Research on Protection Property of Running Sportswear Fabrics Based on 3-D Motion Capture System

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Abstract
The running sport was regarded as the research subject in the topic and the sports biomechanics was applied to the research of the sport protective apparel fabric with the spring-mass model. And the running movement was simplified and the mechanics model between the human body and the fabric, namely the running protective model, was established. On the basis of the model, elasticity and thickness of fabric were further changed to verify their impact on the protection property of the human joints, taking advantage of the 3-D motion capture system to acquire the data of the movement trajectory. The result shows that the changing rate of momentum can be used as the parameter evaluating the protective performance from the protective model in running movement. The change of the fabric elasticity and thickness has some influence on the evaluating parameter of skeleton. Moreover, the effect of the fabric thickness is more obvious and representative of the protective performance of joints, which could serve as the basis that designs and develops the running protective sportswear.

Keywords
Garment Fabrics; 3-D Motion Capture System; Running Protective Model; Protection Property; Elasticity; Thickness

Introduction
In running, joints and bones of the lower limbs hurt easily because of frequent extension and squeeze. The lower limbs are always strained especially for both running lovers and professional athletes. The injury may cause serious life obstacles, which usually continues for a long time. It has been said that about 35%-65% of the healthy and professional players underwent the lower limb injuries in the domestic study (Wei, 2011). And the incidence of the lesions caused by running sport was 19.4%-92.4%. Moreover, the knee injury incidence was 7.2%-50.0%, which was the main lesion part (Zitian and Hui, 2012). The foreign study also has found that 40%-50% of the sports crowd had injuries related to the running sport every year (Renxiang et al, 2012). At the present stage, the research of sportswear still stays in comfort, design and other aspects (Qinqin and Peng, 2003; Xianghui et al, 2009; Jiali et al, 2007; Graham, 2006), ignoring the study of the protection property of sportswear. Thus, it is going to be the future trend to develop the protective sportswear that reduces the lesion of skeleton or muscle based on sports biomechanics.

The running sport was regarded as the research subject in the topic and the mechanics model between the lower limbs and fabrics was established with the spring-mass model. And the running trajectory parameter was acquired through the three-dimensional motion capture system. The effect was further achieved that elasticity and thickness of fabrics had on protection of joints with kinematic and kinetic parameters, which would have a great significance of researching and developing protective sports pants in the future.

Principle of Running Sports Injury
In movement, the injury is caused by the external mechanical force, whose principle is the force action between two objects. When the body is affected by the external force, body parts are going to carry on the active force through the brain. While the active force is equal to the external one, the body will not be damaged by the shock. However, the external force is larger than the active one or the maximum that the
body can withstand, which causes that the body is harmed.

Therefore, the body injury is mainly caused by the mutual force action in motion. In other words, force exceeds the one that skeleton can withstand. In running, a gait cycle can be divided into two stages: the stance duration and the swing one. The former accounts for 60% and the latter for 40% (Haibo, 2008). During the stance phase, the lower limbs need to bear the body weight of 2-3 times, which is the key reason resulting in the skeleton injury of the lower extremity (Weijie et al, 2013).

Joints and bones of the human body can’t be directly shocked, which buffers force action with the muscle ligament tissue in order to protect them. In the process of running, as muscle covering bones has a certain flexibility, when the lower limbs receive the force reaction, muscle absorbs the external force action on joints and bones so that the human skeleton can be protected (Nicola and El, 2012). Thus, the outside muscle attached to the bone is taken as the body’s first protective barrier.

Establishment of Evaluation Parameter of Running Protection

Running Protective Model

Muscle buffers the external force in virtue of its elasticity in movement to shelter skeleton. Based on the feature of the muscle protection embodied in the ability of its elasticity, the model had been revised properly to establish the running protective model that met the demand, taking advantage of the spring-mass model in Physics (Ghigliazza et al, 2003) and considering the character of running (as Fig.1).

Amendment 1: Repeal the fixed end of the spring and the spring was connected only with the oscillator.

