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Calculating the Percentage of Body Measurement Changes In Dynamic Postures In Order To Provide Fit In Skiwear

Kayak Giysilerinde Vücuda İyi Uyumun Sağlanabilmesi İçin Vücut Ölçülerinin Dinamik Duruşlardaki Yüzdesel Değişimlerinin Hesaplanması

Derya TAMA*[1], Ziynet ÖNDOĞAN[2]
[1]Ege Üniversitesi, Tekstil Mühendisliği Bölümü, Bornova İzmir; Türkiye
[2]Ege Üniversitesi, Moda ve Tasarım Yüksekokulu, Bornova İzmir, Türkiye

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Araştırma Makalesi / Research Article

CALCULATING THE PERCENTAGE OF BODY MEASUREMENT CHANGES IN DYNAMIC POSTURES IN ORDER TO PROVIDE FIT IN SKIWEAR

Derya TAMA[*1]
Ziynet ÖNDOĞAN[2]

[1]Ege Üniversitesi, Tekstil Mühendisliği Bölümü, Bornova İzmir; Türkiye
[2]Ege Üniversitesi, Moda ve Tasarım Yüksekokulu, Bornova İzmir, Türkiye

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ABSTRACT: The aim of this study is to investigate the local body measurement changes in movements during Alpine skiing and to calculate these changes in "percentages" in order to use in garment pattern preparing process to achieve the best clothing comfort characteristics in alpine skiing suits. For that purpose, an anthropometric measurement study was conducted, which involved measuring 31 male volunteer's body sizes in static and dynamic postures. Within this context, the sizes to be measured were identified as static and dynamic by specifying the anthropometric landmarks on the body using ISAK (The International Society for the Advancement of Kinanthropometry) practices as the base. It was found that percentage changes in the anterior knee length, anterior leg length, hip length, elbow length and posterior arm length were 43%, 2%, 35%, 40% and 9%, respectively, from the measurements collected from 31 male recreational Alpine skiers. Afterwards, regarding to the obtained data, the three body dimensions such as inseam, back waist rise and sleeve length were re-calculated to use in the preparing of pattern for tight-fitting garments. Ultimately, a base layer thermal bottom's garment patterns were developed and evaluated using a 3D virtual try-on system. Consequently, it was found that the inseam length and sleeve length should be reduced while the back waist rise needs extra ease allowance. With respect to the virtual fitting, the developed pattern was more fit than the original pattern and had more ability to adapt dynamic postures.

Keywords: Static anthropometry, dynamic anthropometry, Alpine skiing, body movement comfort, body measurement changes, tight-fitting garments' patterns.

KAYAK GİYSİLERİNDE VÜCUDA İYİ UYUMUN SAĞLANABİLMESİ İÇİN VÜCUT ÖLÇÜLERİNİN DİNAMİK DURUŞLARDAKİ YÜZDESEL DEĞİŞİMLERİNİN HESAPLANMASI

ÖZET: Bu çalışmanın amacı, kayak sporu Alp disiplini hareketlerinde bölgesel olarak oluşan vücut ölçü değişimlerini araştırmak ve Alp disiplini kıyafetlerinde en iyi giyim konforu özelliklerini elde edebilmek amacıyla giysi kalıbı hazırlığı aşamasında kullanmak üzere bu ölçü değişimlerini yüzdesel olarak hesaplamaktır. Bu amaçla, 31 erkek gönüllünün vücut ölçülerinin statik ve dinamik duruşlarda ölçüldüğü antropometrik bir ölçüm çalışması gerçekleştirilmiştir. Bu bağlamda, vücut üzerinde antropometrik referans noktaları (landmark) belirlenerek, statik ve dinamik olarak alınacak ölçüler ISAK (The International Society for the Advancement of Kinanthropometry- Uluslararası Kineantropometri Geliştirme Topluğu) uygulamaları temel alınarak tanımlanmıştır. 31 erkekten alınan ölçümlerde, ortalama diz ön uzunluğunda, bacak ön uzunluğunda, kalça uzunluğunda, dirsek uzunluğunda ve dış kol uzunluğunda yaşanan değişimlerin sırasıyla %43, %2, %35, %40 ve %9 olduğu belirlenmiştir. Daha sonra, elde edilen veriler ışığında, vücudu saran giysilerin kalıp hazırlığında kullanılmak üzere, iç bacak, arka bel yüksekliği ve kol uzunluğu ölçüleri tekrar hesaplanmıştır. Sonuç olarak, bir alt termal içliğin giysi kalıbı hazırlanmış ve 3B sanal giydirme sistemi kullanılarak vücuda uyumu değerlendirilmiştir. Çalışma sonucunda, iç bacak ve kol uzunluğu ölçülerinin azaltılması gerekirken arka bel yüksekliği ölçüsünün artırılması gerektiği görülmüştür. Sanal giydirme sonuçları değerlendirildiğinde ise, geliştirilen kalıbın orijinal kalıba göre vücuda daha iyi oturduğu ve dinamik duruşlarda vücuda daha iyi uyum sağladığı belirlenmiştir.

