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Influence of weft knitted fabrics tensile characteristics and garment size on the body movement comfort

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The effect of fabric tensile property and garment size on the clothing pressure variation has been studied, considering the pressure alteration during the body movement with various ranges. The results reveal that for a constant body dimension, smaller clothing size applies higher pressure. In addition, fabric's tensile modulus is a determinant parameter of the clothing pressure. Increment in the body movement range exerts more pressure on the body due to the greater strain of garments. Clothing pressure assessment confirms the pressure relaxation during the wearing time.

Keywords: Acrylic yarn, Clothing size, Fabric tensile property, Pressure garment, Polyurethane elastic yarn

The pressure garments are used in various applications, such as medical, sport and for shaping the body. However, in the clothing that is utilized for daily consumption, the exerted pressure by the garments during the body activity is considered as an aspect of clothing comfort. In other words, the compression comfort deals with the applied pressure in a range when people feel comfortable, and garments do not limit the body movement and people's performance. In this regard, the clothing pressure has been investigated by researchers from different points of view. Yamada and Matsuo[1] developed new approaches to evaluate the pressure of clothing worn on a cylinder model with the same strain, as a strip sample on the biaxial tensile testing procedure. Wang and Zhang[2] examined the impact of fabric mechanical characteristics, such as tensile modulus, shear rigidity and bending rigidity on the clothing pressure variation during the wear. In another research, Chan and Fan[3] investigated the pressure of girdles both subjectively and objectively, for obtaining the relationship of girdle's pressure and rigidity perception by the subjects. You *et al*.[4] studied the effective factors on the exerted pressure of pant, such as size and fabrics tensile properties. These researchers in another study[5] examined the relationship of subjective tactile perception and clothing pressure. Ng and Hui[6] developed a model in terms of fabric's tensile modulus, limb's perimeter and required pressure to calculate the needed reduction factor of the garment. Ng and Hui[7] inspected the influence of hem edge designing of the pressure garments on the distribution of exerted pressure. Cieslak *et al*.[8] probed the applied pressure of two warp knitted fabrics with various structures by *in-vivo* and *in-vitro* test method. For both fabrics, the pressure obtained through *in-vitro* method presents higher value that is due to the greater rigidity of plastic model in comparison with the body's soft tissue. Zhang *et al.*[9] developed a finite-element model based on the fabric's mechanical properties and contact between body and garment to simulate the clothing pressure variation during wear, dynamically. Salleh *et al.*[10] developed a 3D model for the pressure of garments based on the detailed information obtained about body dimension by a 3D body scanner and fabric's mechanical characteristics in order to make 2D patterns for clothing with intended pressure. In another study, Salleh *et al*.[11] modelled the interfacial pressure between skin and garment in terms of 3D measurement of the body dimension, in order to predict the applied pressure of garments. Cheng *et al.*[12] presented a mathematical model in order to examine the interfacial pressure of men's underwear in terms of fabric's properties and clothing ease. Liu *et al.*[13] explored the pressure of pants in various points by using 3D model, numerically and applied the data mining approach to evaluate the results. Maleki *et al*.[14] investigated the pressure change of garments with different reduction factor involved with knitted fabrics after the repeated laundry.

Since garment covers the skin surface, it may encounter to various strain, in a way that enhances the exerted pressure on the body, and even restricts the human's performance due to the body movement in

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different points. The pressure increment that is related to the clothing dynamic pressure (pressure exerted on the body due to the body movement) is usually higher than the static pressure of garment (pressure exerted by garment), that is considered in the rest positions. Furthermore, the clothing is worn during the long time and this duration of time will alter the clothing pressure. Hence, present study is intended to examine the effect of fabric's tensile properties and clothing size on the pressure exerted by garment on the body during the wear time, under the condition of body movement, both subjectively and objectively.

Experimental

Materials

In order to study the impact of tensile property of the knitted fabrics on the body movement comfort, fabrics with the same knit pattern were obtained by altering elastic yarn usage in the fabric structure. Stoll's electronic flat knitting machine was used, considering the gauge of seven needles per inch. Fabrics were knitted of 100% acrylic yarn with 40 Nm count and polyurethane (PU) elastic yarn with 206 tex count. All fabrics were knitted with the rib 1×1 knit pattern. To change the fabric's tensile property, three various samples were knitted with different density of PU elastic yarn, namely polyurethane yarn (i) after each six courses, (ii) after each three courses and (iii) without polyurethane yarn. The properties of the fabrics are presented in Table 1.

