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Impact of Male Body Posture and Shape on Design and Garment Fit

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Abstract
This paper presents a study of the impact of body posture and the presence of functional and structural body changes on garment fit. 3D scanning on a sample of 50 male test subjects was performed. Body posture indicators were determined on 3D body models and a statistical analysis of the results obtained was performed. Test subjects from the sample were divided into three groups according to body posture types. Three body models with different body dimensions and different physiological spine curvature were selected and imported into a 2D/3D CAD system for computer-based garment simulation. 3D simulation of a men's jacket in the closest garment size was performed on selected body models. Garment fit was analysed on every simulated model and based on the analysis performed, garment pattern elements and measurements where it is necessary to enable modifications were determined. The most complex part of the research refers to the development of a parametric computer-based garment model which will be able to adjust according to anthropometric body measurements and body shapes with a different physiological spine curvature. Relationships between targeted body measurements and their impact on modifications of pattern segments were investigated as a starting point for defining mathematical expressions according to which values of measurement changes on the garment pattern will be calculated. A parametric garment model pattern which enables adjustments according to different body sizes and body postures types was developed. Verification of the method developed was performed using computer-based 3D simulations on 3D body models with prominent problems of body posture.

Key words: *clothing, computer-based construction, 3D simulation, parametric cut pattern, body posture.*

Introduction

Studies of body postures are primarily dealt by researches from the field of medical sciences, kinesiology and anthropology, where the focus of research problems is on irregular postures and disorders that occur as a result of such postures [1 - 4]. An early diagnosis of an irregular posture and targeted kinesitherapy training can affect functional disorders of body posture and body posture improvement. However, if those kinds of disorders are not treated, it will progressively lead to deviation of particular body segments from the proper posture, which can be divided into irregular functional and structural states such as diagnosis of scoliosis, lordosis or kyphosis [5 - 8]. Irregular body posture and the presence of functional and structural body states also presents a problem in garment design in the sense of appropriate fit and functionality of garments from the aspect of the design and construction of garment models. Posture issues are especially pronounced in the adult population and are present in both sexes. Diagnostic procedures used to analyse body posture and to determine the presence of functional disorders or deviations of particular body segments can be performed in several different ways characteristic for a particular field of application [5, 9]. A number of methods for analysing and assessing body posture is based on photographing test subjects in a defined body position and on the assessment of body posture using computer-based 2D body representation and calculation of deviation values for body posture indicators [10 - 12]. Anthropometric measurements of the human body, determined according to precisely defined anthropometric measuring points, are the starting point for garment construction [13, 14]. The traditional method of taking anthropometric body measurements, using conventional measuring equipment, enables accurate determination of body dimensions, only if performed by a trained measurer who will always take measurements in the same way, according to Standards ISO 8559 and ISO 9407, which define human body measurements for the needs of the clothing and footwear industry. The application of contemporary technologies for anthropometric body measurements, such as different kinds of 3D body scanners, enables non-contact computer-based body measuring, where a large number of measurements are determined in a short period of time [15]. Besides determining body dimensions, the application of 3D scanners enables visualisation of the shape and assessment of body posture [16], which is significant for garment construction. Also measurements determined and the computer-based 3D body model can be further used in 2D and 3D software packages for developing computer-based garment prototypes according to individual anthropometric body characteristics. This field of research has been intensively developed over the last decade and is the focus of researchers in the field of developing CAD systems for computer-based construction and garment adjustment according to individual measurements [17 - 20]. Mainly methods and CAD systems developed for pattern adjustment for a particular individual are based on grading sets of cutting parts for a range of standard garment sizes. These adjustments are mainly related to modifications according to individual body measurements and do not take into account deviations from good body posture nor the possible presence of structural body changes. There are some literature guidelines for the conventional adjustment of garment patterns according to some deviations from good body posture and smaller body deformities, but they are usually based on the experience factor. However, computational methods and systems that enable an automated computer-based process of garment pattern adjustment when it is necessary to modify basic cutting parts according to different deviations from good posture and consequently present structural body changes, have still not been developed. In the research previously published [21], the authors developed a method for computer-based adjustment of a men's jacket according to individual measurements, which was successfully verified on male body models in terms of body shape and measurements. This paper presents an extension of the research regarding the development of a parametric pattern that will enable adjustment according not only to anthropometric measurements, but will also take into account the deviation from good posture and the presence of structural body changes.

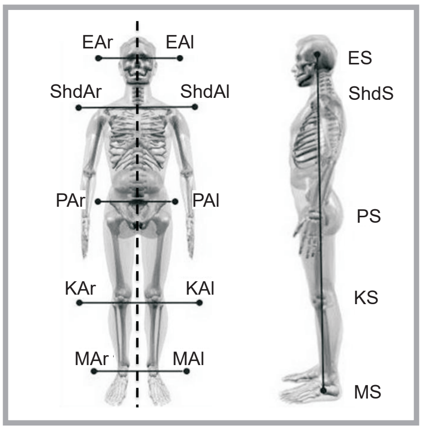


__Figure 1.__ Proper body posture with positioned gravity line and points for body posture assesment [5].

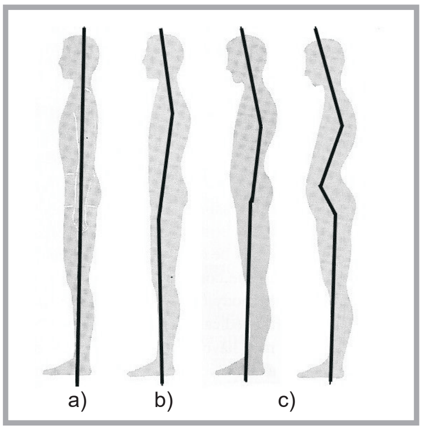


__Figure 2.__ Irregular body posture types a) good posture, b) slightly irregular posture and c) higly irregular posture [25].

