Analysis of 3-D body measurements to determine trousers sizes of military combat clothing

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ABSTRACT

The aim of this paper was to analyse several measurements of soldiers to provide a reference for trousers sizes of military combat clothing. For sizing and fitting of military clothing, information on the body measurements of the user population is a precondition. More than 400 soldiers in the Estonian and Latvian Defence Forces as well as the military personnel were measured using Human Solution 3-D scanner. It focused on collating basic human body measurement data for the revision of size charts by STANAG 2335. Fit and comfort of trousers mainly relate to the following measurements: waist girth, leg inseam, leg length, and waistband. Present parameters play a significant role in the quality of trousers to ensure the wearer's mobility in all situations particularly concerning the activities of soldiers. Correlating measurements and existing sizing systems are made to offer recommendations for manufacturers. In addition, this paper helps to provide sizing and fitting criteria of military combat clothing to STANREC document compiled by NATO RTO HFM-266 Group.

KEYWORDS

3-D body measurements, waist girth, leg inseam, leg length, military combat clothing

INTRODUCTION

In the present study, a three-dimensional (3-D) scanner was used to capture the body contour of male military personnel and soldiers to provide different inputs. For example, for logistical purposes such as inventory management, for production purpose such as producing the required volume, and for ergonomic design. Body scans enable a wide variety of measurement possibilities with more precision than those taken with a tape measure. They are quicker and less intrusive and thus more reliable. Body scanning technology enables the collection of approximately 300.000 data points as xyz coordinates that can be used to calculate circumferences, cross-sectional slice areas, surface areas, and volumes. Compared to one-dimensional measurements, a more complete set of indicators are available to quantitatively address problems of garment fit [1]. According to previous studies, the satisfaction with the fit of special clothing is very important. However, it has not been achieved. People need to perform different actions and body positions during daily activities such as lying or kneeling, climbing, crouching, etc. Thisis why it is important that clothing does not block any necessary movements or activities.

Under extreme circumstances, garments can become critically important determinants of the safety and performance of the design. For example, loose industrial clothing can be caught in machinery and cause accidents [2].

A previous study on firefighters' clothing outlines the problems of both the trousers and the coat. The satisfaction with the fit of trousers among female and male firefighters was studied. Female firefighters scored significantly lower in satisfaction with the crotch while walking and in case of extreme limb movements [3]. More than 10% of participants of the survey reported that the crotch is too low and bulky which causes impaired mobility in lower body for many job-related tasks such as ladder operations, walking, and climbing. The NATO work group HFM-RTG-266 is working on the project „3D Scanning for Clothing Fit and Logistics" drawing up the STANREC document for the sizing and fitting of military combat clothing. It states that a good fit is the result of a good match between body shape and size and product shape and size. Movement restrictions may occur when the fit is too tight and snagging hazards may occur when the fit is too loose. Inadequate fit is not only related to discomfort but may also affect the effectiveness of military operations. Furthermore, inadequate fit will also affect the safety of military personnel and soldiers.

The aim of this study was to provide a stepwise approach to the design and evaluation of military combat clothing, particularly trousers design. The importance of wearing the right size of trousers is very high. The person's height has to be measured and standard measurements such as natural waist, trouser waist, inside leg, body rise and seat have to be taken for a regular sizing of men's trousers [4]. It is important that measurements are taken carefully to ensure the best fit. According to the European and British standards, size charts are determined by two factors: type of garment and market. For example, trousers require a different size chart which is based on waist size.

According to international standards, anthropometric measurements have been provided in ISO 7250 part 1 which can be used for technological design as a basis for comparison of population groups [5]. For clothing design, especially trousers design, the following measurements can be found: body height, crotch height, and waist circumference, taken from a standing subject. Measurements taken when the subject is sitting such as body rise, are not included in this standard. For establishing anthropometric databases analysing the design of men's trousers, British standard is taken as the basis defining the positions and methods for taking body measurements required for clothing [4]. According to the previously mentioned British document, the standard measurements for trousers are as follows: seat, natural waist, trouser waist (4 cm lower from natural waist), inside leg, body rise and trouser bottom measurement is taken as an extra. This paper focuses on the analysis of previously reported measurements taken from Estonian and Latvian military personnel and soldiers.