Sample Preparation

Test samples were sewn in a cylinder shape to wear on the hand of 20 subjects with the age of 18-20 years old. The length of the cylinder was 30 cm and its circumference was determined based on the subject's hand measurement. For each person, the hand's circumferences were measured covering the elbow, 5 cm below and 5 cm above the elbow.

On the purpose of examining the influence of garment's size on its comfort, samples were prepared according to the three values of hand and garment perimeter differences, namely 3, 5 and 7 cm. It should be notified that in order to keep the similar garment reduction value, the test samples were made for all subjects, individually. All samples were sewn on the Lockstitch Durkopp Adler sewing machine (Model 271). In order to sew the samples, a 100% polyester sewing thread with the yarn count of 40/2 Nm was employed. Specimens were stitched with the seam allowance of 1cm.

Test Procedure

Evaluation of Fabric's Tensile Property

Fabric's tensile behaviour was measured by the fabric tensile testing machine (Instron 5566) according to the ISO 13934-1:1999 standard test method. Fabric's tensile characteristic was measured for five samples along the course and wale directions. Specimens were cut with the dimension of $25\,cm \times 5\,cm$. A pretension of 30 g was applied for all samples. The gauge length for the tensile test was 100 mm and it was performed with the elongation speed of 100mm/min.

Subjective and Objective Assessment of Garment's Pressure

Since clothing resistance against the body movement limits the human's performance and applies the pressure on the body, to inspect the ease of body movement in garments with various tensile properties and size, exerted pressure on the skin by the garments is considered. The clothing pressure was evaluated both subjectively and objectively. In order to assess the clothing pressure objectively, a Kikuhime pressure sensor HPMKH-01 (Sorø, Denmark) was used to measure the pressure between the skin and garment. This device measures pressure in the range of 0–16kPa (0–120 mmHg). The sensing part is consisted of an air pack with the diameter of 2cm, which is made of a very soft material that linked to a digital pressure meter.

After wearing the sample on the hand, the pressure sensor was placed between the garment and skin on the arm, above the elbow. On the aim of investigating the impact of body movement on the applied pressure, at

Table 1 — Fabric characteristics

Fabric code	Weight g/m^2	Thickness, mm	Courses/cm	Wales/cm	Tensile modulus (cN/mm^2)	
					Course	Wale
E0	283.8	2.51	5	4	73	510
E6	287.6	2.5	5	4	91	590
E3	314.63	2.5	5	4	121	600

first, the subjects were asked to hold their hand in straight position (zero degree). Then the pressure was recorded during 10 min with a minute as a time interval. After that, they were requested to bend their hands at 90°. Again, the pressure was noted during 10 min with a minute as a time interval. The purpose of the clothing pressure recording during 10 min was to probe the pressure variation with the time and study the possible pressure decay. Finally, subjects were asked to bend their hand at 180° in comparison with the initial position and the similar measurement was executed.

In order to evaluate garment's comfort subjectively, people were asked to declare their perception of pressure during the test. In this regard, at each position as explained before, people were requested to state their feeling about the applied pressure with some criteria, such as high and unbearable pressure (graded as 1), high pressure (graded as 2), moderate pressure (graded as 3), low pressure (graded as 4) and no pressure (graded as 5). All samples were conditioned and tested under standard testing condition (20°C and $65 \pm 3\%$ RH).

Results and Discussion

Tensile Characteristics of Fabrics

When the garment is made with a reduced amount than body dimension, during wear, it will extend to adapt with body dimension. In this regard, fabric tensile behavior can determine fabric extensibility and stored strain energy in the fabric that leads to the application of pressure on the skin. Even in some cases when the exerted pressure is high, it can affect body movement and performance, negatively. To evaluate fabric tensile performance, their tensile modulus is considered. The results of fabric's tensile modulus in both course and wale directions are presented in Table 1. It can be observed that for all fabrics, tensile modulus in wale direction is higher than in course direction. This outcome is due to the loop formation in the course direction. Therefore, any slight increase in the tensile load is sufficient to extend the fabric in the course direction. This means that the fabric deforms easily in the course direction. Another point that should be noticed is the inserting elastic yarn in the fabric structure and its density increment that, in turn, enhances the fabrics tensile modulus.