Test subjects and methods

3D body scanning and body posture analysis

The study was performed on a sample of 50 adult male test subjects aged 20 to 35 years. 3D body scanning of all test subjects was performed using a laser body scanner - Vitus Smart (Human Solutions, Germany), according to ISO standard 20685 [22]. The primary intent of this standard is to ensure comparability of body measurements currently defined by Standards ISO 7250 (1996.-Basic body measurements for technological design) and ISO 8559 (Construction of clothing and anthropometric surveys – body dimensions), but measured with a 3D body scanner rather than the traditional anthropometric instruments [23, 24]. The determination of anthropometric measurements was performed by the automatic computer-based measurement process, whereby 150 body measurements were taken for every test subject. Furthermore a computer-based analysis of body posture was performed on a sample with the purpose of selecting test subjects with deviations from the normal posture and presenting structural body changes, especially on the upper body part i.e. trunk. Body posture analysis in the frontal plane was performed according to the method by Paušić [5], where the basic condition for the assessment of proper body posture is the balance of body segments i.e. symmetry of particular body segments in the dorsal view of the anteroposterior plane (***Figure 1***). In proper body posture, the gravity line passes through the middle of all vertically aligned joints. The gravity line is presented by a drawn vertical that passes through the body gravity center, located in the second sacral vertebra, which connects the middle point between the eyes, the center of the chin, the tip of the sternum, the center of the pubic area and the middle point between the ankles (***Figure 1***). The line that connects the middle point on the upper part of the ear, the middle of the shoulder, hips, knee and ankle joint was analysed in the sagittal plane [5]. With proper posture, the line is vertical (***Figure 1***) and in different types of irregular postures, point positions deviate from the gravity line (***Figure 2***). Using the method described, analysis of the body posture is usually performed with Scoliosometer or surplus [5] or by capturing 2D images of subjects which are computer-based processed. The gravity line was inscribed on photographs together with points according to which the alignment of body segments was analysed.

For the purpose of this research, point positions on the body in the frontal plane were determined on computer-based 3D body models of test subjects on which body symmetry was analysed. Irregular body posture types were identified in the sagittal plane according to deviations of control points (***Figure 3***).

The application of a 3D body scanner and innovative computer-based method for 3D body model analysis not only enables the assessment of body posture but also very precise measurement of parameters for body posture assessment. In this sense, body posture analysis of test subjects in a sample was performed using computer-based cross-sections of 3D body models with frontal, sagittal and transverse planes positioned through points according to which body symme-