***Anahtar Kelimeler*:** Statik antropometri, dinamik antropometri, Alp disiplini, vücut hareket konforu, vücut ölçü değişimleri, vücuda saran kıyafetlerin giysi kalıpları

***Sorumlu Yazar/Corresponding Author:** derya.tama@ege.edu.tr*
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1. INTRODUCTION

Today, clothing comfort is one of the main factors that consumers desire from their clothes. In particular, for active sportswear, consumers prefer the ones that will adapt to environmental conditions and are appropriate for movements involved in a sport. Therefore, correct pattern preparation, as well as the raw material properties, are important factors that affects clothing comfort.

Measurements used in pattern preparation for tight-fitting clothes are obtained by reducing the sizes of the nude body according to some rates. However, in apparel manufacturing companies, the patternmakers estimate these rates by their experiences considering the stretching feature of the fabric, but it can be argued that it is due to the lack of practical formulas for their use. Moreover, besides the stretching values of the fabric, the local size changes of the body must be considered during the calculation of these rates.

Anthropometry, which has been used more than one hundred years [1], is the measurement and analysis of body characteristics, including stature, size of body parts, and the space in which the body functions, e.g., reach limits and clearances for movement [2]. Anthropometry is aimed at supplying the correct body dimensions required to provide a good fit or product to the user [3]. It is a standardized technique; even if different individuals take measurements, it is possible to acquire the same results [4]. Anthropometric data types are categorized as "Structural Anthropometric Data - Static Anthropometry" and "Functional Anthropometric Data - Dynamic Anthropometry". Static anthropometry is the data obtained by measuring the body size of a person in static positions. The measurements are performed upon a certain anatomic structure or a fixed point on space. Dynamic anthropometry, on the other hand, is the data identifying the movements of a certain part of the body at a fixed reference point [5]. The process involves selection of body dimensions to reflect actual conditions of use, such as a forward-bending stance, reaching out, and presence of accessories such as a helmet or mask [3]. A better understanding of dynamic actions of the body mechanism should also provide help in coaching athletic performance [6].

In traditional anthropometrical method, simple, quick, non-invasive and easy-to-calibrate instruments have been used such as a weight scale, measuring tape, anthropometer, spreading caliper, sliding compass and a head spanner [7]. The human measurers decide the landmark locations on the human and take measurements manually using these traditional instruments. Many of these landmarks are defined on specific locations of bones or easily identified features of soft tissues such as nipples and the navel [1]. With the inclusion of technology into body sizing field, the human body has been quantified by different tools including laser and structured light systems, millimeter wave radar and multi-view camera methods [8].

3D body scanning technologies are capable to obtain the body measurements, body shapes, angles and relational data points with ease [7]. In these systems, major joints and limbs are identified as landmarks used to define the body regions [8]. There are methods to obtain 3D coordinates of the landmark locations. A landmark location can be decided by a measurer manually or it is calculated by the system automatically. Afterwards, in order to obtain 3D coordinates of marker stickers, an operator can manually pick the centres of marker stickers or a system can recognize them and calculate the 3D coordinates. Lastly, an operator manually or the system automatically names each landmark [1]. Besides, standard anthropometric measurements by a flexible tape measure require identifying bony protrusions on the body. It is not possible to palpate these protrusions on 3D avatars, which makes the task of landmarking more challenging [8]. Moreover, unlike traditional anthropometry, landmarking differs depending on the 3D body scanning company. Simmons and Istook (2003), compared three different 3D body scanning companies' measurement definitions and concluded that there is incomparability of measuring techniques between the scanners and in order to use obtained data for mass customization, the usage of 3D body scanners should be standardized [7]. In 2006, ISO 20685 was published which establishes a protocol for evaluating the comparability between the scan-derived and traditional 1D measurements. The quality of the scan also depends on the body sway of the subject during the scan because a human cannot stand completely still for 10 seconds [1].

Bourgeois et al. (2017) found that the coefficient of variations were lower in the repeated flexible tape circumference measurements, while larger variations were observed in the 3D optical system measurements [9]. Soileau et al. (2016), compared two leading 3D scanner systems and found out that the differences in measurement outputs were small for large linear measurements whereas the differences were greater for small volume and circumference measurements [10]. Gordon et al. (2012) conducted an anthropometric survey of U.S. army personnel and concluded that scan-generated measurements tend to be significantly larger than those obtained by manual measurements [11]. Parker et al. (2017) investigated the reliability of 3D body scanning against the established allowable errors from scientific studies available to the public [12]. It was found out that reliability and 3D body scanning is not only contingent on the physical machine and sophistication of the analysis software, but also on the specific body measurement being taken. Chi and Kennon (2006) researched about the limitations of current 3D scanning technology and obtained that for dynamic postures, the 3D body scanner cannot supply fast and accurate results yet [13]. Moreover, Zheng et al (2007) indicated that, 3D body scanning is not suitable for dynamic postures, because some areas are difficult to scan [14].