Applied Pressure on Body

As mentioned earlier, the clothing pressure is evaluated both subjectively and objectively. The outcomes of objective and subjective pressure measurement for all specimens are exhibited in Fig. 1.

It can be seen that for all clothing sizes, after 10 min, the pressure is decreased significantly. The results of subjective pressure evaluation are also displayed in Fig. 1. The subjects obtained the same outcome for the clothing's pressure perception and after 10 min; they graded the perceived pressure as lower pressure.

The correlation of subjective and objective pressure measurement is also examined. Obtaining the correlation coefficient of $R^2 > 0.69$ confirms that the results of pressure perception by subjects are similar

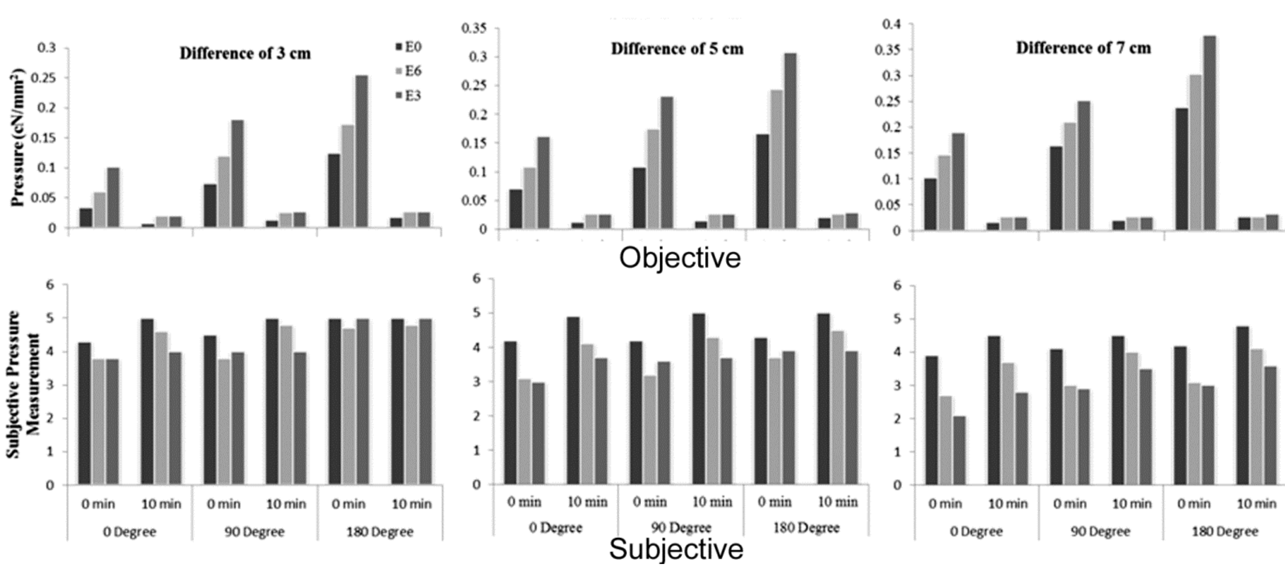

Fig. 1 — Objective and subjective pressure evaluation

to the pressure measured by the pressure sensor.

Influence of Clothing Size on Applied Pressure

The impact of clothing size on the garment's pressure has been assessed for various fabrics and body movement position and their results are presented in Fig. 2.

It is revealed that the increase in body and clothing perimeter's difference develops the exerted pressure on the skin linearly with the high correlation coefficient of $R^2 > 0.94$. According to the Laplace's law ($P = T/R$), the applied pressure on the body (P), depends on the fabric tension (T) and radius of the body curvature (R). In this test, the radius of body curvature and circumference are constant; however, the increase in the body and clothing perimeter's difference leads to the pressure variation. In fact, when garment is smaller than body, it is extended to cover the body surface. Consequently, any increase in differences between the body and garment's perimeter leads to higher clothing extension during wear. As it is known, when the fabric is extended in lower values than the yield's point, it follows the Hook's law ($T = E\varepsilon$); where T is the tension in fabric (cN/mm^2); E, the fabric's tensile modulus (cN/mm^2); and ε, the fabric's strain (%).