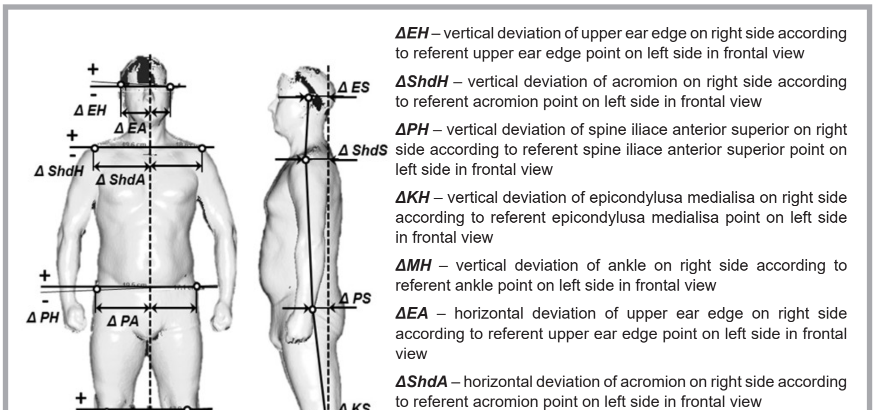


__Figure 3.__ Body balance analysis in frontal plane and body posture assesment in sagittal plane.

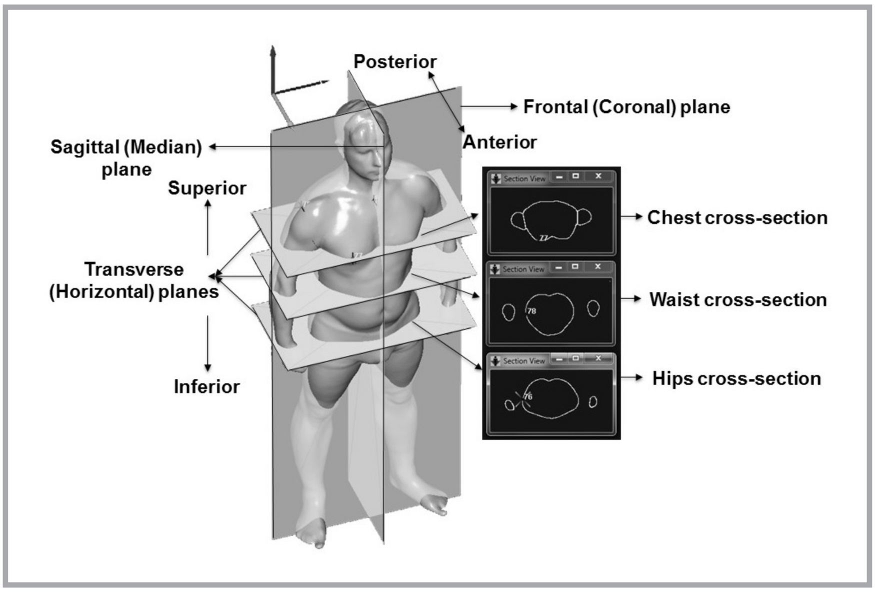


Figure 4. *Cross-section of scanned 3D body model with anatomical planes.*

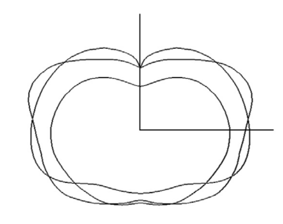
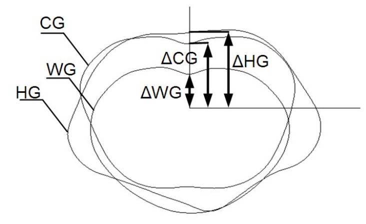
try was analysed (***Figure 3***). As shown in ***Figure 3,*** body posture assessment of test subjects in a sample was performed based on statistical data analysis of four posture indicators in the sagittal view: deviation of the upper ear edge on the left side of the body from the gravity line (*ΔES*), deviation of the acromion on the left side of the body from the gravity line (*ΔShdS*), deviation of the spine iliace anterior superior on the left side of the body from the gravity line (*ΔPS*), and deviation of epicondylusa medialisa on the left side of the body from the gravity line (*ΔKS*). The fifth indicator (ankle point) is considered as the reference point for placing the gravity line, according to which deviations of the other four indicators were determined. The method applied enables identification of three body posture types: proper body posture, slightly irregular body posture and highly irregular body posture, as shown in the results. In the next stage of of the research and development of the parametric garment pattern, three computer-based body models with different physiological spine curvatures were selected from a sample of test subjects with a highly irregular body posture. The effect of an irregular body posture and different spine curvature on garment pattern fit and determination of parametric pattern parameters were further analysed on selected models. Symmetry and shape analysis of particular body parts on selected body models with irregular body postures was performed using computer-based analysis on 3D body models, which enables very precise positioning of the gravity center inside the human body and of the gravity line directly through that gravity center. In this way, unlike the methods previously used [5, 25], body posture analysis in the sagittal plane was performed using variables determined according to the gravity line positioned in the gravity center inside the body and not in relation to the ankle, in order to determine spine curvatures on selected body models. The symmetry of the left and right body side was computer-based analysed using body cross-sections in the midsagittal plane positioned directly through the gravity center in the pelvis and transverse planes positioned on the lines of chest, waist and hips. In doing so, special attention was paid to analysis of the cross-sectional shape of the curves as additional parameters for later pattern modification and calculation of percentage shares of pattern segments in the total circumference (***Figure 4***).

The body cross-section in the midsagittal plane [26] enables very precise analysis of physiological spine curvature, as well as a shape analysis of the curve on the front side, which has a great impact on the development of a parametric garment pattern. The body cross-section in the parasagittal plane [26] over the outermost (most protruding) point of the scapula enables analysis of the curve shape of that body segment, important for garment construction and pattern modification.

In such a way, relationships of particular body measurements are investigated for each test subject, such as measurements of chest girth (CG), waist (WG) and hip (HG) lines, the shape and symmetry of cross-section curves on characteristic lines and the distance between points of the back middle line for every characteristic circumference and body gravity center (***Table 1)***. ***Table 1*** presents determined values of distances between points of the back middle line and body gravity center for three selected test subjects with a highly irregular body posture.

For the body models selected from the total number of anthropometric measurements determined, 16 characteristic body measurements were selected for computer-based modification of the garment pattern: chest circumference, waist circumference, hip circumference, height of seventh cervical vertebra,

Table 1. *Distance between points on the back middle line on the chest, waist and hip line and the body gravity centre.*

Cross-sections on chest, waist and hip line on symmetric body model with correct posture	Cross-sections on chest, waist and hip line – distance between points on back middle line and body gravity center, mm	Test subjects	ΔCG	ΔWG	ΔHG
	 	I	103.32	79.01	84.49
		II	101.54	53.61	118.76
		III	99.20	57.40	137.26

scapula height, chest line height, waist line height, hip line height, back width, back length measured over the spine, back length measured from the shoulder line over the outermost scapula point to the waist line, and shoulder width measured over the seventh cervical vertebra, front height and chest width.

Computer-based preparation of cutting pattern and 3D simulation of men's jacket in graded sizes

The construction and grading of a men's jacket pattern in a set of grading sizes from 44 to 56 were performed using the CAD system Optitex and a software package designed for the computer-based construction of 2D garment patterns and 3D simulation of garments. Grading was performed proportionally based on calculated values of grading rules determined according to the differences between basic body dimensions and construction measurements. 3D simulation of a men's jacket in the closest garment size was performed on each of the three 3D body models selected, where the selection of a size was based on the body dimension of the chest circumference. Garment fit analysis was performed on body models by determining the following parameters: difference in circumference values measured on the garment model and on the body's waist and hip lines, the jacket length in relation to the waist line and alignment of the jacket length, the position and length of the shoulder seam, garment width according to body width on the back side measured over the scapula and form of the garment pattern on the back middle line.

Development of parametric men's jacket pattern for adjustment according to different body posture types

Transformations of cutting parts using a conventional 2D CAD system are performed by translations of individual points of the pattern contour segments. In doing so, the implementation of transformations of one cutting part does not depend on the other cutting part, and thus in computer-based processing of patterns, each cutting part should be separately processed, which greatly exceeds the time for pattern preparation. The application of the innovative 2D/3D CAD system designed for 2D/3D construction and simulation of clothing enables simultaneous modification on several cutting parts, which is most important for pattern adjustment according to individual measurements, but it is necessary to predetermine the development steps which will enable the transformation of 2D cutting parts from a vector into a parametric form. In order to enable the adjustment of cutting parts according to individual measurements and different types of body posture, body posture analysis was performed using the method previously presented and in accordance with the requirements and rules of conventional clothing construction. The parameters that indicate a need for adjustment according to particular posture types are determined based on the results of the fit analysis of graded jacket models simulated on body models with present deviations from good posture. All parameters, including the need not only for measurement adjustment but also shape modification of particular cutting parts according to morphological body changes, are taken in consideration. Accordingly it is necessary to perform the systematic development of a garment pattern in order to transform vector 2D cutting parts into a parametric format suitable for automatic computer-based adjustment according to targeted measurements, where desired changes of targeted segments and relations of changes on corresponding segments and measurements on cutting parts are defined. In order to verify the new method as a possible replacement for conventional pattern grading, a set of men's jacket grading sizes was used as the starting point for calculation and control of segment measurement shares in the total dimensions of targeted body circumferences. In this sense, it is initially necessary to define the positions of fixed points, which will be used to block a cutting part in the particular point, defining the directions of segment modifications during adjustment. It is also necessary to define the horizontal and vertical axes, where the vertical is usually positioned through the fixed point as the axis of proportionality, in relation to which modifications of narrowing and enlarging cutting parts for the particular proportionality coefficient will be made. After placing the axis lines, horizontal, vertical, diagonal and curve measurements are defined for the cutting parts. A change in the positioned measurement value affects simultaneous changes in related segments on the cutting parts. In this manner, the garment pattern is transformed into the parametric form, which can be tested by the interactive movement of segments defined with a particular measurement. Targeted connections of measurements enable simultaneous modifications of all connected segments of the pattern contour. Measurements on the cutting part, which are defined and positioned according to conventional construction rules and directions of segment movements during modification, are defined according to values of body posture indicators of test subjects with a highly irregular body posture. That way, modifications of the pattern form and shape according to different irregular body posture types and physiological spine curvatures are enabled.

