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The relation between body surface angle and apparel ease distribution under the motion state

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Abstract

Purpose – The purpose of this paper investigates dynamic ease distributions of clothes at bust and waist lines with different body surface angle by using a Qualisys three-dimensional motion capture system (3DMCS).

Design/methodology/approach – The current method first obtain the specific markers of participants and their clothes along the bust and waist lines through 3DMCS, then using the least square method and four piecewise polynomial fitting participants and their clothes' bust and waist curves. The coordinates of the markers were tracked by the 3DMCS, while the participants under different body surface angle walked on a treadmill calculated the distances of markers coordinates to the participants' bust and waist curves. Finally, the data of samples were analyzed. It was found that the dynamic ease distributions showed different patterns at different body surface angle.

Findings – The results revealed the bust convex angle is 26.53 degrees (Specification:X3) and back slope angle is 13.96 degrees (Specification: Y1), the fluctuation of participant ease distributions on bust section was most obvious, and the maximum fluctuation value was ±20 mm and ±25 mm. The ease distributions of participant waist section fluctuated most obviously when the bust convex angle is 28.10 degrees (Specification: X5) and the back slope angle is 13.96 degrees (Specification: Y1), and the maximum fluctuation was ±30 mm and ±20 mm. The bust convex angle has the greatest influence on 1# garment, and the back slope angle has the greatest influence on 2# garment.

Originality/value – Currently, there is little information in the literature about dynamic ease distributions of garment on a different body types. This paper takes different body surface angles as the research objects to analyze the ease distributions of different clothes, the conclusion can provide reference data for 3D garment modeling and improve the authenticity of virtual garment fitting.

Keywords Dynamic ease distribution, Body surface angle, Garment pattern

Paper type Research paper

Introduction

Ease allowance, usually measured by the circumferential differences between clothes and the wearer's body (Xu *et al.*, 2009), which is an important factor that cannot be ignored in the study of three-dimensional (3D) clothing simulation, clothing fit and safety of protective clothing (Liu *et al.*, 2014, 2017; Barker and Hamouda, 2004). It is far from enough to use the information obtained by traditional measurement method to reflect the complex relationship between human body and clothing, and the distribution of ease was closely related to human body shape and human movement state. The traditional research method of ease distribution was to use 3D scanner to obtain the data of mannequin and clothing, and explore the correlation between fabric properties, ease allowance and ease distribution through different methods. Based on the distance between clothing and human body, the

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relationship between ease allowance and ease distribution at different section angles of human body was obtained (Xu and Zhang, 2008; Zhang *et al*., 2012). The volume of space under clothing was also used to represent the ease distribution to explore its relationship with fabric properties and its influence on the overall thermal insulation performance of clothing (Spelic *et al*., 2018; Yu *et al*., 2012). Agne Lage improved the fitness of 3D virtual fitting software by studying the influence of fabric mechanical properties on the dressed ease (Agne and Kristina, 2017). Although these studies provide some information between ease distribution and clothing, but for the study of complex relationship between human body and clothing is not enough, and the body shape and motion state was important factors affect ease distribution, therefore, it was necessary to study the distribution of ease on different body shape during activities. Emel M and Choi, S studied the spatial distribution under clothes of different section of human in different postures based on human body postures (Emel and Agnes, 2017; Choi and Ashdown, 2011). Takada. S and Lee, D.W uses CFD to analyze the flow of static and dynamic air layer under the clothing (Takada, 2016; Lee *et al*., 2018). However, all these studies use mannequin or thermal manikin as the research object, ignoring the difference of body shape and the change of ease distribution.

The goals of this paper were to develop a practical method for acquiring dynamic ease distributions of clothes on different convex angles of body surface. We used a three-dimensional motion capture system (3DMCS) to capture the coordinates of designated points on bust and waist cross-section of a dressed participant when the participant was in different bust convex angle and back slope angle. The least square method and quartic polynomial were used to fit the cross-section curve of participant. MATLAB was used to calculate the shortest distance of markers coordinates to the participant bust and waist curves, and define the distance as the value of ease distribution. Analyze the influence of the bust convex angle and the back slope Angle to the bust and waist section ease distributions. The results can be used to improve the authenticity of the dynamic 3D simulation of clothing, and can also provide a reference for the optimization of clothing patterns design from different body shape.

Experiments

Even if an ease allowance at a landmark (bust, waist, etc.) is given, the ease would be distributed around the waist section depending on factors such as the clothes structure, material properties, body size and its posture. People spend most of their daily lives walking and running. In this experiment, these factors should be determined first.

Material and methods

Setting method of body surface angle

This paper studies the fluctuation distribution of ease on bust and waist section in dynamic state, by examining the size data of Chinese female aged 18–25 in human dimensions of Chinese adults (GB10000-88), this paper selects two body surface angles, the bust convex angle and back slope angle, as shown in Figure 1, which can reflect the morphological characteristics of human bust and shoulder measurements. In order to improve the authenticity of the experiment, one experimental subject of this paper was a Chinese female with a standard body shape (bust circumference is 84 cm, height is 160 cm). Based on her bust convex angle and back slope angle, six different specifications of bust convex angle are obtained by experimenter with wearing bar of six different thicknesses, as shown in Plate 1. The number of reconstructed bust convex angle was measured by Geomagic, which was numbered X1–X7 and used as the parameter specification of the bust convex angle, In the

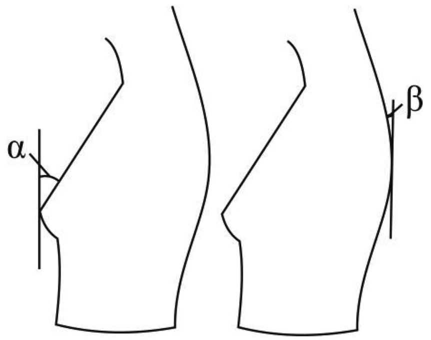


Figure 1.
Bust convex angle and back slope angle

Plate 1.
Setting and measurement of bust convex angle

same way, based on the original back slope angle of the experimenter, taking 2^0 as a file difference, three different back slope angles are reconstructed and numbered as Y1–Y3 as the parameter specification of the back slope angle, Tables 1 and 2 are the specifications of the bust convex angle and back slope angle of the subjects.

The experimental garment

According to the preliminary experiment, it was found that when the experimenter wore garments made of thin and loose fabric, the three-dimensional coordinates of the marks on the experimenter body could be captured by 3DMCS. On the other hand, as shown in Table 3, cotton fabric is the most widely used fabric in the garment industry. The thickness, drape coefficient and structural tightness of plain cotton fabric are moderate. Therefore, cotton fabric is used as the experimental garment material in this paper, and then Japanese cultural prototype was used to make eight experimental garments with different ease allowance (Figure 2). The specific specifications of the garments are shown in Table 4.