Based on above two laws, increment in the fabric extension causes fabric tension enhancement. The subsequent strain energy is saved in the fabric and after putting on the sample, it exerts the pressure on the body. As presented in Fig. 2, for all fabrics, the higher clothing pressure is obtained for smaller garments. In order to investigate the influence of clothing size on the exerted pressure on the skin statistically, ANOVA analysis has been implemented for sample E_0, when the person held his hand in the straight position (zero degree) and its result is illustrated in Table 2. According to the statistical analysis, P-value is lower than 0.05, consequently the effect of clothing size on the applied pressure in the confidence level of 95% is meaningful. Same statistical outcomes are obtained for rest of the fabrics and hand positions.

Effect of Fabric Modulus on Applied Pressure by Garment

As described before, the garment pressure is due to fabric extension and, in turn, it depends on the fabric tensile modulus. Fig. 2 shows that the fabrics with higher tensile modulus, apply more pressure on the body after wearing. This phenomenon can be interpreted by Hook law. According to this law, not only fabric strain, but also its tensile modulus affects the fabric tension. In other words, fabric with higher modulus needs more tensile force to attain the certain extension level and to be able to cover the body surface.

Therefore, fabrics containing polyurethane yarns apply higher pressure on the skin and this pressure

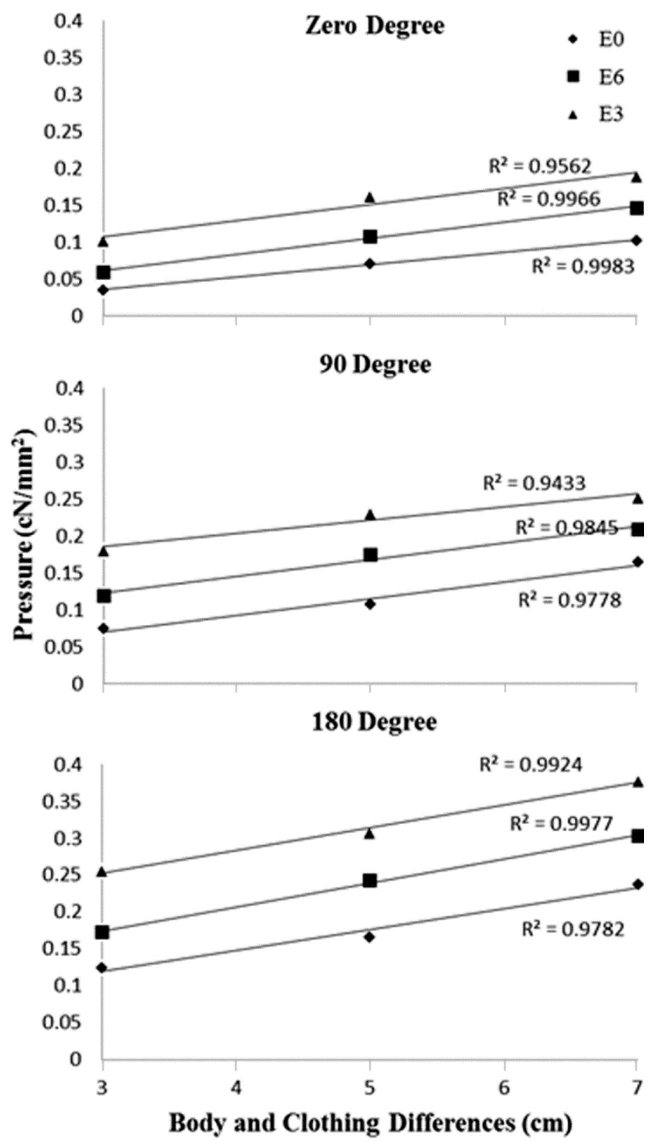

Fig. 2 — Effect of clothing size on garment's pressure

Table 2 — ANOVA analysis for the effect of clothing size on applied pressure

Parameter	Sum of squares	df	Mean square	F	Sig.
Between groups	0.007	2	0.004	49.776	0.000
Within groups	0.000	6	0.000		
Total	0.008	8			