Defining mathematical expressions for connecting measurement sets on cutting parts

Defining mathematical expressions for calculating segment dimensions on cutting parts, where it is necessary to ensure that during modification of a particular cutting part all corresponding ones are changed to the same degree or for the specific coefficient of proportionality, presents the most complex part of the research. When defining mathematical expressions, all segments constituting a particular circumference or total length should be considered. The coefficient of ease should be kept constant regardless of the size for which the adjustment is carried out. If there are any folds on the garment model, which should be modified proportionally according to a change in the targeted measurement, the fold coefficient should also be defined. In addition, it is necessary to predict and determine the coefficients for the adjustment of particular measurement percentage shares in the total circumference. Problems of irregular body posture and a different physiological spine curvature are especially evident in this part of the adjustment. Conventional pattern grading and the parametric pattern previously developed [16] enable the adjustment of the pattern according to measurements of a particular garment size or individual measurements, but do not take into account irregular body postures and present morphological body changes. By analysis of body cross-sections, deviations from regular distribution on the anterior and posterior parts using the frontal plane are determined. The analysis of cross-sections in the sagittal plane and particular transversal planes also determined a deviation in body symmetry (***Figure 4***). In addition, the distances of points on the middle back line on characteristic body circumferences of the chest, waist and hips according to the body gravity centre, which

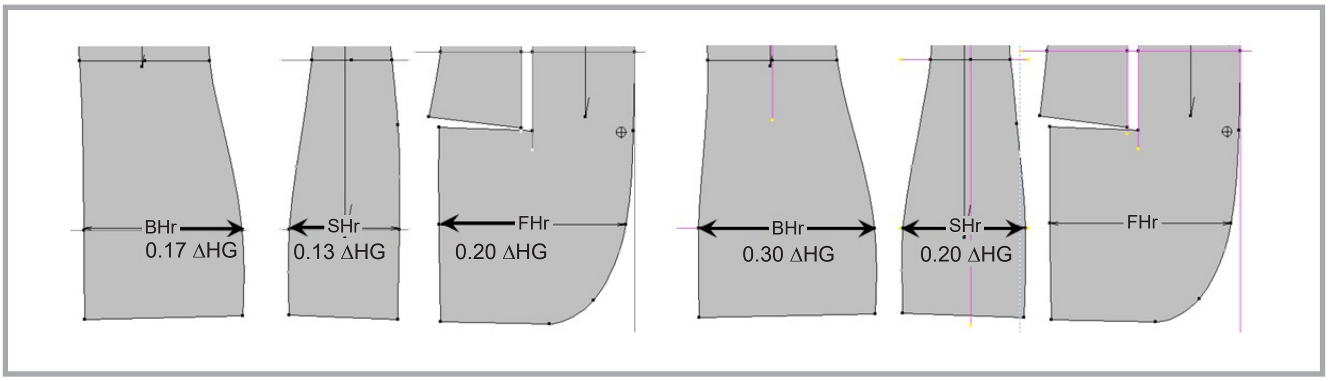


Figure 5. *Set of measurements on the pattern line of the hip circumference with directions marked for segment modification during adjustment of a) good body posture and b) highly irregular body posture.*

indicates differences in the spine curvature and morphology of the back body part, also requires changes in adjusting the back and side cutting part for a particular body posture type (***Figure 5***).

As described above, the complete development of a men's jacket garment pattern was performed using the computer program Modulate. In the next step, considering all specified influences and values of particular parameters, mathematical expressions for the targeted main body dimensions are defined. The calculation of particular sets of predefined measurements with the purpose of achieving the exact value of the targeted dimension will be performed based on the mathematical expressions defined. Values of all determined measurements of pattern segments which are contained in the hip circumference (*FH* – front hip segment, *SH* – side hip segment and *BH* – back hip segment) are shown in ***Table 3***. The dimension of the pattern hip circumference (*HG1*) is defined as the sum of segment measurements, and the ease coefficient is obtained from the difference between the dimension of the pattern circumference and that of the body circumference (*HG*) defined by the standard garment size.

Measurements of pattern segments on the chest (*FC* – front chest segment, *SC* – side chest segment and *BC* – back chest segment) and waist circumferences (*FW1* – front waist first segment, *FW2* – front waist second segment, *SW* – side waist segment and *BW* – back waist segment) were determined in the same way, and based on the results obtained, mathematical expressions (1), (3) & (5) for calculating the jacket's circumference on the chest (CG_1), waist (WG_1) and hip (HG_1) lines with an added amount of ease were defined. In order to obtain the value of body measurement for the targeted chest (*CG*), waist (*WG*) or hip (*HG*) circumference which is to be used in the system for pattern adjustment, the values determined for the garment circumferences need to be reduced for the amount of ease allowance, which is defined in expressions (2), (4) & (6).

$$CG_1 = (FC + SC + BC) \cdot 2 \quad (1)$$

$$CG = CG_1 \cdot \text{ease coefficient} \quad (2)$$

$$WG_1 = (FW1 + FW2 + SW + BW) \cdot 2 \quad (3)$$

$$WG = WG_1 \cdot \text{ease coefficient} \quad (4)$$

$$HG_1 = (FH + SH + BH) \cdot 2 \quad (5)$$

$$HG_1 = (0.21 \cdot \Delta HG + 0.12 \cdot \Delta HG + 0.17 \cdot \Delta HG) \cdot 2 \quad (5a)$$

→ good and slightly irregular posture

$$HG_1 = (0 \cdot \Delta HG + 0.2 \cdot \Delta HG + 0.3 \cdot \Delta HG) \cdot 2 \quad (5b)$$