The use of (3-D) body measurements made by Human Solution scanner has made certain terms more professional in the field of clothing. For example, trouser waist is called a waistband, inside leg is called an inseam, and seat is called buttock girth. The body rise measurement is not measured because all the measurements are taken while the subject stands. Instead, leg length or side seam at waist are measured. By subtracting leg length and inseam leg measurement we can calculate the body rise.

For work or special clothing, it is necessary to provide an approach to the design and equipment sizing systems in such a way that most of the wearers have a well-fitting product combined with a minimum number of product sizes. Currently, a document is being drafted by the NATO workgroup HFM-RTG-266 STANREC to provide a stepwise approach to the design and evaluation of military clothing. It is intended for NATO staff responsible for clothing and equipment procurement or issuing. This document does not

provide, an in-depth analysis but intended as a guide for clothing and equipment sizing. The more military population have been studied in different countries, the more specific recommendations can be incorporated into the above mentioned document.

The analysis in this paper seeks to find the best solution to the sizing system of men's trousers for military staff. As stated above, it would be ideal to have a minimum number of product sizes corresponding to the majority of the studied military staff. The size designation for military garments is stated in STANAG 2335 [6]. Over time, manufacturers have developed their own measurement tables in different countries based on the development of clothing. The size of waist and chest circumference are the primary measurements for determining the size of jacket and trousers. In the past, the third decisive measurement for determining the size of trousers was body height. However, after measuring with the 3-D scanner and analysing the results, the length of inseam is the third most important measurement for trousers.

The first step in this study was to identify whether the length of the inseam corresponds to the size chart by STANAG 2335 based on height of the subject and waist circumference. More than 400 young soldiers from Estonia and Latvia were examined with a 3-D scanner. After analysing the results, it was necessary to compare them with the existing sizing systems of the Estonian and Latvian military trousers. It is important to develop the existing sizing system continuously as it does not always perform as expected. One reason may be that the population changed.

EXPERIMENTAL

Materials and Methods

This study involved the development of an infrastructure for measurement where soldiers in the Estonian and Latvian Defence Forces and the military personnel were measured using a (3-D) body scanner. It focused on collating basic human body measurement data for the revision of size charts by STANAG 2335. For sizing and fitting of military clothing, information on the body dimensions of the user population is a prerequisite. In this study, all subjects were measured in standing position A where the head is in the Frankfurt plane position, the feet parallel to one another and 200 mm apart, and the hands raised at a 20^{o} angle from the sides of the torso [7]. Basic knowledge and specific know-how skills are required to validate (3-D) measurements. As (3-D) scanning can be used to collect measurements such as lengths and circumferences, it is important that the measurement extracted from a (3-D) image corresponds to the traditional measurement and a skilled person is required to minimise the errors made by the measurer.

