm at the upper central line of the front piece for the clothing pressure is close to zero. Moreover, the central line curve is difficult to seam due to the zipper. We cut down some ease allowance at the upper central line to straighten the line (Figure 5). Meanwhile, the dynamic clothing pressures increased at points F4, F9, F10, F11, F12, F13, F14, F15, F16, F17 and F18. These points correspond to the lower and side front piece. We tried to add 1.5 cm ease allowance at the side seam line for reducing these parts’ clothing pressure. We continued adjusting until results were satisfactory enough. The ultimate optimized pattern is shown in Figure 5.

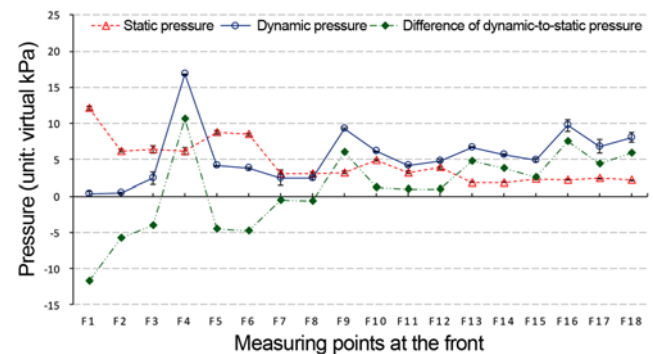


Figure 4. Comparison of static and dynamic clothing pressure at the front.

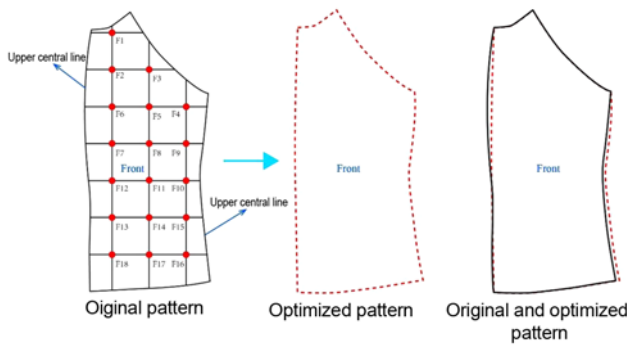


Figure 5. Clothing pattern optimization based on clothing pressure.

Analysis of Clothing Pressure on the Back and Optimization of the Back’s Pattern

The back is an important part that influences the wear comfort. The whole back is usually designed as one piece. However, this construction design is unreasonable, because the human back is not flat but uneven. It is best to be designed as at least two pieces. In this research the back is designed as two symmetrical pieces.

Many cyclists say that they always feel uncomfortable on the back after long times of cycling. There are many reasons for this question, such as style, pattern and material. Whether style and pattern or material, these factors influence the output of clothing pressures ultimately. The change of clothing pressures leads to the wear comfort deteriorating. So, our main objective is to reduce the back’s clothing pressure by modifying garment patterns. As shown in Figure 6, the dynamic clothing pressures of whole back increase except point B1 compared to static clothing pressure. Especially, this increase is significant at points B4, B5, B6, B7, B8 and B9. Points B4, B5, B6, B7, B8 and B9 correspond to the upper middle part of the back. In this context, we tried to add 2 cm ease allowance at the back central line (note: this value is according to our design knowledge and experience); particularly we added more ease allowance at the middle of

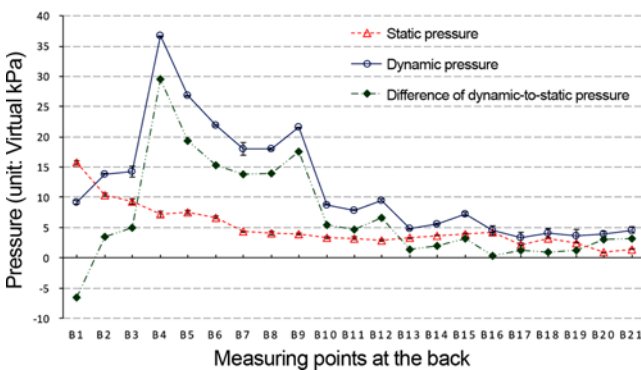


Figure 6. Comparison of static and dynamic clothing pressure at the back.