Tight-fitting clothes, which was researched in this paper, are expected to show features similar to human skin, namely stretching depending on the body movements and reverting to its original shape [15]. Thus, it is necessary to consider the changes in human body size in the static and dynamic postures and determine body movement ranges to ensure that an item of clothing has a good fit and movement clearance.

In 1966, Kirk and Ibrahim examined the dimensional change of human skin on 6 different measurement points in a crouching position [16]. Hatch (1993) detected the percentage changes in shoulder, hip, arm, leg, wrist and ankle of body in action [17]. Bozkurt (1995) took main and secondary measurements that were used in the preparation of garment patterns for Turkish women in static and dynamic positions; within the study, body movements' effects on clothing features were evaluated [15]. Voyce et al. (2005) included body stretching rates in their studies in which they evaluated elastic textiles in sport clothes [18]. Lee and Ashdown (2005) found significant variations in upper body measurements of women by comparing three active postures [17]. In order to maximize the comfort and mobility of the wearer, Liu and Kennon (2005) suggested cutting the garment panels to follow the constructional components of the human body [19]. Chi and Kennon (2006) took the measurements between anatomical landmarks both manually and using a 3D body scanner [13]. Ng et al. (2007) calculated the dynamic ease allowance for maximum reachable points for the range-of-motion [20]. Choi and Ashdown (2010) took the measurements of women in standing and sitting position [21]. Wang et al. (2011) proposed a method to measure the human body in static state and also in 17 dynamic postures and suggested a dynamic block patternmaking method for high-performance clothing design [22]. Gersak (2014) performed an overview of the ease allowance necessary to provide comfort during body motion [23]. Malengier et al. (2019) presented the results of their shape project which was conducted to develop comfortable and well-fitted sportswear for athletes [24]. They assessed upper arm girth, thigh girth, knee girth, back length and width manually by a measuring tape and evaluated the pressure between the skin and the sportswear at upper arm and thigh in static and dynamic postures for cycling and rowing. Back length and width were most affected measurements by posture and differed from static to dynamic posture by 12% and 16% for male rowers, and respectively by 11% and 13% for female rowers. Musa et al. (2019) investigated the correlation between the anthropometry and the archery performance [25]. They took the measurements of the arm span, calf, hip, thigh and abdominal circumference using a measuring tape regarding to the ISAK protocol, same as this study. It was concluded that successful performance in the sport of archery could be influenced by the archer’s physical attributes. In order to develop the patterns of the protective overall for sport aircraft pilots, Bogovic et al. (2018) focused on comparative analysis between the static and dynamic body postures [26]. They took measurements of five male subjects in static posture and three different postures namely standing posture with arms forward, standing posture in a forward bend, and sitting posture with arms stretched towards knees. An increase in the front overall lower length was determined for all subjects and there was no connection between the increase in body heights and the increase in the knee length in the sitting posture. Consequently, it was suggested that a well-fitting special protective garment needs to be made according to the exact body dimensions of the individual. Wu and Kuzmichev (2018) evaluated body measurement changes during diving to determine the ease values on laying prone postures underwater [27]. The measurements were taken in six dynamic postures and the elongation value of the fabric was also measured. An adjusted pattern was designed considering these data and simulated in 3D virtual try-on software. In conclusion, it was suggested that, the new pattern had a better try-on performance and the final pattern can be directly used for factory efficiency production inspection.

It is very important to perform correct calculation of measurements to be used in the phase of garment pattern preparation for obtaining the best clothing comfort in active sport clothes in order to provide mobility of the wearer and affect the performance positively. Therefore, primarily the type of sport is needed to be specified, afterwards, movements in this sport should be analysed, and also garment pattern measurements should be calculated by specifying the percentage changes of the body measurements while the athlete is performing the necessary movements. Therefore, in this study, in order to determine the local body measurement changes in movements during Alpine skiing, the existing studies were initially analysed, in which Alpine skiing was evaluated using movement analysis and the angles of joints were specified during dynamic positions [28-32]. Afterwards, the measurements for static and dynamic postures were defined and an anthropometric measurement study was performed. Regarding to obtained data, the inseam, back waist rise and sleeve length measurements were taken from size charts and re-calculated for tight fitting garments. In the final step, a base layer thermal bottom’s garment patterns were developed and afterwards evaluated using a 3D virtual try-on system.