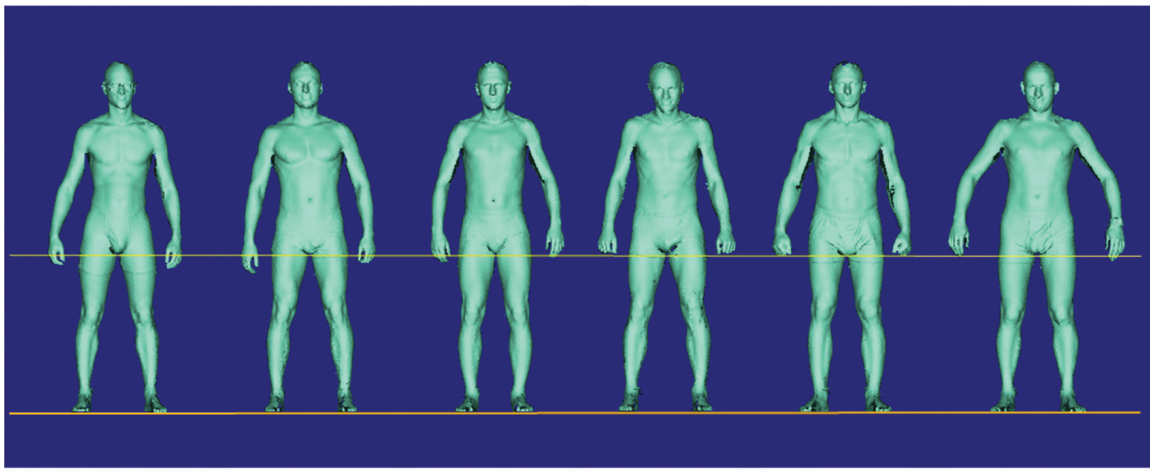
The measurement data of 300 male subjects from Estonia (mean age 28) and 150 male subjects from Latvia was imported into the XFit analysis program and MS Excel and were statistically analysed according to the NATO interchangeability combat clothing sizes. Key dimensions of trousers in basis size such as inseam, waist girth, and body height are presented in Table 1. Both the Estonian and Latvian clothing suppliers take the inseam as the basis for the primary measure. Before this study, the size of the trousers in Latvia was predetermined on the basis of waist circumference and body height. The size interval of inseam according to body height is 5 cm. It is important to note that size designation varies from one NATO country to another [6]. Estonia uses the same designation as GBR where chest girth is also presented for trousers, and Latvia uses the same designation as the USA.

Table 1. Size designation of Estonian and Latvian military trousers for the basis size

Country	Inseam by size chart*	Inseam, cm	Waist girth, cm	Chest girth, cm	Body height, cm	Size designation
Estonia (EST)	80	83	88	104	175 - 185	80/ 88/ 104
Interval (EST)	77.5 – 82.5	80.5 – 85.5	86 – 90	102 – 106	10	-
Latvia (LV)	80	REG	M	-	REG	M/ REG
Interval (LV)	77.5 – 82.5	81 – 84	78 – 86	-	179 – 185	-

*STANAG 2335 [6]

The (3-D) body scanner from Human Solution (Vitus Smart XXL) is based on laser technology using the Anthroscan 2016 (3.4.0) software. Visualized (3-D) scans can be delivered by the VITUS whole body scanner using the 8 sensor heads, an optical triangulation process and specific software. It provides about 140 body measurements in 3D with an accuracy of 1 mm in 12 seconds. Data can be exported in BSF, BTR, OBJ, ASCII, DXF, STL (ASCII), STL (Binary), JPG, PNG or AVI formats. Depending on the license, the scanner includes a remote control integrated into the Anthroscan screen interface with various Scan Wizards. One possibility of analysis is given in Fig 1 to show the frontal view of selected body images (n=6) and comparing the waistband with the inseam of the right leg.



Measure	S1	S2	S3	S4	S5	S6
Waistband	79,3	83,2	84,5	85,5	87,2	90,1
Inseam right	85,6	85	84,9	86	84,9	83,9

Figure 1. Frontal view of body images comparing inseam of the right leg

The position of the subject in the scanning volume is important for obtaining reliable data that can be used in an anthropometric database. It is also important that the subject holds the posture during the entire scanning process. For all postures, normal breathing should be adopted. Shoulders should be straight without being stiff and muscles should not be tense. [7]

The measurements obtained using this technology are more precise and reproducible than those obtained through the traditional physical measurement process [8]. If the subject is included the corresponding data bases, then the measurement data can be renewed or revised at any time. For the logistics purpose, the current situation and continuous measurements are important for the majority or all military personnel.