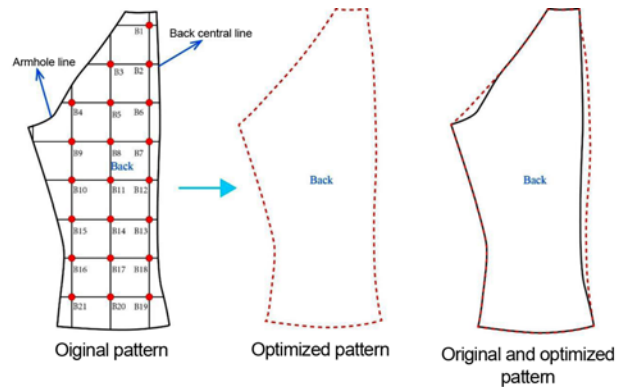


Figure 7. Comparison of static and dynamic clothing pressure at the sleeve.

the back (Figure 7) until the result was satisfying. As the dynamic clothing pressures at points B4, B5, B6, B7, B8 and B9 increased much more, the added ease allowances at middle back still could not fully eliminate the increased clothing pressure. We added some ease allowance at the armhole line of the back piece for two reasons: first, reducing dynamic clothing pressure; second, straightening the back’s armhole line for easy sewing. The ultimate optimized back piece’s pattern is shown in Figure 7.

Analysis of Clothing Pressure on the Sleeve and Optimization of the Sleeve’s Pattern

The sleeve is the most complex part of cycling jersey; it is usually designed as raglan sleeve. This kind of sleeve is more conducive to movement and offer more fit to the shoulder and arm. Some cyclists complain that the armpit feel uncomfortable during cycling. There are two main causes of the discomfort: firstly, a large amount of sweat is generated in armpit after a prolonged period of cycling, and that sweat doesn’t be evaporate or dry up in time; secondly, the sleeves are excessively tight and result in high clothing pressures at the armpit. Some excellent air and moisture permeable fabrics have been developed to solve the first problem. Optimization of the construction of sleeve pattern to reduce clothing pressure is a feasible solution for the second problem; therefore, pressure analysis is an effective method to evaluate sleeves’ wear comfort.

As shown in Figure 8, the static and dynamic clothing pressures at the sleeve are both high except at points S1 and S2; especially, at point S11. It shows that the wear comfort at the sleeve is bad and the sleeve pattern needs a great adjustment. The cyclist’s body leans forward during cycling (Figure 2). This condition results in generation of many wrinkles in the front armpit and tightening the back armpit. In order to reduce the clothing pressures around point S11, we increased this part’s ease allowance and the length of the back armhole curve. If the length of the back armhole curve increases along the direction of sleeve length, the cycling

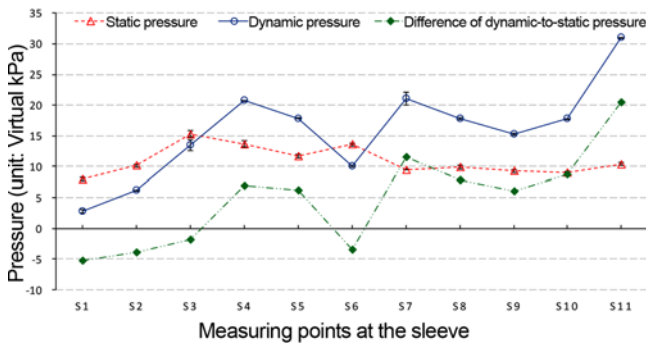


Figure 8. Comparison of static and dynamic clothing pressure at the sleeve.

Table 2. OD values for quantitative analysis of optimized results (Unit: Virtual kPa)

Fabric type	Collar	Front	Back	Sleeve
Fabric A	1.80	1.73	7.52	9.38
Fabric B	27.54	9.99	28.65	34.92

Note: OD is optimization degree.