Although there are published researches about the body measurements in dynamic postures, only a limited number of them are particularly related with specific sports. Thus, it still needs to be investigated especially for specific sports in order to achieve fit in sportswear. The body measurement changes were evaluated by Bogovic et al. (2018) in dynamic sitting postures simulating inside the aircraft [26] and by Wu and Kuzmichev (2018) in six dynamic postures simulating diving [27]. However, unlike the present research, these studies do not include detailed information about dynamic positions such as body angles. From this point of view, it can be argued that this research contributes to the literature and future studies.

2. METHODOLOGY

Ziynet Ondogan Clothing Development Methodology was used in the present research in order to develop Alpine skiing suits to provide good clothing comfort specialties. This methodology tries to bring a new aspect to the garment development process, especially for the garments used in extreme conditions or for a purpose. According to this methodology, firstly the conditions of use needs to be stated clearly, afterwards, the materials, which answer the needs of this conditions, should be determined. In order to generate a desired garment design, different materials can be combined on the garment, by being placed on different body parts regarding to the body reaction in terms of sweating or heat loss. In parallel with that, in order to provide perfect fit, the movement analysis of the activity should be conducted and the body postures in dynamic positions of the activity should be taken into consideration. This new method has been already used by some researchers [33, 34, 35] and the method enables researchers to develop specific garments in a better way.

2.1. Anthropometric Measurements Study

Relationship between body movements, fabric characteristics and clothing construction are very important for developing clothes according to the target population and activities. Therefore, in order to calculate measurements correctly for active sportswear with a good fit, the percentage changes in anterior knee length (AK_L), anterior leg length (AL_L), elbow length (E_L), posterior arm length (PA_L), and hip length (H_L) were specified - which are the most important measurements in the pattern preparation of the tight-fit garments. Within this scope, descriptions for each measurement in both static and dynamic postures were developed and the anatomical landmarks on the body were identified (Table 1, Table 2, Table 3, Table 4, Table 5). ISAK (The International Society for the Advancement of Kinanthropometry) practices were used as a base while developing the descriptions. In anthropometric data collection, traditional manual tape measurement method was used, which is the most common and accurate method in dynamic postures. A goniometer was utilised to help the subjects to keep correct postures when taking measurements [14, 22, 36]. In order to provide the correct posture, the angles of joints during the downhill and turns in Alpine skiing were determined according to the investigated previous studies. As it can be seen in Figure 1, the angle for knee was 60º, for body was 70º and for arm was 60º.

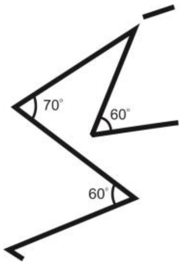


Figure 1. Angles of joints used in the study.

Table 1. Measurement descriptions of anterior knee length.

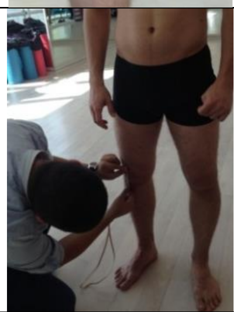
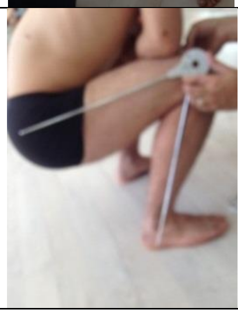
Anterior Knee Length (AKL)		
Preparation phase	The subject assumes an anatomic standing position and inferior and superior borders of the patella of his right leg are detected and marked. The point 3 cm below the inferior point and the point 3 cm above the superior point are marked.	
Measurement at the static posture	The person measuring stands at the right side of the subject. The distance between two points marked when the subject assumes an anatomic standing position is measured during the full extension of leg.	
Measurement at the dynamic posture	The person measuring stands at the right side of the subject. Knees of the subject are twisted on sagittal plane during measurement. One side of goniometer is placed on the malleolus lateralis and the other side is placed on the trochanterion to generate a 60˚ angle between the subject's lower and upper legs. The distance between two marked points is then measured.	

Table 2. Measurement descriptions of anterior leg length.

Anterior Leg Length (ALL)		
Preparation phase	The subject assumes a sitting position, and the point intersecting the right leg with lateral line on the crotch line and other point intersecting the lateral malleolus of the ankle with lateral line on the anterior leg are marked.	
Measurement at static posture	The person measuring stands at the right side of the subject. The distance between two points marked when the subject assumed an anatomic standing position is measured during the full extension of leg.	
Measurement at dynamic posture	The person measuring stands at the right side of the subject. Knees of the subject are twisted on sagittal plane during measuring. One side of goniometer is placed on the malleolus lateralis and the other side is placed on the trochanterion to generate a 60˚ angle between lower and upper legs of the subject. The distance between two marked points is then measured.	

Table 3. Measurement descriptions of elbow length.