Experimental installation

3DMCS (Plate 2) from Sweden is adopted in this paper, which is the only optical motion capture system in the world that supports passive and active motion capture. It supports two types of marker balls, one is the passive marker ball captured through reflection, and the other is the active marker ball captured by the lens by emitting infrared light. The active marker ball specification is 16×10 mm, and the passive marker ball specification is 6 mm or 16 mm. Both kinds of marker balls can be firmly attached to clothing and body surface.

Table 1.
Specification parameters of bust convex angle

Bust convex angles	X1	X2	X3	X4	X5	X6	X7
Degrees/(°)	13.96	24.49	26.53	27.93	28.10	31.22	33.42

Table 2.
Specification parameters of back slope angle

Back slope angles	Y1	Y2	Y3
Degrees/(°)	13.96	15.96	17.96

Table 3.
The fabric performance

Fabric	Fabric structure	Fabric composition	Density (The root/ 10 cm) Wrap	Weft	Thickness (mm)	Drape coefficient
Cotton fabrics	Plain	100% Cotton	400	340	0.18	46.00

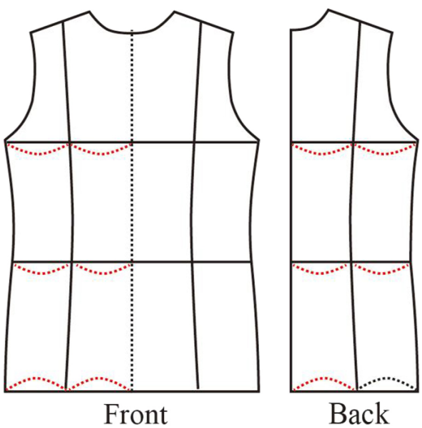


Figure 2.
Pattern of the experimental garments

When human body moves, nine high-resolution cameras can record its spatial coordinates synchronously. In this paper, only a small passive marker ball (6 mm) was used on the surface of the garments because the active marker ball has a cable, which may limit the drapiness of the clothes. 6 mm passive marker ball weighs 0.2 g, its weight can be ignored when glued to garments.

Experimental procedure

Researchers adopted a Qualisys 3D motion capture system as the experimental equipment.

(1) That determine the capture area and running posture of experimental.

(2) The experimental wore bras of different thickness, and 20 marker balls were evenly pasted on her bust, including 2 active marker balls and 18 passive marker balls.

(3) The experimental entered the experimental capture area, stood in a stable position and collected the coordinates of bust marker points for 30 s.

(4) A total of 18 marker balls were pasted equidistant from the waist of the experimental, including 2 active marker balls and 16 passive marker balls. The coordinates of waist marks were obtained according to the operation method in Step (3).

(5) The experimental removed the passive marker balls from her body, wore the garment 1# and stick 14 passive marker balls equidistant to the bust section of the garment

Number of garments	B(cm)	W(cm)	H(cm)
1#	86	70	86
2#	90	74	90
3#	92	76	92
4#	94	78	94
5#	96	80	96
6#	100	86	100
7#	103	89	103
8#	106	92	106

Table 4. Size specification of the experimental garments

Plate 2. 3D motion capture system

except for the front center point and back center point. The experimental entered the experimental capture area and ran according to the fixed running posture (4 km/h). The researchers obtained the coordinates of marker points on the bust section of the subjects during running.

(6) A total of 14 passive marker balls were evenly pasted on the waist section of the 1# experimental garment except for the front center point and back center point. And the researchers obtained the coordinates of marker points on the waist section of the experimental during running

(7) The experimental replaced the chest pad in the bra, and proceeded to the next experiment according to steps (5) and (6). Experimental were asked to wear bras of six different thicknesses in seven experiments.

(8) At the end of each experiment, the experimental changed the garments and repeated the above steps.

(9) After seven different bust convex angle tests, subjects performed three different back slope angle tests using the same procedure described above.

In order to avoid the human error of experimental operation, each garment was tested three times under each grade difference specification, and the mean value was taken as the experimental result.

Ease calculation

Many methods have been used to characterize the cross-sectional ease of the clothes and body. This paper adopts the method proposed by Liu *et al.* (2019) to obtain the cross-sectional ease.

Polynomial curves were used to fit the bust and waist section curves of human body, and then the coefficients of polynomial equations of each segment fitting curve were obtained by using the principle of least square method. The fitting equations of bust and waist section curves were shown in Formula (1).

$$f(x) = \sum_{i=0}^{4} p_i \, x^i \quad (1)$$

where p_i is the fitting constant, x is the coordinate value of a marker point.

Although the body contorted and fluctuated in the process of movement, the overall shape of bust and waist did not have significant deformation. Therefore, the coordinates of the marks on the bust and waist section of garment are projected onto the plane of the bust and waist section by translation method. Then the shortest distance from the mark point on the garment to the fitting curve of the human body was calculated (Figure 3).

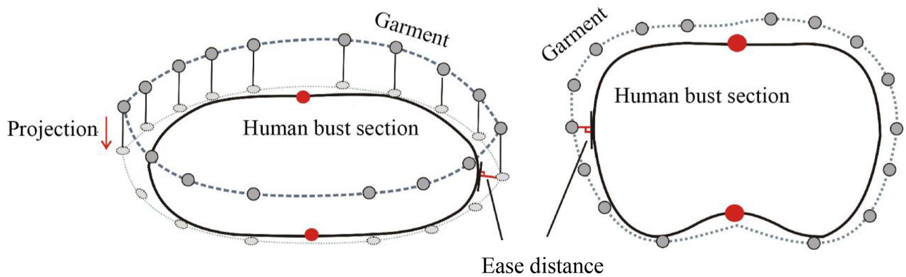


Figure 3. Projection of a clothes cross-section to the plane of the corresponding body cross-section

Since the overall shape of bust and waist did not have significant deformation during running, the fitting equation of the human cross section curve in the static state was also applicable to running. According to the coordinates of the mark points in front point and back point of the bust and waist section of subjects during running, the cross section curve equation of the human body in running can be obtained by translating the cross section curve. Let (x_1, y_1) and (x_2, y_2) be the front and back center coordinates of the subject was at rest, and (x_3, y_3) and (x_4, y_4) be the corresponding two-point coordinates under the running state, then the translation of the section curve was:

$$\Delta \mathrm{x} = \frac{[x_4 + x_3 - (x_2 + x_1)]}{2} \tag{2}$$

$$\Delta y = \frac{[y_4 + y_3 - (y_2 + y_1)]}{2} \tag{3}$$

The curve of bust and waist section in Formula (1) was translated by Formula (2) and (3) to calculate the fitting equation of bust and waist curve under running state.