Amendment 2: In order to simplify the model, the human skeleton was counted as the rigid body and the muscle protection for skeleton as the confirmed value.

Spring, muscle and fabric had the common feature, namely elasticity, whose performance was indicated by the elastic recovery rate in this study. In the spring-mass model, the force, from the unfixed end, was applied to the oscillator through the spring indirect action. Therefore, the body skeleton was regarded as the rigid body in the running protective model. The external force acted on the bone indirectly, which was cushioned by muscle and fabric. And the protective action of muscle was treated as the confirmed value in this protective model.

![FIG. 1 RUNNING PROTECTIVE MODEL BASE ON SPRING-MASS MODEL: A. CONTRACTION OF SPRING; B. DEFORMATION RECOVERY OF SPRING.](image)

In Fig. 1, rectangle was equivalent to the skeleton and spring represented fabrics. While spring was subjected to the external force and owned the speed $v_1$, spring had started deforming. Several seconds later, it recovered little by little and speed $v_1$ turned into $v_2$ in a running gait cycle. According to Momentum Theorem (Jianhua, 2013), $F_t = m(v_2 - v_1)$.

In the protective model, the force $F'$ from the ground reaction had an effect on fabrics and fabrics began deforming. When the distortion reached the maximum, fabrics rebounded gradually and buffered the force action on skeleton to achieve the protective purpose. In the process, force acting on skeleton was the following formula, namely $F'' = F' - F (F = kx)$. $F$ was the average of force that fabrics bore during the period $t$. And fabrics had a certain elasticity, which could be indicated by the elastic recovery rate $k$. The maximum of deformation was $x$.

Evaluation Parameter of Protecting Injury

In the duration when the elastic distortion recovered, the momentum of body had a great influence on the force $F$. In other words, the smaller the momentum was, the less the force $F$ was during the same time.

According to the formula $F = (mv_2 - mv_1)/t$, the changing rate of momentum was also less. Therefore, skeleton endured lighter injury and the protection property of fabrics was greater; that was to say, the changing rate of momentum, namely $mΔv/t$, was smaller; that was to say, the changing rate of momentum could be regarded as the evaluation parameter of protecting injury at the stance phase of running.
Relation of Fabrics Parameter and Biomechanics

At the stance phase of running, the lower limbs withstood the force $F'$ from the ground reaction and the muscle protective action was considered as the constant value $M$. Force acting on Lower limbs skeleton was the following formula:

$$F_a = F' - F - M$$
$$F_k = F_a - M$$

$F_a$ and $F_k$ were the force that ankle and knee bore respectively. $F$ represented the force that fabrics buffered.

The above formula could also be converted:

$$P_a = F't - Ft - Mt,$$ namely $P_a = mv - kxt - Mt$

$$P_k = Fat - Mt,$$ namely $P_k = P_a - Mt$

$P_a$—ankle momentum, $P_k$—knee momentum, $mv$—momentum of stance phase, $t$—recovery time of fabrics deformation, $k$—elastic recovery rate of fabrics, $x$—fabrics deformation.

Experiment of Fabrics Elasticity and Thickness

Experiment Object

Protection property of running sports garment fabrics doesn't change on account of different height and weight of the object. In this experiment, the object was a medium build student, who was 155-165cm and on good condition without disease and injury. And the anatomic structure and function of her lower limbs were also normal.

Experiment Equipment

There were two experiment instruments in this experiment. One was the treadmill for running and the other the three-dimensional motion measurement system for capturing trajectory (as Fig.2).

The motion measurement system is the Optotrak_Certus dynamic capture equipment that NDI company produces. The system owns a markedly high testing precision, which can reach 0.1mm accuracy in the range of 1.5-3m before the device. The movement trajectory of skeleton has been acquired and three-dimensional coordinate data exported, tracking markers fixed to the body surface through the high-speed camera. Finally, kinematic and kinetic parameters have been obtained via a series of calculations of physical and mathematical formulas.