Elbow Length (EL)		
Preparation phase	The right arm of the subject is turned from elbow at a 90^0 angle and the inferior point of the radiale is marked. Then, the arm assumes a straight position. The points 3 cm below and above the landmark are marked.	
Measurement at static posture	The person measuring stands at the right side of the subject. The subject assumes an anatomic standing position and distance between two points, which are marked when the arm of the subject is parallel to sagittal plane, is measured by positioning and using the tape measure on the elbow.	
Measurement at dynamic posture	The person measuring stands at the right side of the subject. During the measurement, the right arm of the subject assumes a position parallel to the sagittal plane, ensuring a 60˚ angle to the frontal plane. The subject assumes a measurement position ensuring a 60˚ angle between lower and upper arm by positioning one side of the goniometer on the acromion and the other side on the styloid process of the ulna. The distance between two marked points is then measured.	

Table 4. Measurement descriptions of anterior posterior arm length.

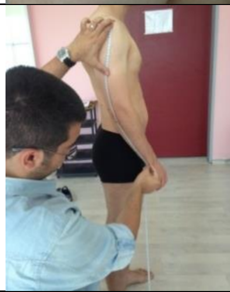
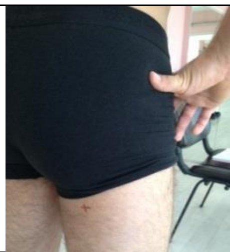
Posterior Arm Length (PAL)		
Preparation phase	The subject assumes an anatomic standing position, and the acromion of his arm and the styloid process of the ulna are marked.	
Measurement at static posture	The person measuring stands at the right side of the subject. The subject assumes an anatomic standing position and distance between two points, which are marked when the arm of the subject is parallel to the sagittal plane, is measured by crossing the tape measure over the elbow.	
Measurement at dynamic posture	The person measuring stands at the right side of the subject. During the measurement, the right arm of the subject assumes a parallel position to the sagittal plane ensuring a 60˚ angle to the frontal plane. The subject assumes a measurement position ensuring a 60˚ angle between the lower and upper arm by positioning one side of the goniometer on the acromion and the other side on the styloid process of the ulna. The distance between two marked points is then measured.	

Table 5. Measurement descriptions of anterior hip length.

Hip length (HL)		
Preparation phase	The subject assumes an anatomic standing position and the point of intersection of the vertical plane with the waistline is detected. Right below, the fold next to the gluteal muscles is detected and the point 3 cm below that part is marked.	
Measurement at static posture	The subject must assume an anatomic standing position during this measurement. Two persons standing behind the subject must perform measurement. The distance between two marked points is marked by crossing the tape measure over the hip.	
Measurement at dynamic posture	The angle between upper legs and body of the subject is measured as 70˚ by positioning one side of a goniometer on the line bisecting body on lateral and the other side on a line bisecting the leg—with the centre of goniometer on the trochanter point—and the subject assumes the measurement position. Two persons standing behind the subject must perform measurement. Distance between two marked points is marked by crossing the tape measure over the hip.	

Afterwards, the study of anthropometric measurements was completed with 31 male recreational skiers (Table 6), who were recruited from Ege University, Institute of Sports Sciences to participate in pre-measurement study. In order to determine the participant's number, a pre-measurement study was conducted with 9 volunteers and the number of subjects was calculated for each variable with 95% confidence interval, ensuring that it is within ±10% of average. As an exploratory study, in order to determine the percentage changes of body measurements in two states, all subjects were selected from the same size group.

Table 6. The information about volunteers

	Mean	Std. Deviation
Age	22	1,99
Height	181	4,76
Body weight	75	5,18
BMI	22,89	1,6

Moreover, this study was designed according to the rules and the principals of the Helsinki Declaration protocol and it was approved by the university ethics committee (EGE. ETK. 2012.12-3/18).

2.2. Determination of the elasticity of fabric

The elasticity of the fabrics was measured regarding to the "TS EN 14704-1: Determination of the elasticity of fabrics" standard. As the standard indicates, the warp test specimens were prepared with the length parallel to the wales and the weft test specimens parallel to the courses. The length of the specimens was (400±1,0) mm x (130±1) mm wide. The wide edges of specimens were sewn together at a distance 10 mm from the edge by using type 301 lockstitch. Afterwards, a 130 mm long line was drawn in the middle of specimen. Figure 2 shows the placement of the specimen to the test apparatus. A uniformly increasing and decreasing force was used for four times, and during the fifth cycle, the same force was used for 10 seconds and the line was measured. The force is between 0 N and 40 N for tight-fitting garments. The elongation of the specimens is calculated as a percentage by using the equation (Eq 1).

$$S = \frac{E-L}{L} \times 100 \qquad (1)$$

where
S Elongation
E is the extension (mm) at maximum force on the 5th cycle
L is the initial length of line (mm)

Figure 2. The placement of the specimen to the test apparatus [34].

In this research, the elasticity of the fabric presented in Table 7 was evaluated. Due to the knitting structure of evaluated fabric, the force was determined as 7 N to apply to the specimens.