$$y = f(x - \Delta x) + \Delta y \tag{4}$$

In this paper, the shortest distance from the clothing marker point to the body cross-section was calculated by using the steepest descent method, which is defined as the function is differentiable and defined at a certain point, then the function descends fastest along the opposite direction of the gradient at that point. Since the magnitude value of dressed ease was greater than 0, the steepest descent method is adopted to solve the sum of squares of distance (Formula 5), and its square root value was dressed ease.

$$D(x) = d^2(x) = (x - X)^2 + (y - Y)^2 \tag{5}$$

According to the Taylor expansion, the formula can be described as below:

$$D(x^{\mathrm{i}} + tp^i) = D(x^i) + tp^i \nabla D(x^i)^T + o(\|tp^i\|) \tag{6}$$

The infinitesimal of higher order $\mathrm{O}(\|\mathrm{t}p^i\|)$ can be omitted generally. The formula can be expressed as the following:

$$D(x^i) - D(x^i + tp^i) = -tp^i \nabla D(x^i)^T \tag{7}$$

when $p^{\mathrm{i}} = -\nabla D(x^{\mathrm{i}})$, the function goes down the most. Therefore, the minimum value of $D(x)$ can be calculated according to the following steps:

Step1: Define the initial point $x0$ and the termination error $\varepsilon > 0$. Set $i = 0$.

Step2: Calculate $\nabla D(x^{\mathrm{i}})$. If $\|\nabla(x^{\mathrm{i}})\| < \varepsilon$, terminate the iteration and output x_i. Otherwise, set $p^{\mathrm{i}} = -\nabla D(x^{\mathrm{i}})$, find t_i with a one-dimensional search method satisfy:

$$D(x^i + t_i p^i) = min_{t \geq 0}(x^i + tp^i) \tag{8}$$

Step3: Set $x^i + 1 = x^i + t_i p^i, i = i + 1$. Return to step 2 and continue the iteration. Search the optimal step length t_i with the one-dimensional optimization method as shown in Formula (9).

$$\mathrm{D}(x^{\mathrm{i}+1}) = \mathrm{D}(x^i - t_i \nabla \mathrm{D}(x^{\mathrm{i}})) = \min_t \mathrm{D}(x^i - t \nabla \mathrm{D}(x^{\mathrm{i}})) \tag{9}$$

When the iteration terminates, the value obtained was the minimum value of D. Take the square root of D to get the value of ease.

Results and discussion

The ease distribution was irregular, if all the marker points are analyzed together. In order to clearly describe the changes of ease distribution in the bust and waist sections, the body cross-section of bust and waist sections were divided into four regions: front, back, left and right for regional analysis, as shown in Figure 4. Calculate the value of ease, and then obtain the average value, as shown in Figure 5. It can be seen from that the ease value of marked points in each region is relatively consistent. Table 5 was the correlation analysis of the marker points ease in different bust regions. The correlation between the marker points ease in the same region was significant, and the variance analysis shows that the variance of ease in the same region was not significant. Therefore, this paper selects the mean value of dressed ease in each region to research the change rule.

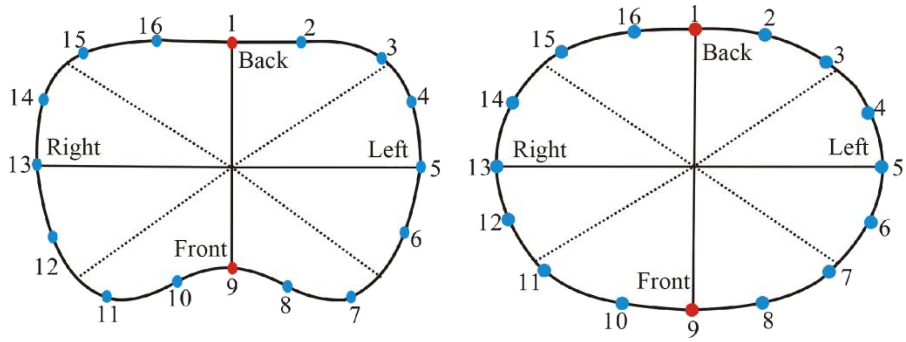
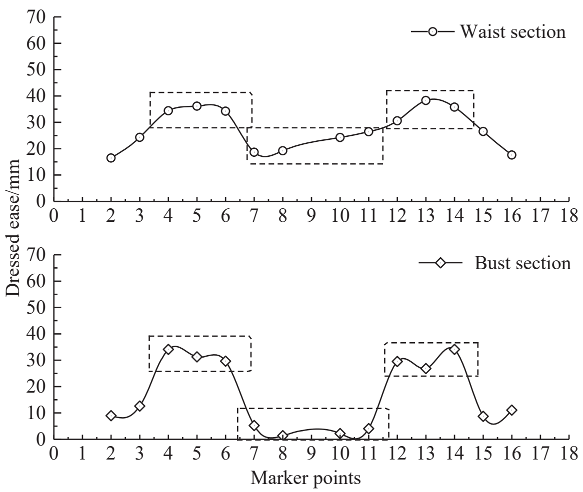


Figure 4. The distribution of marker points in bust and waist section



Note(s): The circle represents the mean value of waist section dressed ease in 200 frames, and the diamond represents the mean value of bust section dressed ease in 200 frames

Figure 5. The ease distribution of bust and waist section of 5# garment

Dynamic ease distribution of bust section analysis

Effect of bust convex angle on ease distribution at bust section. People in the process of running, the bust section ease distribution interval of present certain regularity, Figure 6 shows ease distribution between the opposite trend of fluctuations in the left and right region of the bust section, between highly negative correlation (r = 0.961, $p < 0.001$), and this is because the people in the process of running the arm back and forth reciprocating motion affects bust moving on both sides of the garment, which led to the change of ease distribution in the left and right regions of the bust section. Due to the consistency of the posture during running, the front and back regions of the bust section showed the same fluctuation trend, and there was a highly positive correlation between the two ($r = 0.995, p < 0.001$). Because the garments in the front regions were relatively close to the human bust, the fluctuation of the dressed ease value was smaller than that in the back regions during running.

The fluctuation rule of ease distribution in different regions of bust section during running was related to the size of bust convex angle. When people with different bust convex angles wear different size garments, the front region of bust section is more suitable to the garments and the fluctuation was small during running. Therefore, there was no correlation between the value of ease in the front regions of the bust section and the bust convex angle ($R = 0.236$, $p > 0.05$). There was a weak correlation between the size of the bust convex angle and the value of ease in the back region ($R = 0.425, p < 0.05$), and a high correlation between the size of the left and right regions ($R = 0.936$, $R = 0.921$, $p < 0.001$).