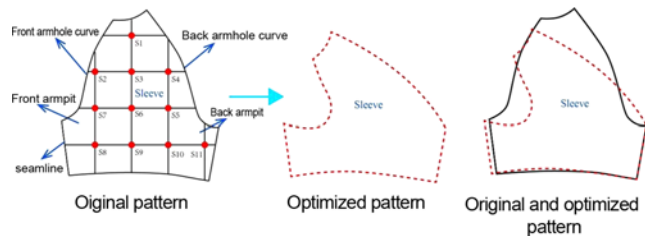


Figure 9. Comparison of static and dynamic clothing pressures based on different fabric properties.

cloth’s style will change (the sleeve length is different from the original sleeve pattern). For this reason, the length of the back armhole curve was increased along the direction of the front armhole curve (Figure 9), which leads to a shortened length of the front armhole. Combined with many wrinkles in the front armpit during cycling, we increased the length of the sleeve’s armhole curve along the direction of back armhole until the length of the front piece pattern’s armhole curve equaled the length of the sleeve pattern’s armhole curve. Moreover, we added 1 cm ease allowance at the sleeve seamline to reduce the static and dynamic clothing pressure. Until the result was satisfying, we continued adjusting. The principle of adjustment is that the optimized sleeve pattern’s area should be kept as equal as possible to the original sleeve pattern’s area. The ultimate optimized sleeve piece’s pattern is shown in Figure 9.

Results and Discussion

Virtual Try-on and Validation of the Result of Pattern Optimization Based on two Kinds of Entirely Different Fabrics

The aim of the pattern optimization is to improve the wear comfort in dynamic condition. Different fabric mechanical properties impact clothing pressures obviously [33]. In order to test the optimization effect in the condition of different fabrics, the original and optimized patterns are applied to two fabrics (Fabric A and Fabric B) with extreme different fabric mechanical properties. The mechanical parameters of fabric A and fabric B are shown in Table 1. For fabric A, we measured dynamic clothing pressures with the original and optimized patterns; and then conducted the same procedure with fabric B. The results obtained are shown in Figure 10.

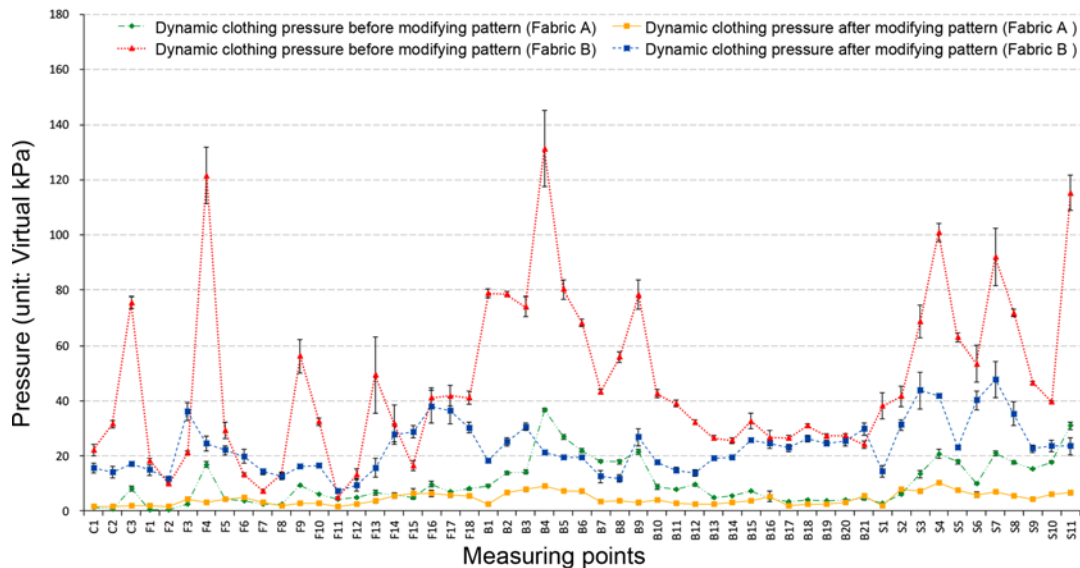


Figure 10. Comparison of static and dynamic clothing pressures based on different fabric properties.