Table 7. Fabric properties.

Yarn combination	Knitting construction	Mass per square meter (g/m^2)	Thickness (mm)
80% Coolmax / 20% Wool	1x1 Rib Knit	239,5	0,910

When a certain force in one direction is applied to the fabrics, the length of the specimen increases in the direction of the force, with a slight decrease in the width of the specimen, which is in a vertical direction. Based on this, the wide of the specimen at the fifth cycle was also measured and the percentage change in negative direction was calculated as contraction value.

2.3. Calculating Garment Pattern Measurements

Since the final measurements used in pattern preparation for tight-fitting garments are obtained by reducing the nude body dimensions by certain rates, the garment pattern measurements for tight-fitting garments were calculated by taking into consideration the percentage changes of body measurements as well as the elongation and contraction values of the fabric in wale and course direction.

2.4. Garment Patterns Design and Virtual Fitting

A base layer thermal bottom's garment patterns were prepared according to the both original method and developed method using Gerber AccuMark CAD System (Figure 3). As traditional method, garment patterns' measurements were calculated by reducing the body sizes with a percentage of "5%". Afterwards, the 2D patterns were virtually seamed on Optitex 3D Pattern Design System. The virtual fitting was conducted with an avatar created according to the standard body sizes researched in this study.

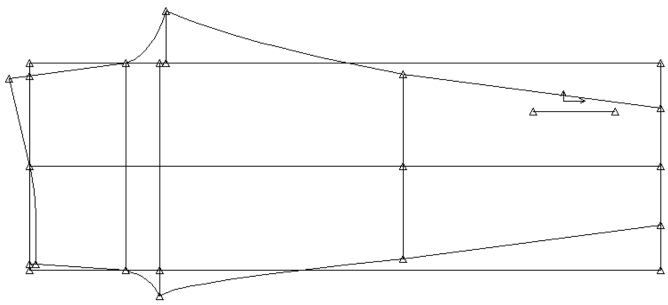


Figure 3. The base layer thermal bottom's garment patterns.

3. RESULTS AND DISCUSSION

3.1. Anthropometric Measurement Study

In Table 8, the body measurements of volunteers in the static and dynamic postures are presented; the differences as well as the percentages between body measurements in the static and dynamic postures were also calculated.

Table 8. Differences between body measurements in static and dynamic postures.

Body Measurements		Anterior Knee Length	Anterior Leg Length	Hip length	Elbow Length	Posterior Arm Length
Static Posture	Min. (cm)	11,50	78,80	25,40	6,10	55,00
	Max. (cm)	16,20	95,50	43,80	7,20	67,70
	Mean (cm)	13,48	85,93	35,87	6,54	62,35
	Std Dev.	1,40	4,07	3,54	0,33	3,18
Dynamic Posture	Min. (cm)	15,60	79,20	34,80	8,50	2,00
	Max. (cm)	22,60	95,60	58,00	10,20	9,50
	Mean (cm)	19,25	87,86	48,51	9,17	5,50
	Std Dev.	2,06	4,19	5,07	0,48	1,78
Difference (Dynamic Post. – Static Post.)	Min. (cm)	3,60	0,10	8,10	1,30	2,00
	Max. (cm)	8,10	6,40	16,40	3,70	9,50
	Mean (cm)	5,77	1,93	12,64	2,63	5,50
	Std Dev.	0,97	1,77	2,38	0,54	1,78
Percentage	Min. (%)	30,00	0,10	24,90	24,30	3,00
	Max. (%)	58,70	7,80	47,00	55,70	15,70
	Mean (%)	**42,87**	**2,26**	**35,29**	**40,43**	**8,88**
	Std Dev.	6,43	2,11	5,96	7,70	2,96

Among all measurements listed Table 8, the anterior knee length had the most significant changes. Since this measurement was about the body part, which the joint mainly exists, it showed that the skin extends the most, by 43% when knee joints bend. Nevertheless, due to the body parts included to the definition of the anterior leg length, the average measurement change in percentage was 2%. The anterior knee of the leg has the most skin extension during leg movement and it is the key measurement in pattern preparation phase for lower body garments. The garment designer should take into consideration the skin extension, especially for tight-fit garments in order to provide mobility of the wearer or to prevent the bagging of the garment at the knee. The average measurement change in percentages in the hip length, in the elbow length and in the lateral arm length were 35%, 40%, 9% respectively. The percentage of the measurement change in the elbow length was much higher than the percentage of the measurement change in the lateral arm length. Therefore, the elbow length is also a key measurement for long sleeve upper body garments [33].

3.2. The Elasticity Values of Fabric

The fabric's elongation (S) and contraction (C) values both in wale and course direction are given in Table 9. The elongation in length of fabric was calculated for the specimens which were prepared in course direction 58% and the contraction in width 18%. Additionally, the elongation in length in wale direction was determined as 21% and the contraction in width as 12%.