For different garments, with the increase of the bust convex angle, the value of ease in the left and right areas of the bust section showed a decreasing trend on the whole. The number 5# garment showed the most obvious decreasing trend, and there was a high correlation between the bust convex angle and the value of dressed ease ($r = 0.997, p < 0.001$), indicating that the number 5# garment was most affected by the bust convex angle. Ranges for all the experimental garments, when the bust convex angle specifications for X3, left and right

Table 5. Analysis of regional variance of bust section

Bust section	Pearson correlation analysis (sig.) 1#	2#	3#	4#	5#	6#	7#	8#
Back region (15/16/2/3)	0.659	0.865	0.902	0.628	0.879	0.857	0.835	0.734
Right region (4/5/6)	0.702	0.928	0.857	0.745	0.701	0.771	0.935	0.849
Front region (7/8/10/11)	0.899	0.735	0.947	0.827	0.936	0.901	0.981	0.961
Left region (12/13/14)	0.798	0.728	0.805	0.917	0.761	0.914	0.659	0.923

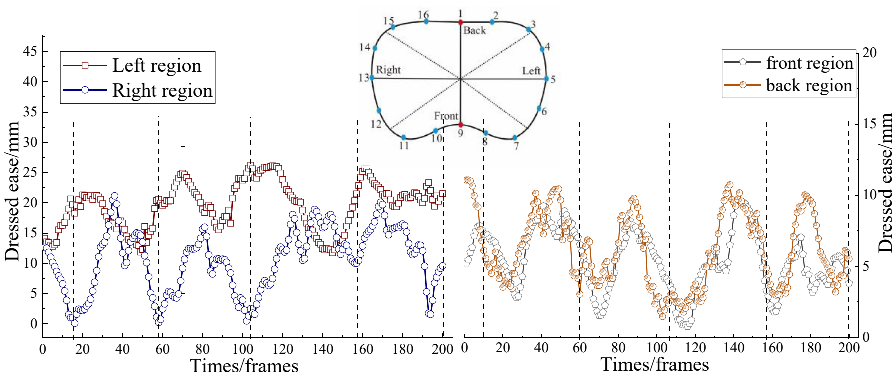


Figure 6. Fluctuation chart of ease distribution in bust section of 5# garment

regions ease distribution fluctuations around the most severe thoracic (20 mm, −20 mm) this is due to the bust convex angle size was moderate, which guarantee the left and right regions has a certain ease allowance, and in the front region provides a certain space, make the garments in the process of running in the bust section deformation was obvious. The effect of the bust convex angle on the fluctuation of the ease distribution with the increase of the garment size.

In the process of running, the fluctuation of ease distribution in the bust section of the 1# garment was most affected by the bust convex angle (−10 mm, 10 mm). As the increase of the garment allowance, the garment in the left and right regions are gradually away from the bust. Therefore, the fluctuation of ease distribution in the 8# garment was basically unaffected by the size of the bust convex angle (−5 mm, 5 mm).

Effect of back slope angle on ease distribution at bust section. The back slope angle was located at the position of human scapula, so the change of ease distribution in the back region and left and right region of human bust section was greatly affected by the back slope angle ($r = 0.986, r = 0.932, r = 0.911, p < 0.001$). There was no correlation of ease distribution between the front region of the bust section ($R = 0.241, p > 0.05$) because the garment of the front region of the bust section was fitted to the body, and the distance from the back slope angle was far. As shown in Figure 7, the back slope angle during running has a significant impact on the fluctuation of ease distribution in the back region of different size garment, and the most significant impact is on the 1# garment. With the increase of the back slope angle, the fluctuation of the ease distribution gradually tends to be gentle, which indicates that the larger the back slope angle was, the less the influence on the fluctuation of the ease distribution was.

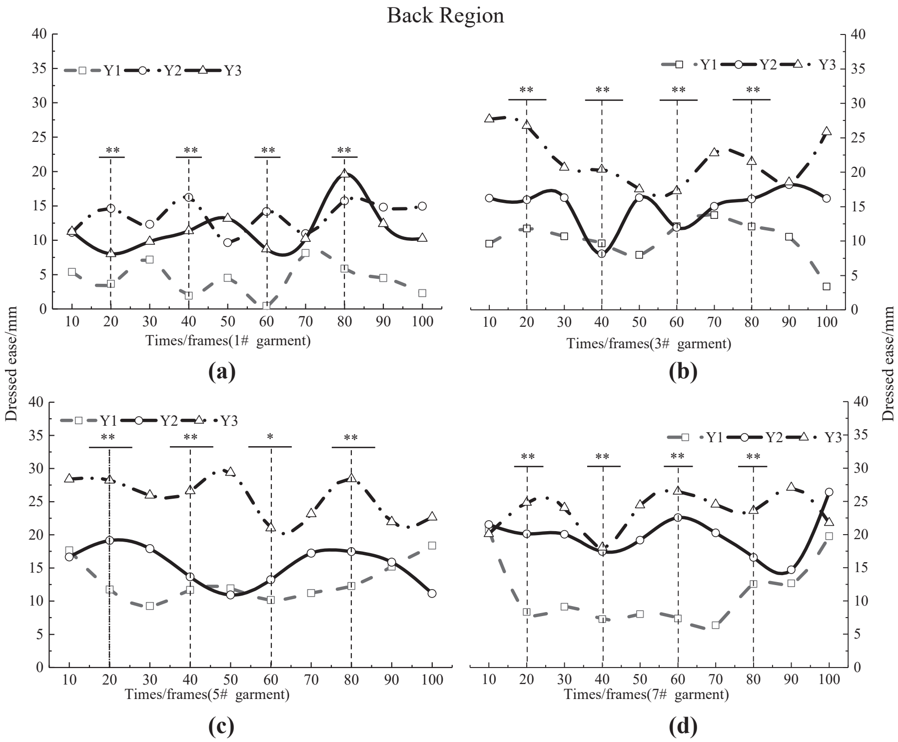


Figure 7.
The ease distribution fluctuates on back region

As can be seen from Figure 8, for garments of different size, the value of ease in the right region gradually decreases with the increase of back slope angle, and the value of ease in the right region of each garment decreases by 20 mm at most. In the process of running, the fluctuation of ease distribution in the right region was the most severe (−10 mm, 10 mm) when the back slope angle specification was Y2, and the fluctuation was the most gentle (−2.5 mm, 2.5 mm) when the back slope angle specification was Y3, indicating that the fluctuation of ease distribution in the right region was not affected by the too large or too small back slope angle.