RESULTS AND DISCUSSION

The statistical analysis was based on the comparison of the actual dimensions of subjects with the size chart. As previously mentioned, one of the most important measure for trousers fit is the inside leg length. The mean inseam of measured Estonian military population (n=300) was 81.0 cm and 79.1 cm for Latvian military population (n=150). The data for both countries were compared to the inseam given in STANAG 2335, as shown in Tab 2. The interval of inseam was taken ±2.5 cm. In figures 2 and 3, the correspondence of measured subjects is shown with the interval of inseam length.

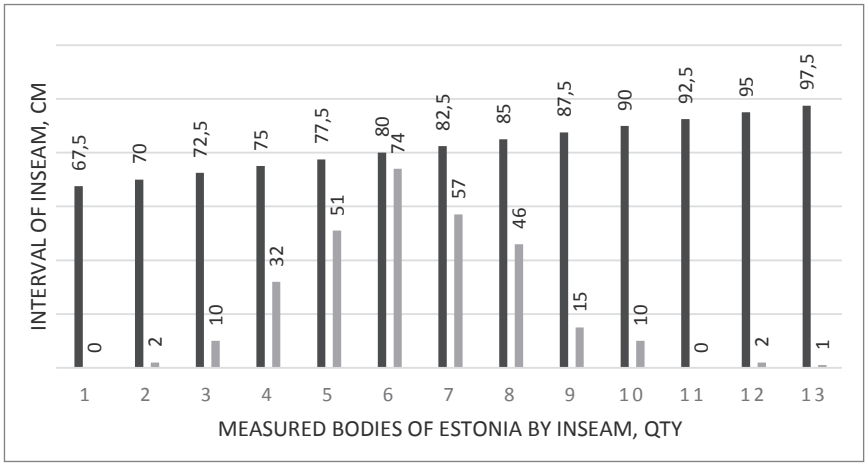


Figure 2. Correspondence of measured bodies of Estonia by inseam length

It shows that 25% (n=74) of all measured bodies correspond to the inseam of basis size 80 cm, see in Table 1. The interval is set to ±2.5 cm as we can see quantities of measured bodies through the total scale per inseam, where there are five lengths of inseam: 70 cm, 75 cm, 80 cm, 85 cm and 90 cm. If the basis size of inseam in range 80.5 – 85.5 according to the Estonian size chart is taken into consideration, then 59% (n=177) of all measured bodies correspond to this range.

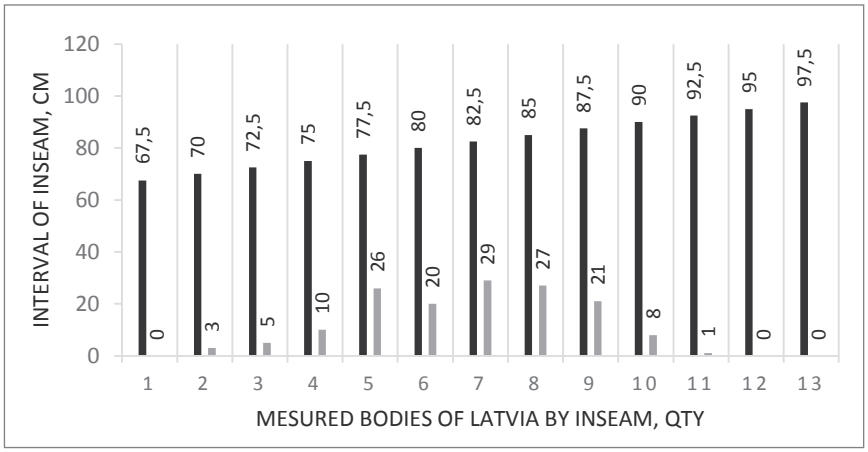


Figure 3. Correspondence of measured bodies of Latvia by inseam length

If the basis size of inseam in range 81.0 – 84.0 according to the Latvian size chart is taken into consideration, then 25% (n=37) of all measured bodies correspond to this range.