3.3. Garment Pattern Measurements Calculation

In order to provide perfect fit in tight-fitting garments, the measurements to be used in the phase of garment pattern preparation were calculated by taking into consideration the percentage changes of body measurements as well as the elongation and contraction values of the fabric in wale and course direction. Therefore, firstly the body dimensions for man were determined, which were related with the measurements used to calculate the percentage changes according to the international standard size charts [37]. The inseam, back waist rise and sleeve length were obtained as 76 cm, 24,5 cm and 44 cm, respectively, according to size 46. Afterwards, the total measurement change value was calculated for each measurement. For that calculation, the anterior leg length, posterior arm length and hip length were used as body measurement changes. During calculation of the total measurement change, the fabric elongation value was used as a negative value because of the fabric elongation property (Eq 2). Additionally, the fabric contraction value and the percentage of the body measurement changing values were used as positive values because of the necessity of movement. Due to the straight line of the garment pattern pieces, the elongation in length of fabric was used for the specimens, which were prepared in wale direction. Nevertheless, the contraction value of the fabric was used for the specimens, which were prepared in course direction. Table 10 shows the calculation process.

$$TMC = S - C - BMC \quad (2)$$

Table 9. The elongation and contraction values of the fabric

Course Direction		Wale Direction	
Elongation in the force direction (S) (%)	Contraction in the vertical direction (C) (%)	Elongation in the force direction (S) (%)	Contraction in the vertical direction (C) (%)
57,95	17,69	21,03	12,05

Moreover, in order to determine the garment pattern measurements by reducing the nude body dimensions, the inseam, back waist rise and sleeve length measurements were multiplied by total measurement change values (Eq 3) (Table 11).

$$GPM = BD + \frac{BD\ x\ TMC}{100} \quad (3)$$

As it can be seen in Table 10 and Table 11, the inseam length and sleeve length needed to be reduced since the fabric elongation was higher than body measurement changes. On the contrary, the back rise measurement needed to be increased due to the considerable amount of body measurement change in hip length. The total measurement change was 7,83 cm for back waist rise. This measurement could be added as back waist height to the lower garment patterns.

3.4. Garment Patterns' Evaluation by Virtual Fitting

In order to evaluate the developed garment patterns, the simulation of material properties, human body and patterns' assembling were done and real wearing effects were obtained. The longitudinal fabric stretching views of the base layer thermal bottom prepared according to the original method and according to the developed method are presented in Figure 4 and Figure 5, respectively. In the software, there are defined body postures and to get the closest dynamic posture for Alpine skiing, the squat posture was chosen.

Table 10. Calculating the total elongation of the body dimension.

Measurement	Elongation in the force direction (S) (%)	Contraction in the vertical direction (C) (%)	Body measurement change (BMC) (%)	Total measurement change (TMC) (%)
Inseam	-21,03	17,69	2,26	-1,08
Back Waist Rise	-21,03	17,69	35,29	31,95
Sleeve Length	-21,03	17,69	8,88	-5,54

Table 11. Calculating the garment pattern measurements.

Measurement	Body Dimension (BD) (cm)	Total measurement (TMC) change (%)	Garment Pattern Measurements (GPM) (cm)
Inseam	76	-1,08	75,18
Back Waist Rise	24,5	31,95	32,33
Sleeve Length	44	-5,54	41,56

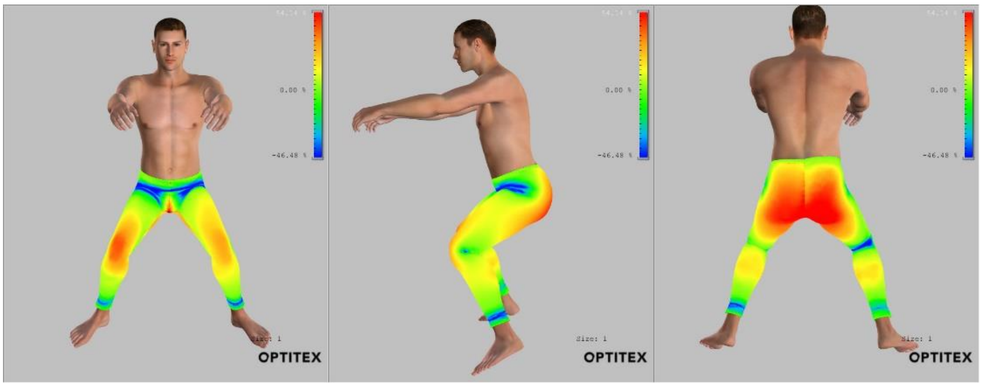


Figure 4. The longitudinal fabric stretching views of garment prepared by original method.