Dynamic ease distribution of waist section analysis

Effect of bust convex angle on ease distribution at waist section. The fluctuation state of the waist section ease distribution was greatly affected by the bust convex angle during the running. As can be seen from Figure 9, there was a highly linear correlation between the sternal angle and the bust convex angle in the front and back regions ($r = 0.924$, $r = 0.931$, sig.<0.001). When the specification of the bust convex angle was X1, X5 and X7, the fluctuation value of the ease in the waist section was ±10 mm, ±15 mm and ±10 mm at most. Among them, the 7# garment with larger ease allowance and the 1# garment with smaller ease allowance are greatly affected by X1 and X7, while the 3# and 5# garments are greatly affected by X5. This indicates that the ease distribution of front and back region too much or too small garments was more significantly affected by the bust convex angle. For the same garment, the increase of the bust convex angle leads to an increase in the front region of the waist section and a decrease in the back region, but the change was not obvious (−10 mm, +10 mm). This is because there was a certain distance between the waist and the bust, and the waist ease distribution was more affected by gravity than the bust convex angle.

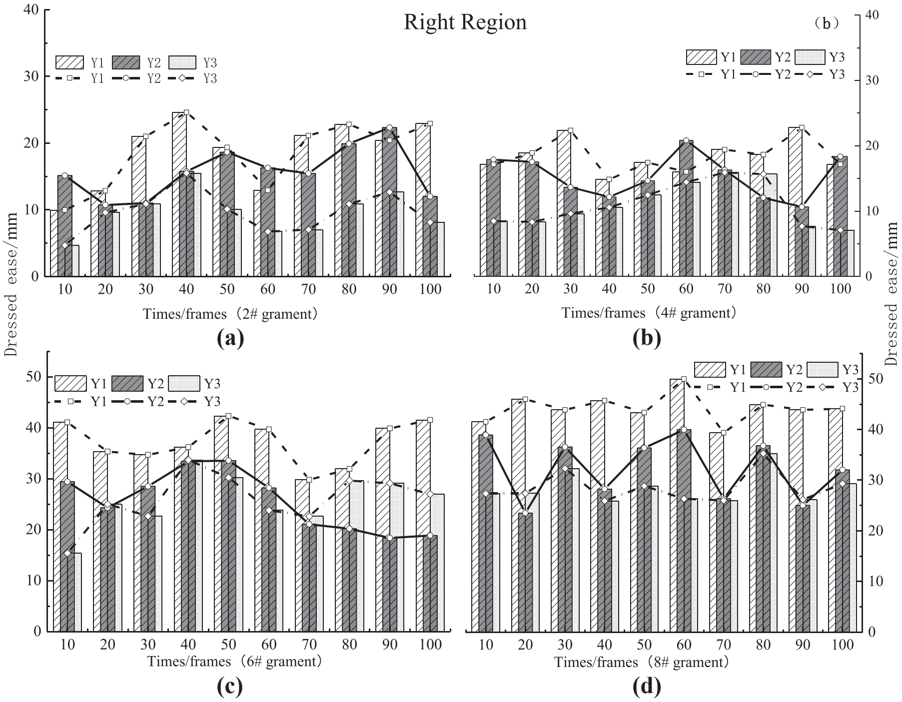


Figure 8.
The ease distribution fluctuates on right region

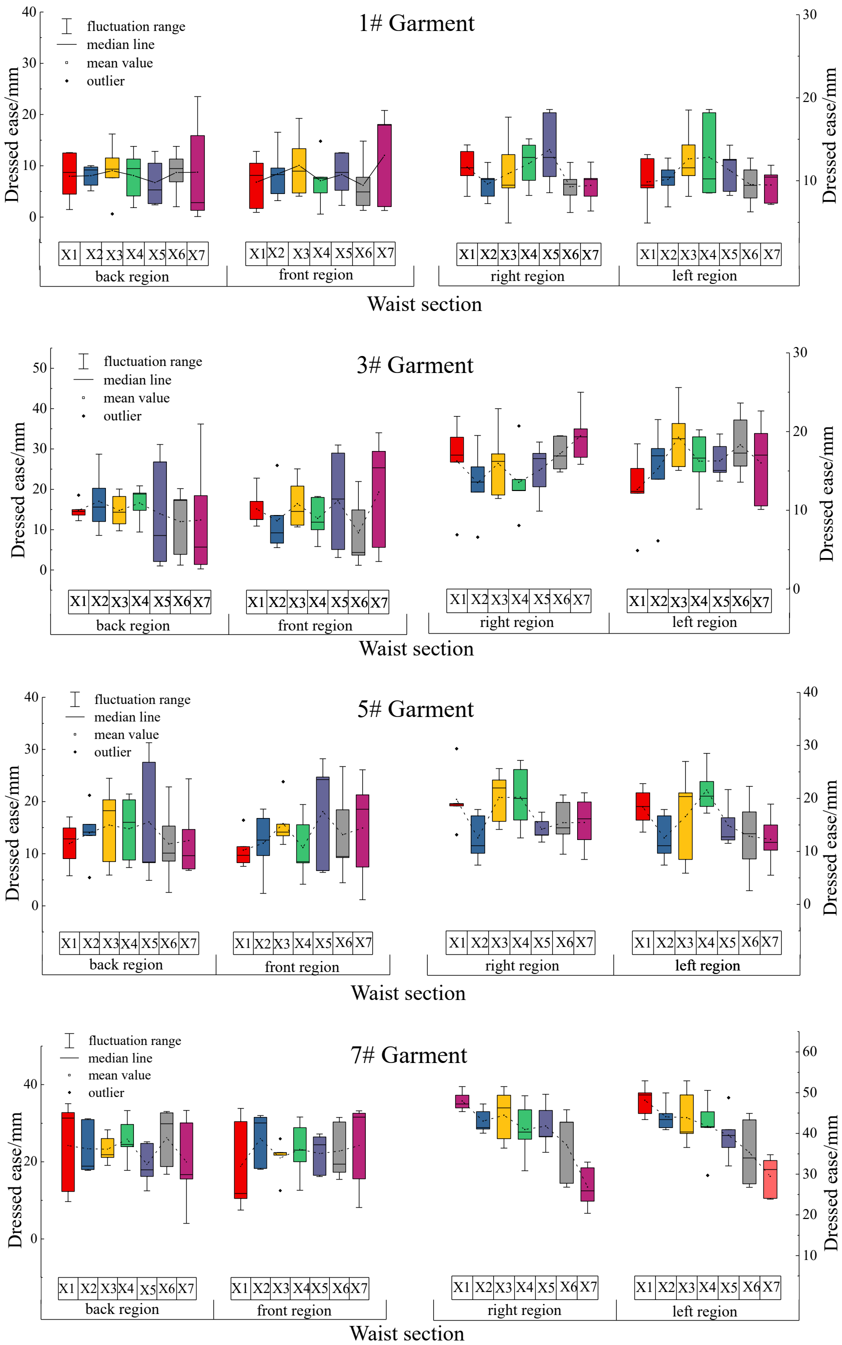


Figure 9.
Ease distribution fluctuates at different bust convex angles

There was a highly linear correlation between the bust convex angle and the value ease in the left and right regions of the waist section ($r = 0.891$, $r = 0.783$, sig.<0.01). As can be seen from Figure 9, with the increase of the bust convex angle, the value of ease in the left and right regions of the waist section showed a decreasing trend on the whole. This was because the position of the bust convex angle was in the front middle region of the human body. Increasing the bust convex angle will lead to the transfer of the ease distribution on the left and right regions of the waist section to the front middle region. In the process of running, the specification of too large bust convex angle (X7) and too small bust convex angle (X1) had little influence on the fluctuation of waist section ease distribution in the left and right areas of different size garments, and the maximum value was ±5 mm and ±2 mm, respectively. This indicates that too large or too small bust convex angle has little influence on the fluctuation of ease distribution of waist section with different ease allowance during running. This was because the small specification of the bust convex angle has a small support effect on the waist section of the sample clothing, and the fluctuation of the left and right regions of the ease distribution was not affected by it. Large size bust convex angle of garment around waist section support leads to left and right regions of garment in a tense state, leading to ease fluctuations in the running process is not obvious.