Marker Points Layout

Due to the particularity of the body joints, marker points could not be easily placed, resulting in abnormal data. With the help of NDI company technicians, utilizing imaginary marker points replaced real marker ones, which not only facilitated the placement of marker points of special parts, but solved the interference problem generated by the coincidence marker points.

Imaginary marker points are on the basis of the rigid body that is made up by marker points. Moreover, the relative position of marker points is unchanged in the rigid body. In the experiment, make 2 rigid bodies and every one consisted of 3 marker points. There were 4 imaginary points set on joint parts. The rigid bodies were distributed on lateral of thigh and shank middle part and medial of thigh and shank middle part. The corresponding relation between the rigid body and the imaginary points was shown in table 1 and marker points were marked as Fig.3.
TABLE 1 RIGID BODY AND CORRESPONDING IMAGINARY MARKER

<table>
<thead>
<tr>
<th>Rigid Body</th>
<th>Corresponding Parts of Imaginary Points</th>
<th>Name of Imaginary Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thigh</td>
<td>Knee (medial and lateral)</td>
<td>LLK (lateral of knee), LMK (medial of knee)</td>
</tr>
<tr>
<td>Shank</td>
<td>Ankle (medial and lateral)</td>
<td>LLA (lateral of ankle), LMA (medial of ankle)</td>
</tr>
</tbody>
</table>

FIG. 3 THE LAYOUT OF MARKER POINTS

Experiment Program

Garment fabrics shelter the human body from injury in the way that fabrics fetter the joints of the body to produce the corresponding pressure for helping share the burden of skeleton. Moreover, the way could improve the overall stability of the joint part and assist in dispersing the momentary excessive force action. However, garments fetter the human body with the elasticity and thickness of fabrics cushioning the external force action on skeleton. In this experiment, the experiment object wore different protectors made by different elasticity or thickness fabrics to run at the speed of 5km/s. In the process, two variables, namely elasticity and thickness of fabrics, were discussed to gain the impact on the evaluation parameter of protection during the running stance phase of 0.48±0.06s (Haibo, 2008; Hualei et al, 2013).

TABLE 2 THE BASIC PERFORMANCE OF 3 KINDS OF FABRICS

<table>
<thead>
<tr>
<th>Fabric</th>
<th>Composition</th>
<th>Thickness (mm)</th>
<th>Elastic Recovery Ratio (%)</th>
<th>Warp</th>
<th>Weft</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>21% spandex, 79% chinlon</td>
<td>0.61</td>
<td>70.21</td>
<td>93.52</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>17% spandex, 83% polyester</td>
<td>0.58</td>
<td>76.24</td>
<td>91.21</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>19% spandex, 81% polyester</td>
<td>0.62</td>
<td>80.01</td>
<td>89.46</td>
<td></td>
</tr>
</tbody>
</table>

To guarantee running successfully, adopting fabrics was used to the sportswear, which had a certain elasticity. There were 3 kinds of fabrics, whose basic performance was shown in the following table 2. In elasticity experiment, 6 protectors were made for knee and ankle joints, ensuring the uniform thickness. However, in thickness experiment, there were one layer, two layers and three layers and 18 protectors were done, keeping the same elasticity.

Results and Discussion

During the running stance phase, the motion capture experiment was conducted under the changing condition of fabrics elasticity and thickness and the evaluating parameter of the lower limb had been analyzed briefly.

Analysis of Elasticity Factor

While the experiment object wore different protective equipment made by different fabrics during the running stance phase of 0.48±0.06s, the changing rate of momentum had also varied and the result was shown in Fig. 4. In particular, it was more obvious in the ankle, because the momentum transmitted from the proximal end to the distal one, which resulted that it would be weakened. Moreover, the fabric B had a markedly influence on the evaluation parameter of protection among 3 kinds of fabrics.

FIG. 4 THE CHANGING RATE OF MOMENTUM UNDER THE SAME THICKNESS

Analysis of Thickness Factor

The preferable protective fabric B was taken as the
example in the test experiment and the result was shown in Fig. 5. Obviously, the changing rate of momentum was influenced by the fabric thickness to a certain extent. Furthermore, it showed an increasing trend with the fabric thickening.