Analysis of both countries' measurements show that inseams of basis size according to STANAG 2335 (in range 77.5 – 82.5) correspond more precisely to the bigger amount of measured bodies.

As previously mentioned, it would be ideal to have a minimum number of product sizes corresponding to the majority of the measured military population. For a long period of time, the clothing industry in both countries has developed the main size chart that is in general use. For example, in Estonia, there are 31 different sizes for military trousers, as shown in Tab 2, in light grey boxes.

Table 2. Size chart of Estonian military trousers

Waist/ chest	Inseam by size chart*	68/ 84	72/ 88	76/ 92	80/ 96	84/ 100	**88/ 104**	92/ 108	96/ 112	100/ 116	104/ 120	108/ 124	112/ 128
Inseam	70	73	73	73	73	73	73	73	73	73	73	73	73
	75	78	78	78	78	78	78	78	78	78	78	78	78
	80	83	83	83	83	83	**83**	83	83	83	83	83	83
	85	88	88	88	88	88	88	88	88	88	88	88	88
	90	93	93	93	93	93	93	93	93	93	93	93	93

*STANAG 2335 [6]

Figure 4 presents the analysis by Anthroscan (3.4.0) software, where the inseam and waist girth of the scanned Estonian military population have been compared with the most commonly used sizes. The blue dots show the measured data and the red dots 31 sizes in use. Analysing the data cloud in Fig 4, a lot of blue measurement dots are noticed in the area of inseam length below 75 cm and in the area of waist girth between 96 and 102 cm, without corresponding sizes marked by red dots. Following this, changes can be made to the size chart such as two smaller sizes 73/72/88, 73/76/92, and two bigger sizes: 78/96/112 and 78/100/116. It would be advisable to put these into use as shown in Tab 2, dark grey boxes and in Fig 4, green boxes. In the area of longest inseam length, range 85 - 90 cm, and biggest sizes of waist girth, 108 cm and more, there are few measurement dots, but manufacturing sizes exist as shown Fig 4, red boxes. According to the measurement data it is advisable to take down the following sizes from the production list: sizes 88/108/124, 88/112/128, 93/104/120, 93/108/124 and 93/112/128 as shown diagonally in Tab 2.

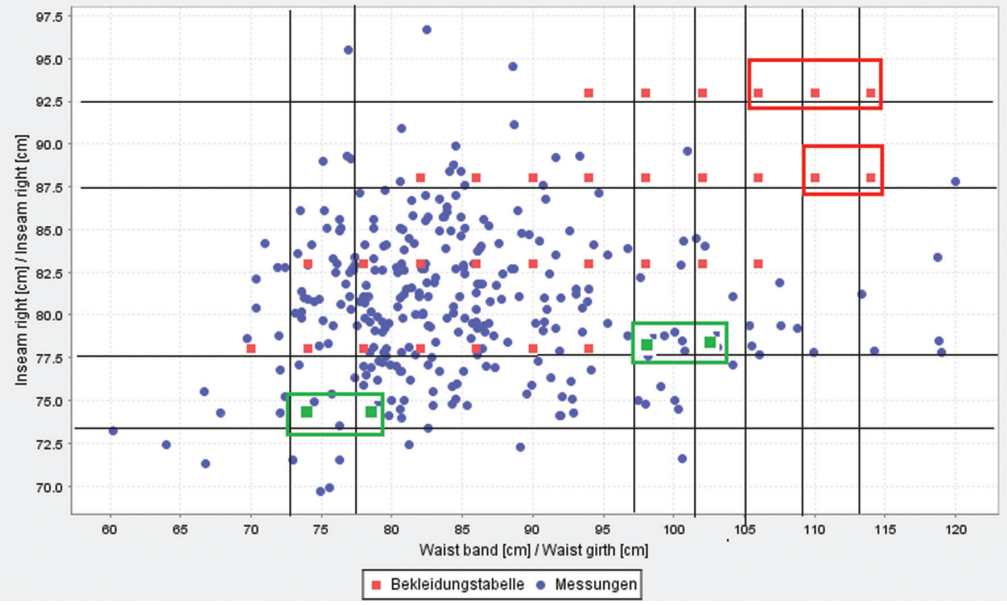


Figure 4. Data cloud of measured bodies in Estonia compared mainly to the sizes used in production