Effect of back slope angle on ease distribution at waist section. The specification of back slope angle had a significant influence on the fluctuation value of ease in all regions of waist section during running ($r > 0.8$, sig <0.001). As shown in Figure 10, the increase of the back slope angle leads to the decrease of the value of ease in the front region and the increase in the back region. The fluctuation of ease distribution in the front region decreases with the increase of the back slope angle (±15 mm~±5 mm). The fluctuation of ease distribution in the back region was less affected by the back slope angle and fluctuates between −5 and 5 mm. The reason for this result was that with the increase of back slope angle, the value of ease in front region of waist section gradually decreases, so as to contain its fluctuation during running. Waist section of left and right region has opposite trends in the process of fluctuations, and back into the smaller the angle, the more obvious this trend. This was because the increase of the back slope angle leads to most of ease distribution on waist section transferring to the back region. The left and right regions of the garments are in a tight state and are less affected by the pulling effect of the force during running. To sum up, the increase of the back slope angle will lead to the fluctuation decrease of the waist section ease distribution during running.

It can be seen from Figure 10a and b that the back slope angle has different influences on the ease distribution of waist sections on different size garments. In the region front and back the waist section, the 2# garment fluctuation of ease distribution was most affected by the back slope angle, with the maximum fluctuation range of ±20 mm, followed by the 8# garment, with the maximum fluctuation range of ±12.5 mm. For the left and right regions of the waist section, except for the 2# garment, the specification of the back slope angle has little influence on other size garments. This shows that the specification of the back slope angle has a more obvious effect on garment with small or large ease allowance.

Application

Affected by factors such as posture, clothing pattern and gravity during running, clothing will be in the process of shaking after human worn, lead to the fluctuation of ease distribution in bust and waist section, which was different from the uniform distribution in static process. This phenomenon will become more obvious with the increase of clothing ease allowance and running speed, which will affect the comfort and fit of human in the process of sports. In order to improve the distribution and fluctuation of ease in the process of movement, and thus improve the comfort and fit of clothing, a pattern in order to improve the distribution and fluctuation of clothing clearance in the process of movement, and thus improve the comfort