Table 3 — ANOVA analysis for the effect of fabric modulus and body movement on the exerted pressure on the skin

Parameter	Sum of squares		df		Mean square		F value		Sig.	
	Fabric modulus	Body movement	Fabric modulus	Body movement	Fabric modulus	Body movement	Fabric modulus	Body movement	Fabric modulus	Body movement
Between groups	0.007	0.016	2	2	0.004	0.008	135.107	860.862	0.000	0.000
Within groups	0.000	0.000	6	6	0.000	0.000				
Total	0.007	0.016	8	8						

promotes with the increase in number of polyurethane yarns inserted in the fabric structure. To inspect the impact of fabric modulus on the clothing pressure statistically, the outcomes of ANOVA test for the clothing and body difference of 3cm and straight hand position (zero degree) are shown in the Table 3. It shows P-value<0.05. Thus, the influence of fabric modulus on the pressure applied on the body, at confidence level of 95%, is found significant. Similar results are achieved for the other clothing size and hand positions.

Impact of Body Movement on Exerted Pressure

In addition to wearing the garment, owing to the body movement, fabric is exposed to more stains that their values depends on the range of body movement. The effect of body movement on the garment's pressure is depicted in Fig. 3.

It can be detected that by bending the hand from the straight position, due to the extra strain that clothing encounters, the pressure is intensified. In other words, this added strain of fabric leads to the higher stored strain energy in the fabric and finally raise the clothing's pressure. Sometimes, high clothing pressure avoids desirable body performance due to the body movement restriction, which makes the garment uncomfortable. Garment's pressure during the body movement is known as an operating pressure; however, the applied pressure on the skin, owning to wearing the cloth is called static pressure. According to the outcomes, the operating pressure is higher than the static pressure. Since garment performs like the second skin of the body and exposes to the body movement and more strains, operating pressure that is related to the physical activity range of an intended garment, should be regarded to inspect its pressure comfort and ease of body movement. The impact of body movement on the clothing pressure is explored statistically by ANOVA test and the obtained result for the sample E0, and the clothing and body difference of 3cm is presented in Table 3. It is noticed that the effect of body movement on the applied pressure on the skin, in the confidence level of 95%, is meaningful. Equivalent trend is obtained for rest of the samples.

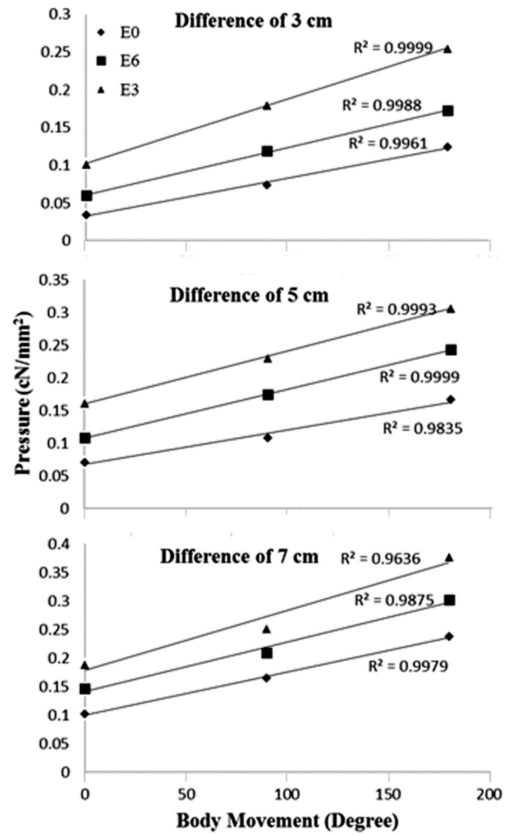

Fig. 3 — Impact of body movement on clothing pressure

Influence of Time on Pressure Variation

Since pressure garments are usually worn for the duration of time, the examination of the pressure variation in terms of time is a significant point that may change its proper performance and should be considered. In Fig. 4, the variation of clothing's pressure in terms of time is presented.