The same measurements were taken for the analysis of the measured Latvian bodies. Figure 5 presents the analysis by 3-D scanner software, where the inseam and waist girth of scanned Latvian military population have been compared with sizes used in production. Based on the results of the 150 Latvian soldiers' measurements, sizes necessary for the production according to the inseam and waist girth range are specified in Tab 3. As previously mentioned, Latvia uses a similar size designation as the United States. Tab 3 shows the full-size chart, marked in light grey boxes, used in the production of military trousers. The base size is marked in bold in Tab 3.

Table 3. Size chart of Latvian military trousers

Waist / Inseam		XS 62- 70	S 70- 78	**M 78- 86**	L 86- 94	XL 94- 102	XXL 102- 110	3XL 110- 118	4XL 118- 126
3XSH	69- 72	XS/3XSH	S/3XSH	M/3XSH	L/3XSH	XL/3XSH	XXL/3XSH	3XL/3XSH	4XL/3XSH
2XSH	72- 75	XS/2XSH	S/2XSH	M/2XSH	L/2XSH	XL/2XSH	~~XXL/2XSH~~	~~3XL/2XSH~~	4XL/2XSH
XSH	75- 78	XS/XSH	S/XSH	M/XSH	L/XSH	XL/XSH	XXL/XSH	3XL/XSH	4XL/XSH
SHO	78- 81	XS/SHO	S/SHO	M/SHO	L/SHO	XL/SHO	XXL/SHO	3XL/SHO	4XL/SHO
REG	**81- 84**	XS/REG	S/REG	**M/REG**	L/REG	XL/REG	XXL/REG	3XL/REG	4XL/REG
LON	84- 87	XS/LON	S/LON	M/LON	L/LON	XL/LON	XXL/LON	3XL/LON	4XL/LON
XLO	87- 90	XS/XLO	S/XLO	M/XLO	L/XLO	XL/XLO	XXL/XLO	3XL/XLO	4XL/XLO
2XLO	90- 93	XC/2XLO	S/2XLO	M/2XLO	L/2XLO	XL/2XLO	XXL/2XLO	3XL/2XLO	4XL/2XLO

A lot of blue measurement dots are visible in the area of inseam length below 72 cm and in the area of waist girth, range 78 - 94 cm, in Fig 5 but no red dots. It is important to point out that in 3% (n= 5) of the measured bodies in Latvia there was inseam length in the range of 69 - 72 cm in sizes M and L, as shown in Fig 5. This measure of inseam was not available in the Latvian size chart, but the data shows these sizes shoould be included, as shown in Tab 3, dark grey boxes and in Fig 5, green box. In addition, sizes XXL/2XSH and 3XL/2XSH should be eliminated from the production list to minimize the number of product sizes, as shown diagonally in Tab 2 and in Fig 5 in red.