→ highly irregular posture

$$HG = HG_1 \text{ ease coefficient} \quad (6)$$

Considering the determined problems of the cutting pattern's ease allowance in the hip region for a highly irregular body posture, the mathematical expressions developed are defined separately for good and slightly irregular posture and highly irregular posture. For the good and slightly irregular posture, the difference between measurement of the garment hip circumference in the closest standard size and individual body hip measurement (*ΔHG*) was divided based on the percentage shares of pattern segments in the total garment circumference measurement (5a), and adjustment is performed on all cutting parts, while for a highly irregu-

Table 3. *Values of garment pattern segments and their shares in the total measurement of the hip circumference with the values of ease allowance.*

HG/Size		44	46	48	50	52	54	56	58	60	Average
FH,	cm	20.60	21.69	22.77	23.85	24.94	26.23	27.52	28.81	30.10	-
	%	20.42	20.64	20.84	21.03	21.21	21.47	21.71	21.94	22.15	21.27
SH,	cm	12.40	12.90	13.40	13.90	14.40	14.90	15.40	15.90	16.40	-
	%	12.29	12.28	12.27	12.26	12.25	12.20	12.15	12.11	12.07	12.22
BH,	cm	17.45	17.95	18.45	18.95	19.45	19.95	20.45	20.95	21.45	-
	%	17.29	17.08	16.89	16.71	16.54	16.33	16.14	15.95	15.78	16.52
HG1, cm		100.90	105.08	109.24	113.40	117.58	122.16	126.74	131.32	135.90	-
HG, cm		94	98	102	106	110	114	118	122	126	-
Ease, cm		6.90	7.08	7.24	7.40	7.58	8.16	8.74	9.32	9.90	8.04
Ease coef.		0.93	0.93	0.93	0.93	0.94	0.93	0.93	0.93	0.93	0.93

Table 4. *Mean values and standard deviations of posture indicators for three body posture types determined.*

Body posture type	Good body posture		Slightly irregular body posture		Highly irregular body posture	
Variables for posture assessment in sagittal plane	$\bar{x}$, cm	*s*	$\bar{x}$, cm	*s*	$\bar{x}$, cm	*s*
Δ ES	-5,23	1,83	-6,18	2,45	-8,68	2,54
Δ ShdS	-0,65	0,46	-3,14	0,93	-6,91	1,99
Δ PS	-2,00	0,93	-3,74	1,30	-5,90	1,85
Δ KS	-0,65	1,37	-0,77	1,57	-2,92	1,68

lar posture, adjustment is performed by modification of segments on the back and side cutting parts according to expression (5b), which will enable additional pattern modification, especially that of the back middle line according to the curvature of the back part of the body.

Results

Body posture types determined on a sample of computer-based 3D body models

According to the results of the analysis in the sagittal view obtained, the presence of all three body posture types was determined on a sample of 50 test subjects (***Table 4*** and ***Figure 6***).

For all body posture types the mean values of posture indicators are negative, meaning that deviations are placed in front of the gravity line (left) in the sagittal view, (***Table 4***). For good and slightly irregular body postures the largest deviation from the gravity line was observed for the head position indicator (*ΔES*), followed by the pelvis position indicator (*ΔPS*), shoulder indicator (*ΔShdS*) and knees indicator (*ΔKS*). For a highly irregular body posture the mean values of posture indicators are placed in an interval between -2,92 and -8,68, where the largest deviation from the gravity line was observed for the head position indicator (*ΔES*), followed by the shoulder position indicator (*ΔShdS*), pelvis indicator (*ΔPS*) and knee indicator (*ΔKS*). The presence (structure) of particular body posture types in the test sample is shown in ***Figure 7.*** The most frequent type is the highly irregular body posture type, with 60 % of test subjects in the sample, while the slightly irregular body posture is represents 32 % and a good body posture - 8% of test subjects in the sample. Based on the analysis of physiological spine curvature on the test subjects with a highly irregular posture, great spinal curvature was determined in 73% of test subjects and a small spinal curvature in 27% (***Figure 7***).

Results of computer-based body analysis and garment fit on test subjects with a highly irregular body posture

Using symmetry analysis of the left and right side of the body, on selected body models with a highly irregular posture, deviation values of symmetry indicators were determined, as shown in ***Table 5***. In the body symmetry assessment, the deviation values of symmetry indicators are expressed for the right side of the body, where the asymmetry of the right side in relation to the left was determined on all three test subjects selected. The values of point deviations obtained on the left

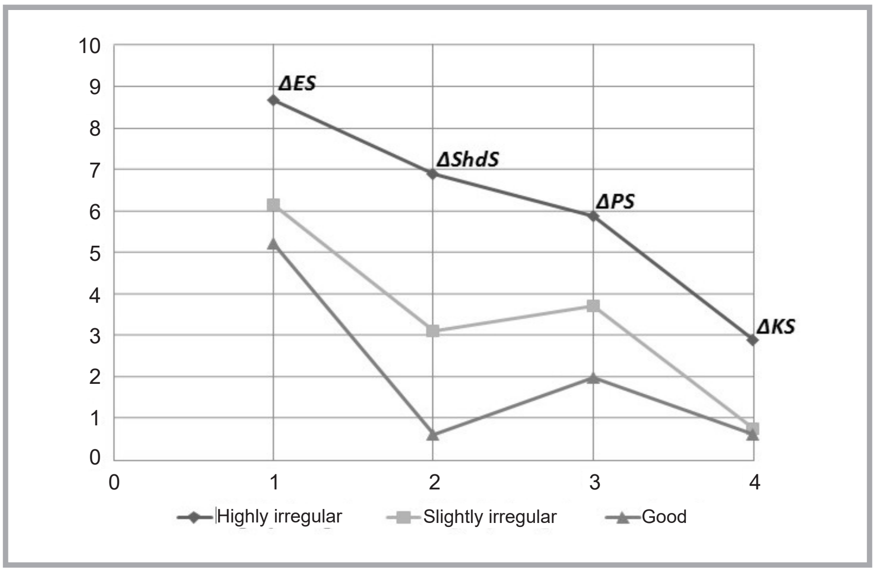


Figure 6. *Mean values of posture indicators for three body posture types determined on a sample.*