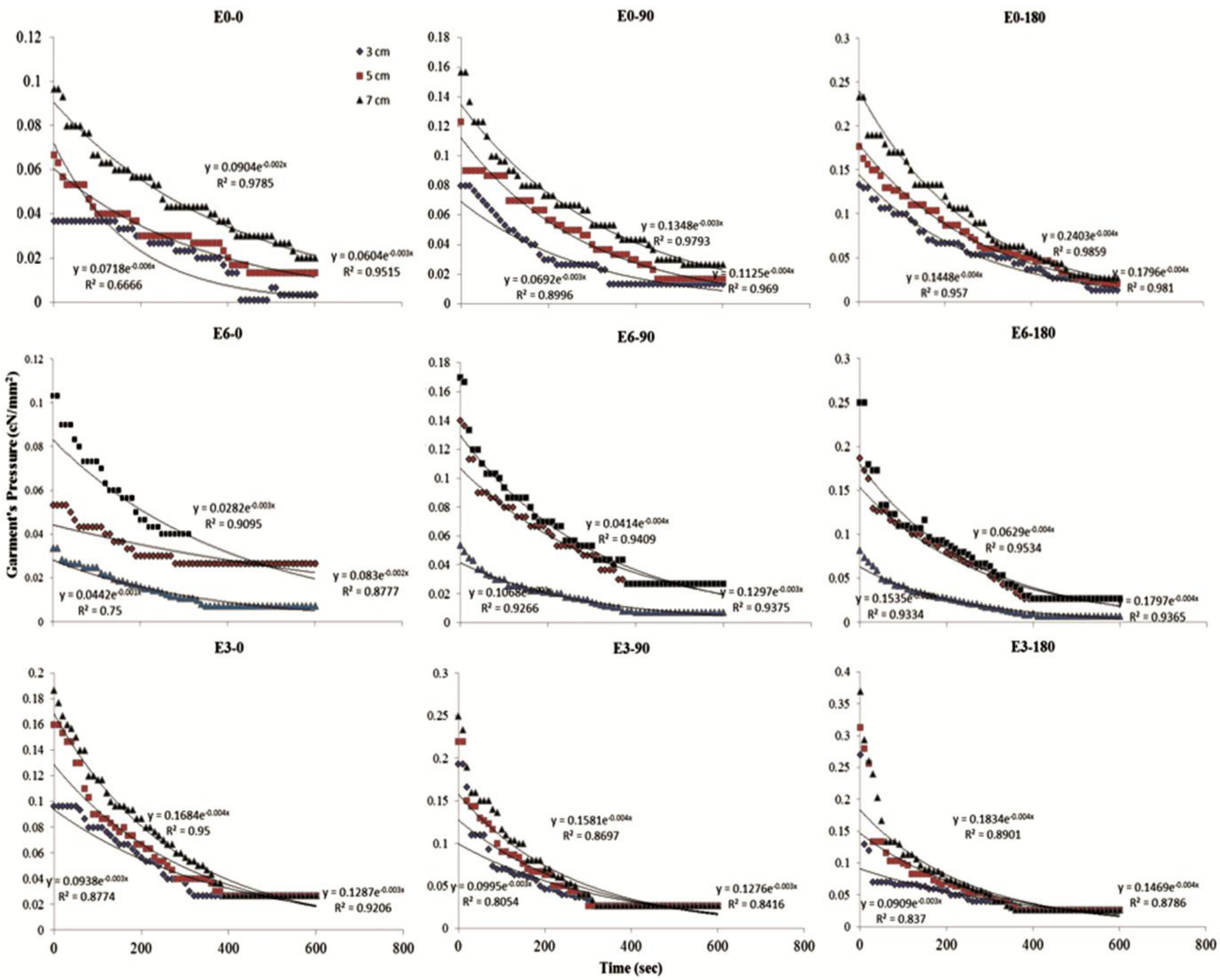

Fig. 4 — Garment pressure variation in terms of time

It can be observed that after wearing the garment, the pressure drops immediately in 100 s and the rest of the pressure relaxation occurs with a lower rate and finally it remains approximately unchanged. In addition, for all samples, garment pressure follows a power function with a high correlation coefficient. It seems that the pressure drop is related to the stress relaxation of the fabrics. During wear, a certain tension is induced in the fabric that depends on the fabric's modulus, clothing size and body movement. In order to calculate the pressure decay during the 10 min, the pressure drop can be computed by the following equation:

$$\text{Pressure}-\text{attenuation}\ (\%) = \frac{P_{\max} - P_{\min}}{P_{\max}} \times 100 \qquad \ldots(1)$$

where $P_{\max}$ is the maximum clothing pressure (cN/mm^2); and $P_{\min}$, the minimum clothing pressure (cN/mm^2). The outcomes of the pressure decay are shown in Fig. 5.

It is discovered that the increase in body movement that induces higher clothing pressure, faced greater pressure relaxation during the time. The similar result is achieved about the garment size. In other words, smaller garments that make higher clothing pressure after the wear encounter with higher rate of pressure reduction. This outcome should be noticed in designing the garment for an especial purpose and in inspecting the clothing comfort in the aspect of exerted pressure.

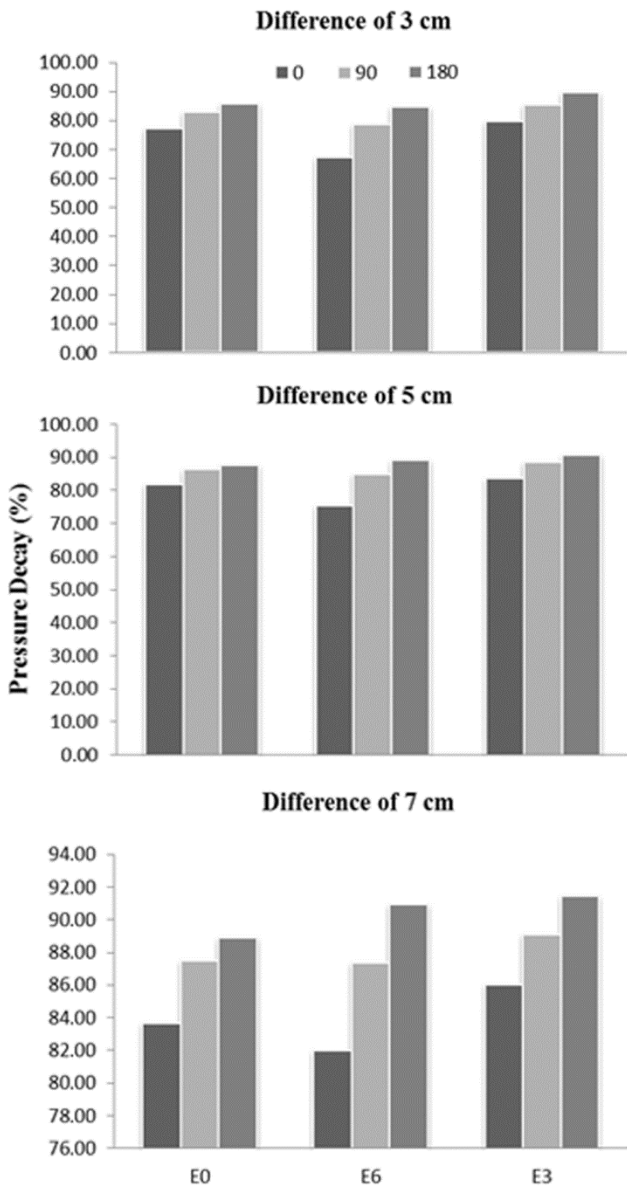

Fig. 5 — Pressure relaxation in terms of body movement

According to the obtained outcomes, smaller size of garment and higher range of body movement lead to the more stored energy in the fabric due to the applying greater rate of strain in the fabric. Hence, the garment exerts higher pressure on the skin. In addition, garments made of fabric with higher tensile modulus, due to the greater required force to create a certain elongation in the fabric, exerts more pressure on the body. The examination of clothing pressure alteration over the time confirms that, during the use, garments pressure is diminished and then it almost remains constant. This pressure decay should be considered in garment designing to achieve the desirable performance.

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