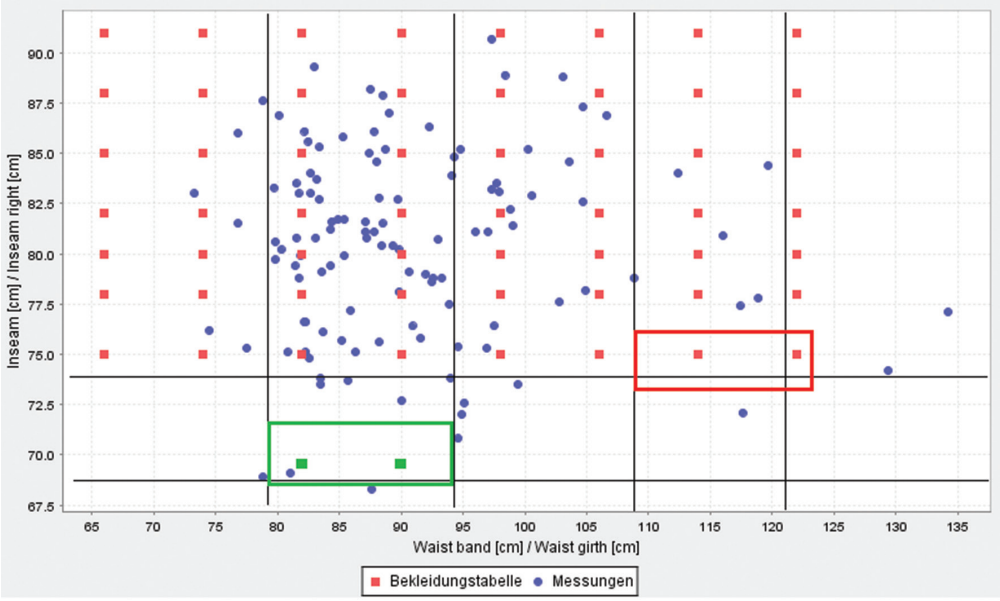


Figure 5. Data cloud of measured bodies in Latvia compared mainly to the sizes used in production

As the number of measured bodies (n=150) was too small, measurements should be repeated to recommend the reduction of sizes in the production.

CONCLUSION

The purpose of the current study was to investigate 3-D scanning methodology according to internationally compatible anthropometric databases and size charts of NATO countries based on Estonian and Latvian example. It focused on one segment of the male military personnel and soldiers aged 21 – 35 in both countries.

In the study, the basic parameters, inseam and waist girth, were investigated which play a significant role in the quality of trousers, in order to ensure the wearer's mobility in all situations in particular the activities of soldiers. Based on the studied groups, the above measurements were compared with the data obtained from the size chart of NATO countries. The inseam length in range 70- 90 according to STANAG 2335 is taken as the basis for the assessment. When analysing the Latvian size chart, the measured bodies were divided into 35 sizes. However, as 3 % of the measured bodies could not be set to the correct size because the table did not have the corresponding inseam, the chart should be supplemented. The Estonian size chart is more reliable than Latvia's if the inseam length is in 70 - 90 range. The following changes are suggested for Estonian and Latvian size chart:

1) it is necessary to add two shortest inseam lengths according to STANAG 2335, 70/72/88 and 70/76/92 to Estonian size chart
2) to add two sizes for inseam length by 75 cm as 75/96/112 and 75/100/116 according the size designation to the Estonian size chart
3) it is necessary to remove 5 sizes from the Estonian size chart which are not in use according to the current study: 85/108/124, 85/112/128, 90/104/120, 90/108/124 and 90/112/128
4) it is necessary to add sizes to the Latvian size chart for the shortest inseam length of M/3XSH and L/3XSH
5) it is necessary to remove sizes XXL/2XSH and 3XL/2XSH from the production list.

One possibility for Latvia is to change the interval of inseam ± 5 cm to produce 5 different ranges according to STANAG 2335. However, it is necessary to review how many sizes of the trousers need to be produced as there are still 35 different sizes after suggested corrections. Furthermore, additional measurements are necessary as the number of measured bodies was too small in both Latvia and Estonia.

Ideally, all military personnel should be measured prior to issuing clothes. Using the 3-D scanner is an important advantage. The right size and correct fitting for each population can be determined based on the taken measurements. There is another important factor in measurements, the logistical needs can be determined on the basis of the measurement data: which size is actually needs to be produced according to the figure of today's male military population.

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