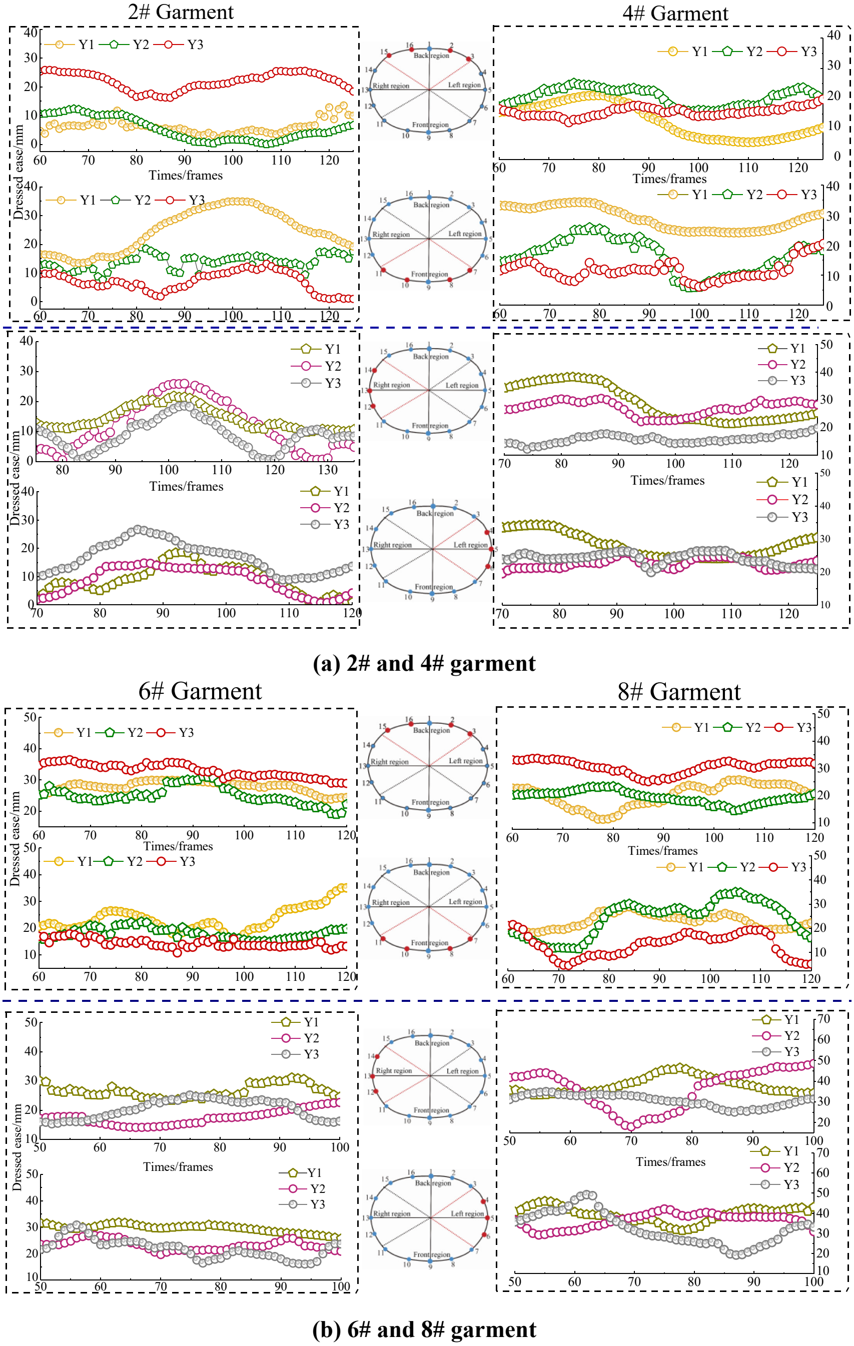


Figure 10.
Ease distribution fluctuates at different back slope angles

and fit of clothing, a pattern optimization method was proposed based on the pattern of the experiment garment adopted in this paper. The specific optimized position was shown in the red line marked in Figure 11.

The above analysis results show that during running, the fluctuation of ease distribution in the bust section was gentle, while that in the waist section was more severe. In addition, the fluctuation of ease distribution in the left and right regions of the waist section was greatly affected by the garment ease allowance and running speed, as shown in Figure 12, the increase of garment ease allowance leads to more obvious fluctuation. Therefore, this paper adjusts the garment pattern based on the fluctuation characteristics of waist section.

The position of clothing parting line was the main factor affecting the appearance effect of clothing and the fluctuation of ease distribution (Xu *et al.*, 2012). Part of the reason for the difference of the waist section ease distribution in the process of running was that the position of clothing parting line changes, thus affecting the fit and appearance effect of clothing. In this paper, by modifying the position of the six parting lines at the waist section of the experiment garment, the garment ease distribution evenly distributed and the fluctuation tends to be gentle. As shown in Figure 13, the red line is the parting line position of the garment after modification, and the black line is the parting line position of the garment before modification. The setting rules for the position changes of the other four parting lines except the side seam of garment are shown in Formula (10).

$$\begin{cases} \theta_{\mathrm{i}}^{c+1} = \theta_i^c - \theta_0 (i = 1, 3) \\ \theta_{\mathrm{i}}^{c+1} = \theta_i^c + \theta_0 (i = 2, 4) \end{cases} (1 \leq c \leq 8) \tag{10}$$

$\vartheta_{\mathrm{i}}^{\mathrm{c}+1}$ is the position of the i parting line of the $c + 1$ garment; $\theta_{\mathrm{i}}^{\mathrm{c}}$ is the position of the i parting line of the c garment; i is the number of the parting line; C is the garment number; $\theta_0 = 2.5^0$.

There are two rules for setting the position of the two parting lines at the side seam of garment. When the bust convex angle specifications are different, the position of the dividing line was moved by Formula (11). When the bust convex angle specifications are different, the position of the dividing line was moved by Formula (12).

$$\begin{cases} \theta_5^{c+1} = \theta_5^c - 1.5° \\ \vartheta_6^{c+1} = \theta_6^c + 1.5° \end{cases} (1 \leq c \leq 8) \tag{11}$$

$$\begin{cases} \theta_5^{c+1} = \theta_5^c + 1.5° \\ \theta_6^{c+1} = \theta_6^c - 1.5° \end{cases} (1 \leq c \leq 8) \tag{12}$$

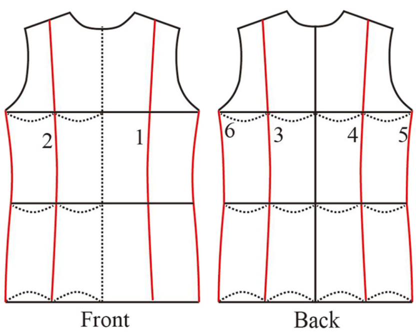


Figure 11.
Schematic diagram of garment pattern modification position

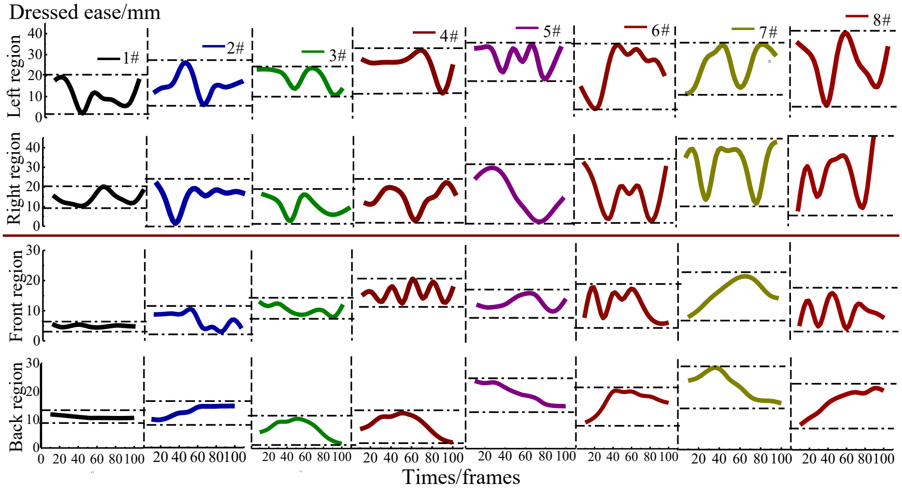


Figure 12.
Waist section ease distribution interval fluctuation

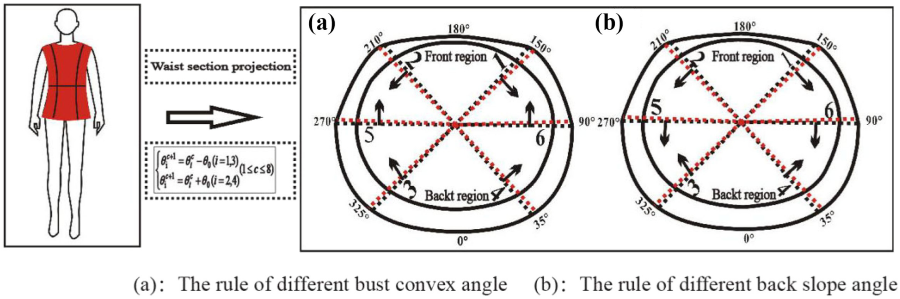


Figure 13.
Schematic diagram of modifying parting line position of garment

θ_5^{c+1} is the position of the five parting line of the $c+1$ garment; θ_5^c is the position of the 5 parting line of the c garment; θ_6^{c+1} is the position of the six parting line of the $c+1$ garment; θ_6^c is the position of the 6 parting line of the c garment; C is the garment number.