**Comprehensive Evaluation**

The preliminary finding was that both elasticity and thickness of fabrics respectively had a certain impact on the evaluation parameter of protecting injury. However, the influence of the only one factor from both could be acquired in elasticity and thickness experiment. On the contrary, whether the two factors exerted a significant effect on the changing rate of momentum or not could not be appraised and estimated comprehensively. Therefore, this paper applied the single factor analysis of variance (Xiaoyong, 2013) to judge the influence of two factors on the evaluating parameter.

Table 3 and table 4 were the result of the analysis. Elasticity and thickness of fabrics were regarded as independent variables and the changing rate of momentum of the lower limb joints as dependent variables in table 3 and 4. With the single factor analysis of variance, the effect of evaluating protective parameter had been discussed on condition of the same thickness (or elasticity), changing elasticity (or thickness). Table 3 was the analyzing result of same thickness and different elasticity and Table 4 was the one of same elasticity and different thickness. Here were the final finishing table and the result P value of analysis, which was displayed.

When the fabric was one and three layers from Table 3, the significance of the changing rate of momentum was much greater than 0.05. Hence, changing the fabric elasticity had little influence on the evaluating parameter in this case. While there were two layers of the fabric, the one of knees was less than 0.05. So under condition of the moderate thickness of fabrics, the elasticity of fabrics had some impact on the protective parameter of knee.

The significance was generally less than or close to 0.05 in Table 4 and changing thickness brought great effect on the one of the body parts, not considering the fabric elasticity. Only the significance of the one layer fabric was about 0.05. The reason leading to the result might be the fabric thickness that didn’t reach the value knee needed.

From the analysis of the effect that elasticity and thickness of fabrics had on the evaluating parameter, thickness produced a more obvious impact on the evaluating parameter of skeleton. But elasticity just had little on the joint of knee and ankle. On the whole, there was no significant influence.

**Conclusions**

Based on sports biomechanics, the mechanics model between the human body and the apparel fabric had been established in movement. In light of the model, the parameter evaluating the protective injury, namely the changing rate of momentum, was obtained. As the trajectory data acquired by the 3-D motion capture system were dealt with and analyzed via the calculating formulas of the running protective model, the following conclusions have been made:

♦ The evaluating parameter of protection, the changing rate of momentum, represents the increasing tendency with the fabric thickening within a certain range.

♦ According to the evaluating parameter, the influence of thickness is more obvious in the experiment of the fabric elasticity and thickness, which can serve as the basis of designing and developing sports protective sportswear.

♦ It is feasible that the mechanical knowledge of biomechanics is applied to the research of the garment protective fabric. In the subsequent study of the protective apparel, it is suggested that adopting the approach of composite materials should further improve the thickness factor of the fabric.

**TABLE 3 SAME THICKNESS, DIFFERENT ELASTICITY**

<table>
<thead>
<tr>
<th>Evaluating injury parameter</th>
<th>P value (one layer)</th>
<th>P value (two layers)</th>
<th>P value (three layers)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Changing rate of momentum of knee</td>
<td>.656</td>
<td>.040</td>
<td>.623</td>
</tr>
<tr>
<td>Changing rate of momentum of ankle</td>
<td>.547</td>
<td>.622</td>
<td>.843</td>
</tr>
</tbody>
</table>

**TABLE 4 SAME ELASTICITY, DIFFERENT THICKNESS**

<table>
<thead>
<tr>
<th>Evaluating injury parameter</th>
<th>P value (fabric 1)</th>
<th>P value (fabric 2)</th>
<th>P value (fabric 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Changing rate of momentum of knee</td>
<td>.049</td>
<td>.031</td>
<td>.029</td>
</tr>
<tr>
<td>Changing rate of momentum of ankle</td>
<td>.031</td>
<td>.018</td>
<td>.014</td>
</tr>
</tbody>
</table>
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REFERENCES


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