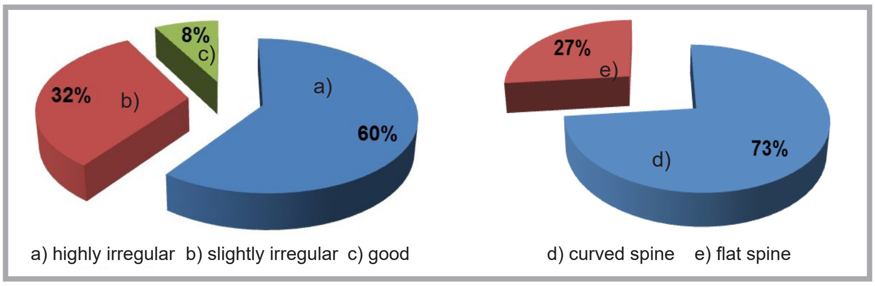


Figure 7. *Stucture of body posture types on a test sample.*

Table 5. *Distance values of points on the left and right side in the frontal plane according to the midsagittal plane and transversal plane positioned through the reference point on the reference left side of the body.*

Indicators of body symmetry in frontal plane according to midsagittal plane		Test subjects I		II		III	
		Distance values of symmetry indicators according to midsagittal plane, cm					
			ΔR- ΔL		*ΔR- ΔL*		*ΔR- ΔL*
Δ EA	L	7.9	+2.8	7.4	+2.6	8.5	-0.5
	R	10.7		10.0		8.0	
Δ ShdA	L	18.6	+1	18.9	-0.4	20.5	+1.1
	R	19.6		18.5		21.6	
Δ PA	L	17.1	+2.4	17.2	0	16.1	+4.1
	R	19.5		17.2		20.2	
Δ KA	L	13.8	+1.5	12.7	-0.5	10.2	+2.8
	R	15.3		12.2		13.0	
Δ MA	L	19.2	+0.2	14.5	+0.7	11.9	+4.8
	R	19.4		15.2		16.7	
Indicators of body symmetry in frontal plane according to transversal plane		**Distance values of symmetry indicators according to transversal plane placed through reference point on left side of body, cm**					
Δ EH		+1.4		+1.0		+1.2	
Δ ShdH		0.0		-1.2		-1.7	
Δ PH		-0.6		+0.5		+0.6	
Δ KH		-0.5		+0.1		-0.1	
Δ MH		+0.4		-0.6		-0.2	

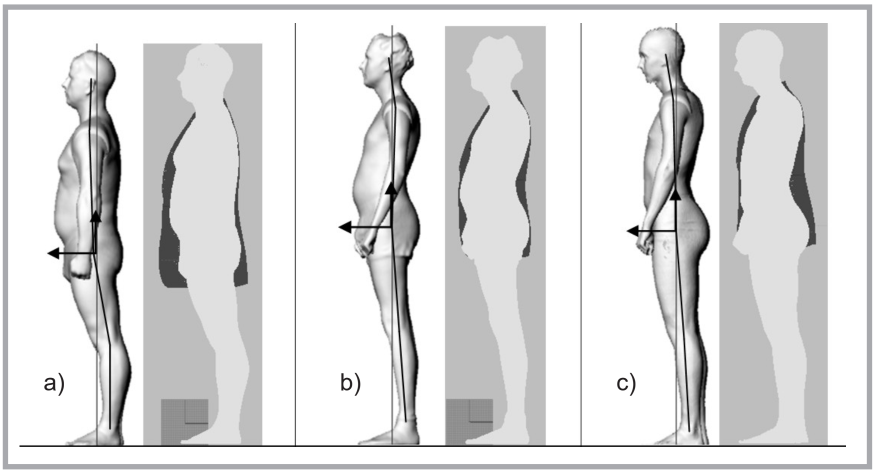


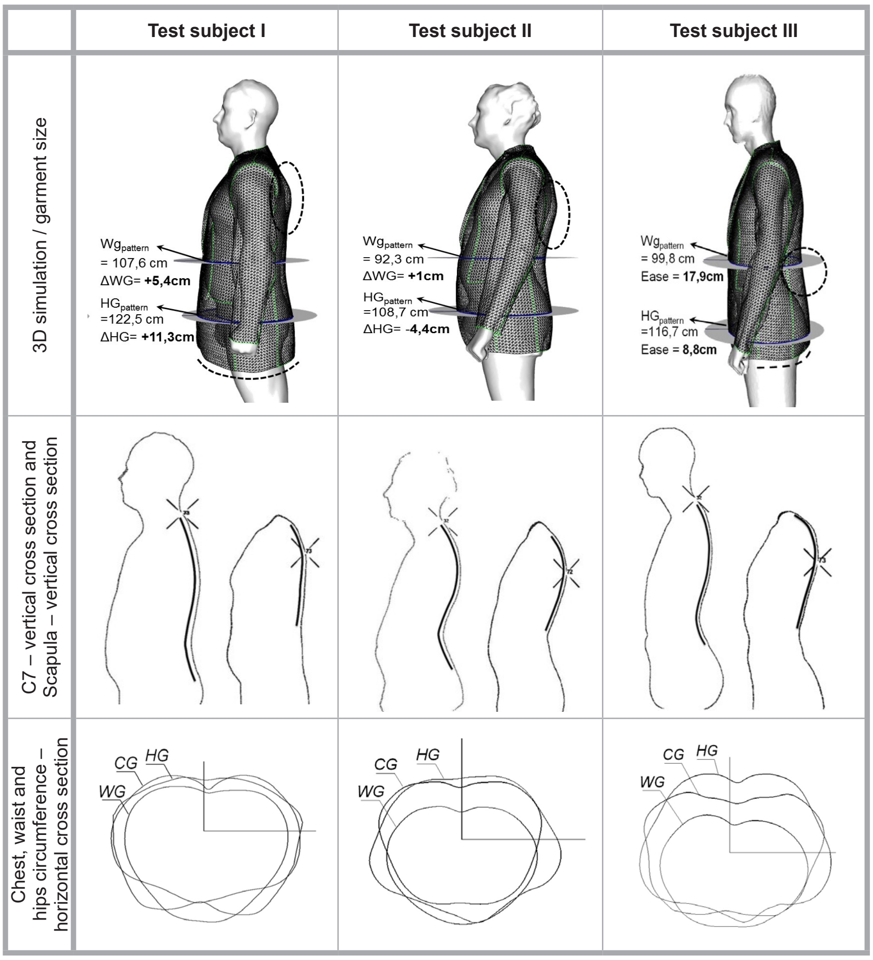
Figure 8. *Body posture analysis in the sagittal plane and the cross-section of the model and simulated garment in the closest garment size. Test subject: a) I, b) II, c) III.*