The dynamic capture experiment was carried out after modifying the eight garments according to the above method, and the ease distribution was obtained according to the above method. Figure 14 shows the distribution of waist section ease distribution after modification in static state, it can be seen from the figure that the distribution of waist section ease after modification was more uniform than before. The difference of waist section ease distribution between the left and right regions (markers 4, 5, 6 and 12, 13, 14) was within the range of 0–15 mm, The difference of waist section ease distribution between the front and back regions (markers 7, 8, 9, 10, 11 and 15, 16, 1, 2, 3) should be within the range of 0–10 mm. The results show that the appearance and fit of the experiment garments have been improved.

Figure 15 was a schematic diagram of dynamic fluctuation ease distribution in waist section after modification. Compared with Figure 12, it can be seen that the fluctuation ease distribution in waist section was significantly slower than before the modification, and the fluctuation range of left region (marker points 4, 5, 6) and right region (marker points 12, 13, 14) was significantly weakened. With the increase of garment ease allowance, the fluctuation became smaller. The maximum fluctuation range of 8# garment was ±5 mm. At the waist

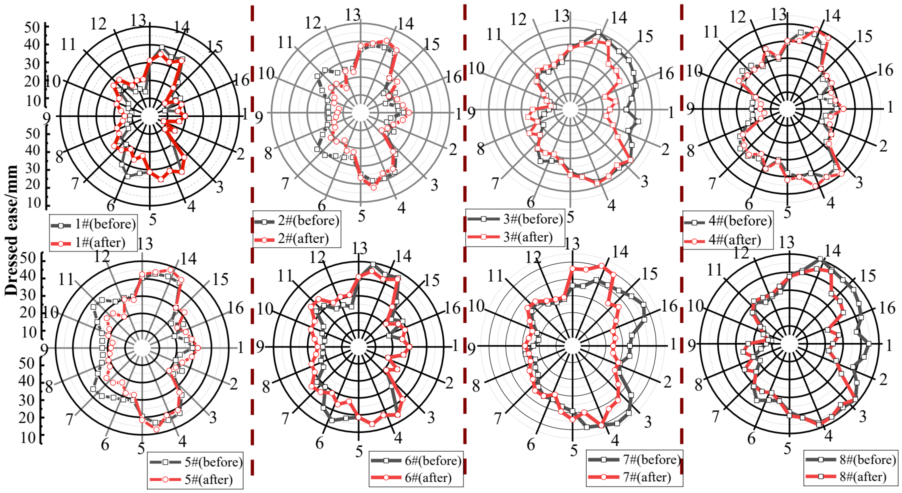


Figure 14.
Static waist section ease distribution of the garment after modify pattern

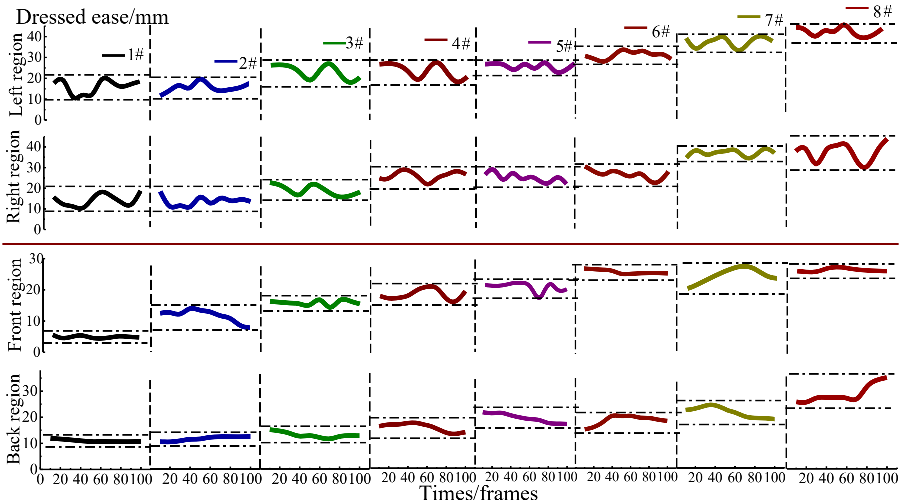


Figure 15.
Dynamic fluctuation of dressed ease in waist section after modification

section, the fluctuation range of ease value was small in the front and back regions, and the maximum value was ±3.5 mm. This further shows that the modification of the experimental garments by the pattern optimization method proposed in this paper can improve the fluctuation of the garment in the process of sports and enhance the comfort of human.

Concluding comments

The ease distributions of dressed clothes were investigated using a 3DMCS in this paper. 3DMCS was used to obtain the spatial coordinates of the marks on the bust and waist section of the participant and her wearing different loose samples under different surface angle during running, and the distance ease at each mark point of the bust and waist section were calculated.

In the process of running, the influence of the bust convex angle on the left and right areas of the bust section is greater than that of the front and rear areas. The correlation between the bust convex angle and the left and right regions of the bust section was $r = 0.936$ and $r = 0.921$, and the correlation between the front and back regions was $r = 0.236$ and $r = 0.425$. When the specification of bust convex angle was X3, the fluctuation was the most severe, and the maximum fluctuation value was ±20 mm. The back slope angle had a significant effect on the front, left and right regions, the correlation was $r = 0.986$, $r = 0.932$ and $r = 0.911$. When the size of back slope angle was Y1, the fluctuation of ease distribution at bust section dressed ease was the most severe, and the maximum fluctuation value was ±25 mm.

The value of ease in the front and back regions of the waist section was greatly affected by the bust convex angle during the running, and the correlation was $r = 0.924$ and $r = 0.931$. When the bust convex angle was X1, X5 and X7, the fluctuation value of ease in the waist section was ±10 mm, ±15 mm and ±10 mm. Back slope angle has a significant impact on the ease distribution in all waist section regions during the running, and the correlation is above 0.8. When the back slope angle was Y1, the fluctuation of ease distribution was the most obvious and the maximum fluctuation was ±20 mm.

Where, 1# garment affected by bust convex angle is the largest, 2# garment back slope angle of influence is the largest.

In this paper, it is of certain reference significance to understand the ease distribution of the human cross section at different body surface angles for the clothing production of different body types and 3D dynamic simulation. In the future, we will further study the value of ease from various aspects, such as fabric, body type classification.

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Further reading

Mir, S. and Young, A.L. (2020), "Identifying key quality features for wearable technology embedded products using the Kano model", *International Journal of Clothing Science and Technology*, Vol. 33, pp. 93-105.

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