In general, dynamic pressures are lower after pattern optimization for cycling jersey with both fabrics A and B. The optimized patterns' dynamic clothing pressure lines are smoother than the original patterns'. This indicates that the whole wear comfort is better after optimizing patterns.

We propose a formula to carry out the quantitative analysis of the optimization degree.

$$OD = \frac{\sum_i^n (C_i - C_i')}{n} \tag{1}$$

where,

OD is optimization degree (unit: Virtual kPa). This quantitative index indicates whether the garment patterns are optimized and the degree of optimization. If OD is positive, it shows that the wear comfort improves after adjusting the patterns. Conversely, if OD is negative, it shows that the wear comfort becomes worse after adjusting the patterns. Moreover, if OD is positive, the larger OD is, the better the optimization is. If OD is negative, the smaller OD is, the worse the optimization is.

n is the number of measuring points of clothing pressures.

C_i is the dynamic clothing pressure of original patterns at the i th point.

C_i' is the dynamic clothing pressure of optimized patterns at the i th point.

According to the formula (1), we calculated OD values, and the results are shown in Table 2. All OD values are positive (Table 2); it implies that the wear comfort of all the patterns improved well. For fabric A and fabric B, the most obvious reduction of dynamic clothing pressures is at the sleeve and back. These two parts are also the most uncomfortable for cyclists when they have a long duration of cycling.

The above analysis results show that the proposed method based on DSDCP is also suitable for other fabrics of different mechanical properties. The result is significant for

practical application. Based on this result, the measurement of fabric mechanical properties can be omitted in the practical application for enterprises without fabric properties' testers.

Real Try-on and Validation of the Result of Pattern Optimization Based on Real Cycling

Although the results in Table 2 show the optimized patterns are better than original patterns, all experiments above were carried out in a virtual environment. The ultimate objective of this research is to develop good cycling clothes products for cyclists. Thus, the real try-on and evaluation are essential for the final cycling jersey. We made two cycling jerseys in the same fabrics according to the original and optimized patterns (Figure 11). The cycling experiments were carried out indoors to eliminate the influence of external conditions, such as, wind and sunlight. A tester, whose body dimensions are equal to dimensions of the 3D body in Figure 2, would wear the jersey, made according to the un-optimized patterns, and then ride a bicycle for 30 minutes. After this, the tester would answer a questionnaire about wear comfort at different

Table 3. The evaluation of wear comfort after thirty minutes cycling

Pattern	Parts	Very uncomfor- table	Fairly uncomfor- table	Little uncomfor- table	No feeling
Original patterns	Collar			√	
	Front			√	
	Back		√		
	Sleeve	√			
Optimized patterns	Collar				√
	Front				√
	Back			√	
	Sleeve			√	



Figure 11. Validation of the result of pattern optimization.

parts of the human body (Table 3). In order to reduce the influence of physical fatigue, we let the tester take a day. In the next day, the tester would wear another cycling cloth made according to the optimized patterns and then ride the bicycle for 30 minutes too. And then he answered the questionnaire again (Table 3). The results of evaluation show that the optimized patterns' wear comfort becomes better in the parts of the collar, front, back and sleeve. The most obvious improvement of wear comfort is at the sleeve (Table 3). The above evaluations indicate that it is feasible to optimize garment pattern based on clothing pressure; the garment pattern optimization method based on DSDCP can improve the wear comfort of cycling clothes significantly.

Conclusion

In this research, we propose a method based on DSDCP to optimize cycling jersey patterns for improving dynamic wear comfort. The experiments are carried out in a virtual environment. This method not only saves the manpower and material resource, improves efficiency, but also easy to operate. It is appropriate for enterprise/commercial application without expensive instruments of clothing-pressure measurement. Through some experiments and analysis above, the main conclusions are summarized as follows:

1. It is feasible to optimize garment pattern based on DSDCP; and the proposed method can improve dynamic wear comfort significantly.
2. OD is a reliable index to reflect to what degree the pattern is optimized.
3. Our proposed method can also be applied to other fabrics of different mechanical properties.

Further study can be along two directions: one is to find the relationship between the garment pressure variance and clothing ease allowance; thus, pattern makers can modify patterns quantitatively according to this relationship. The other is how to apply the proposed method to loose garments.

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