and right side of the body were used as the starting point for defining the possible need for pattern modification with respect to adjusting the body with a great presence of asymmetry. The analysis of values of symmetry indicators according to the transversal plane can also help determine body points for which it is necessary to predict pattern adjustment using visual body correction with targeted pattern modifications.

Body posture analysis in the sagittal plane according to the gravity center inside the body for three test subjects selected confirmed a highly irregular body posture for all test subjects (***Figure 8***). The cross-sections of all three test subjects in the sagittal plane with a simulated model of a men's jacket in the closest garment size are shown in ***Figure 8***. The selection of the closest garment size was based on body measurement of the chest circumference with approximate 10 ± 1.5 cm of the ease allowance value of characteristic body circumferences (chest, waist and hips). The problems of garment fit according to the previously defined garment fit indicators are evident in sagittal cross-sections.

Problems with an inappropriate garment shape and form on the back middle line of the pattern, which consequently affects the curvature of the garment model length, are visible on test subject I, with small spinal curvature determined with the analysis of the cross-section in the midsagittal plane (***Table 6***). A small spinal curvature on test subject I was also confirmed by the cross-section analysis in the parasagittal plane over the outermost point on the scapula and by cross-sections at characteristic body circumferences, where body asymmetry is also visible. The pattern ease allowance on the waist and hip circumferences is too large and unevenly distributed, with the greater part on the front side of the model. The analysis of body cross-sections in the midsagittal and parasagittal planes over the outermost point on the scapula determined a great spinal curvature and all the back body part on test subject II, which also has a negative impact on the shape of the garment model on the back side (***Table 6***). Body asymmetry visible from the analysis of cross-sections and that of the ease on the simulated garment model determined an insufficient ease amount on the hip circumference. On test subject III, analysis of the cross-section in the midsagittal plane revealed greater spinal curvature in the lumbar region, while the cross-section in the parasagittal plane over the outermost scapula point showed greater curvature of the upper back part. Greater curvature of the upper back part is also visible in the cross-sections, which consequently affects the irregular line of the pattern length (***Table 6***). Problems of the garment shape and form on the back side, the large amount of ease on the waist line and insufficient ease on the hip line are visible in the 3D garment simulation. By analysing the shoulder seam position on the garment model, minor deviations in the slope of the shoulder seam were found on all three test subjects, which does not have a sig-

Table 6. *Characteristic vertical and horizontal body cross-sections of test subjects and simulated 3D models of a jacket in the closest garment size.*



nificant impact on 3D simulation results and garment fit evaluation.

Parametric pattern of men's jacket model

Cutting parts were converted from the usual vector to a parametric form, which enables simultaneous modifications on several corresponding cutting parts by developing the cutting parts in relation to the defining axis, measurements and movement directions of particular segments during modifications and by application of defined mathematical expressions in a computer program. The garment pattern prepared was tested in the next step using computer-based pattern modification according to targeted body measurements and by performing simulations on computer-based body models with a highly irregular body posture and different physiological spinal curvature. Since that complete fit analysis of the simulated garment in the closest garment size on the body with a highly irregular posture caused additional adjustment of the front, side and back cutting parts, most of the pattern modifications were performed exactly on these cutting parts, as is shown in ***Figure 9***.