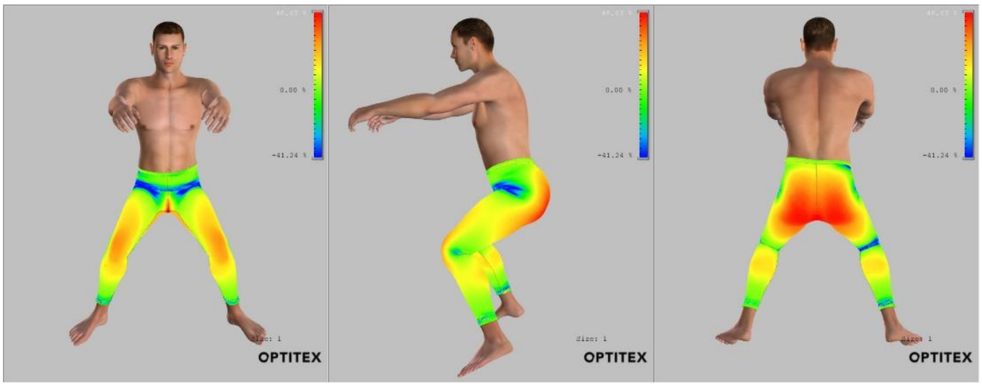


Figure 5. The longitudinal fabric stretching views of garment prepared by developed method.

Table 12. The stretching and tension values of base layer thermal bottom.

		Longitudinal stretching (%)	On (xy) direction stretching (%)	Tension (gf/cm)
Original pattern	Max	54,14	141,16	872,88
	Min	-46,48	-43,43	171,52
	Hip	47	140	849
	Knee	35	86	368
Developed pattern	Max	48,63	130,85	843,94
	Min	-41,24	-37,7	181,36
	Hip	42	130	815
	Knee	29	74	355

Besides longitudinal fabric stretching values, the stretching values on both directions (xy) and the tension values of garment were obtained using the software. Table 12 shows the values for both original pattern and developed pattern including the minimum and maximum values as well as the maximum values for hip and knee.

The stretching was firstly tested longitudinal due to the measurements focused on this study. With the developed pattern, the fabric elongation was reduced on knee 6% and on hip 5%. The maximum fabric stretching was also lower for developed pattern. The results were similar for xy direction stretching and the tensions of the garment. The developed pattern was more fit than the original pattern, and it can also be said that it had more ability to adapt dynamic postures. Moreover, the discomfort on back waist due to the motion was tried to be prevented.

4. CONCLUSIONS

In this study, the percentage of the size changes of body in movements performed during the Alpine ski sport were specified. The experiments were carried out in order to collect five measurements such as anterior knee length, anterior leg length, elbow length, posterior arm length, and hip length both in static state and in dynamic posture. The range of body angles in the Alpine skiing movements, which is a ski sport and object of this study, is quite extensive. Therefore, the body angles used here were based on literature and afterwards the definitions of those five measurements were developed regarding to ISAK practices.

Stretching figures of tight-fitting clothes in Alpine skiing and these percentage changes must be considered when calculating the size of a garment pattern. Therefore, the inseam, back waist rise and sleeve length measurements were also calculated for tight fitting garments by using the percentage changes of anterior leg length, posterior arm length and hip length, and the fabric elongation properties.

Measurements used in the pattern preparation for tight-fitting clothes are obtained by reducing the nude body dimensions at certain rates. Considering the stretching figures of fabric used in calculating these rates and local size changes of the body will ensure better adaptation of clothes to the body without preventing movements of sports participants and thereby will increase the body movement comfort. Therefore, a base layer thermal bottom’s garment patterns were prepared according to the original method as well as the developed method. In order to evaluate these patterns, a 3D virtual try-on software was used and virtual fitting was performed.

After manufacturing the tight-fitting garments according to this method, fitting should be generated with live models and the movement comfort of the garment should be evaluated. If the upper tight-fitting garment's elbow area does not show features similar to human skin-stretching, some other solutions such as splitting the sleeve pattern and changing the straight line of the fabric for the pattern piece of elbow area can be tried as well.

This study confirms that clothes used in related sports should have good quality of stretching and changing back to the original size and shape.

It is herewith suggested that the figures of percentage changes of body sizes obtained as a result of this study should be used by manufacturers to produce high-comfort ski wear. Moreover, the number of studies towards the dynamic structure of a body is limited and researchers must devote more attention to this field.

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ABBREVIATIONS

ISAK	The International Society for the Advancement of Kinanthropometry
BMI	Body Mass Index
3D	Three Dimensional
AKL	Anterior Knee Length
ALL	Anterior Leg Length
EL	Elbow Length
PAL	Posterior Arm Length
HL	Hip Length
S	Elongation
E	is the extension (mm) at maximum force on the 5th cycle
L	is the initial length of line (mm)
C	Contraction in the vertical direction
BMC	Body Measurement Change
TMC	Total Measurement Change
BD	Body Dimension
GPM	Garment Pattern Measurement

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