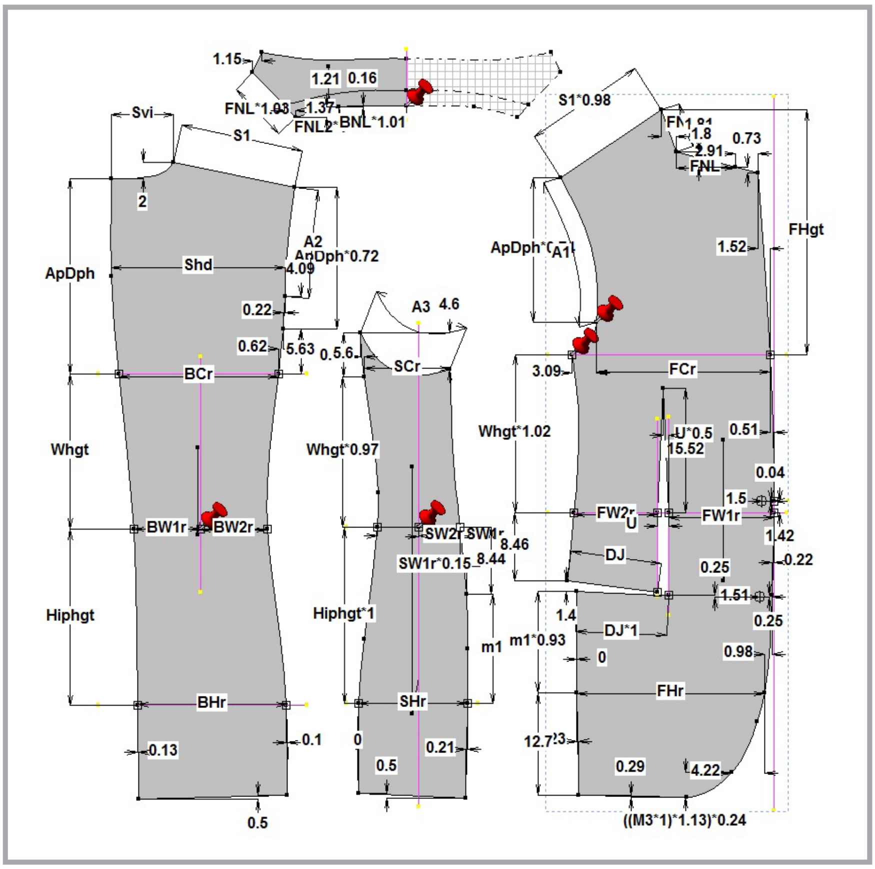


Figure 9. Parametric pattern of men's jacket: FCr – Front Chest right, SCr – Side Chest right, BCr – Back Chest right, FW1r – Front Waist 1 right, FW2r – Front Waist 2 right, SW1r – Side Waist 1 right, SW2r – Side Waist 2 right, BW1r – Back Waist 1 right, BW2r – Back Waist 2 right, FHr – Front Hip right, SHr – Side Hip right, BHr – Back Hip right, ApDph – Armpits lenght, Whgt – Waist height, Hiphgt – Hip height, Fhgt – Front height, Shd – Back width, S1 – Shoulder lenght.

Final results

The gradual, interactive adjustment of a garment pattern according to measurements and body posture for each test subject selected was performed in the final stage by entering measurement values of test subjects and measurements determined according to the mathematical expressions previously defined into the CAD system. Verification of the adjusted pattern for each test subject was performed using 3D simulations along with defining all necessary parameters. Analysis of the pattern ease allowance was additionally performed using computer-based cross-sections of the visualised 3D body model and garment with the purpose of fit assessment. That way, values of the body and garment circumferences on the cross-sections were determined and the ease allowance was calculated from the difference in the values obtained. Also a review of characteristic lengths was performed by interactive measuring of segment lengths on a 3D garment model. ***Table 7*** (see page 158) presents the results of adjusted garment simulations on each test subject, with values of the ease allowance on characteristic body circumferences presented. Appropriate fit was evaluated on each test subject using fit analysis according to the same evaluation parameters used for previous fit verification of models in the closest garment size. That way, the method presented was verified as well as the parametric garment pattern developed. Adjustment of the garment pattern shape according to the shape of the body for which the adjustment was made is visible on the overlaps of cutting parts in the closest garment size, with cutting parts of parametric pattern adjusted according to the individual anthropometric characteristics of test subjects.

Conclusions

The goal of the research presented was to develop a parametric garment pattern which can be adjusted according to the individual measurements of test subjects with different irregular body postures. Based on the results presented, a complete analysis of all simulations performed on computer-based body models and corresponding sets of parametric patterns and patterns graded using a conventional method, the significance of the method developed as a very successful way for garment pattern adjustment can be pointed out. The development of a parametric pattern presents a complex process requiring a high level of knowledge and skill in the field of computer-based clothing construction and pattern adjustment according to particular measurements. However, ultimately only one parametric pattern can be successfully applied for adjustment according to individual measurements of test subjects with different types of irregular body postures. In that sense, the method presented can significantly contribute to the development of a new direction in the field of computer-based clothing construction and pattern adjustment according to individual anthropometric body characteristics.

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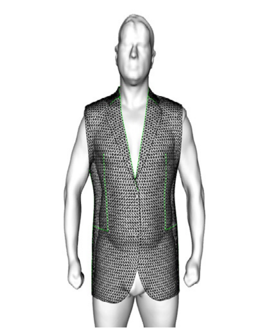
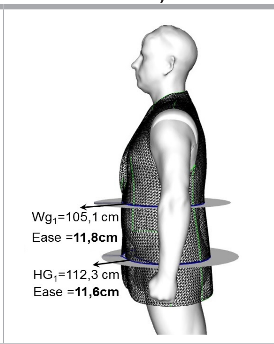
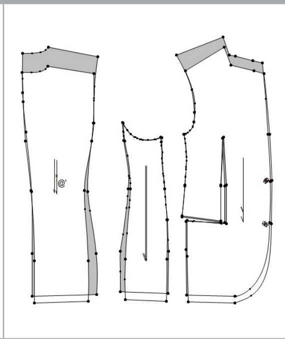
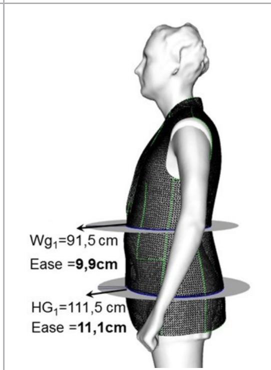
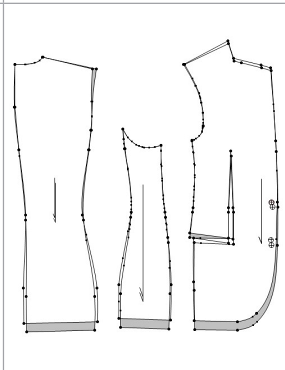
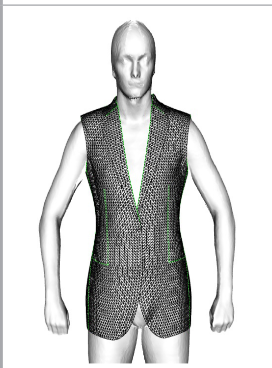
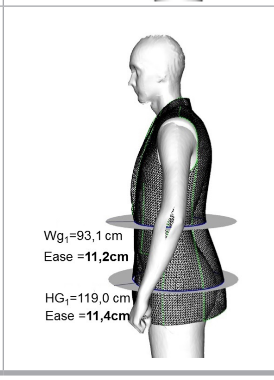
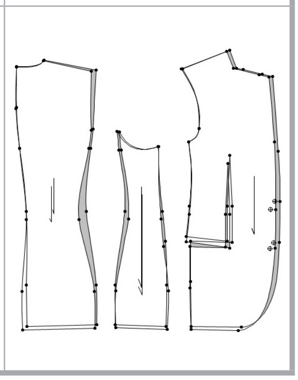
Table 7. *Simulation results of the parametric pattern adjusted for each test subject and fit analysis.*

	Custom pattern (front and side view)		Patterns overlaps
Test subject 1			
Test subject 2			
Test subject 3			

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