ANTHROPOMETRIC SIZING AND LOWER LIMB MOVEMENT RANGE DURING CLIMBING POSITION

Dāboliņa Inga, Lapkovska Eva and Siliņa Liene
Institute of Design Technologies, Faculty of Material Science and Applied Chemistry, Riga Technical University, Riga, Latvia
inga.dabolina@rtu.lv

ABSTRACT

The research focuses on studies of biomechanical parameters of lower limbs for the insight regarding movement character and changes of involved body parts. The aim is to quantify changes of leg measures during climbing posture. 150 workers were scanned using 3D anthropometrical scanner Vitus Smart XXL® in standard stand and step-up posture [1]. Primary body characteristics for trouser size definition [2] served for grouping the participants into size groups. The ability of representatives of a one-body-height group to take the dynamic posture was analyzed. Sets of measures were obtained for the analysis of changes in particular parts of lower limbs.

Key Words: anthropometry, biomechanics, work-wear

1. INTRODUCTION

Clothing sizing and fit is a tough task for everyday clothes, but it becomes especially important if it is necessary to adjust clothing to active workers. Workers' clothing, which is part of the PPE, is designed from rigid fabrics to protect the wearer from the effects of external environment. Thus, the wearer cannot rely on the ability of the garment to adapt to the movements. Unlike knitted and lightweight cloths, work wear makes the slip over the human body and folds around it. The function of protective clothing is primarily to protect the wearer from the effects of external environment and secondly to provide the wearer with comfort during work and duties. One of the most important aspects of wearer comfort is garment fit. Similarly, clothing design is one of the crucial factors in achieving optimum thermal exchange rate between human's body and environment [3].

Even simply enforceable body movements involve a complex of biomechanical processes and the system consisting of number of bones, tendons and muscles by moving individual parts of the body and, as a result, changing the volumes of various body parts. Comprehension of these features may contribute the anticipation of clothing layer interactions with body surface [4].

It is essential that trouser patterns provide both aesthetic and fit requirements without restricting wearer's movements, for example, in work positions or other physical activities that require bending joints [5]. One of the tasks was to determine the ranges of leg measure changes and the most significant deviations usable for work-wear trouser pattern alterations for improving fit while performing daily work postures. In this study, the predictions that people are adjusting their posture during climbing, thus affecting the use of work wear was examined. Therefore, trousers are inspected to gain results from wearer's lower limbs. Depending on sizing and fit matching, the ability of a person to perform a task changes [4], [6], [7]. The first goal is to determine the postural corrections that occur during a climb, knee height during step-up to one height step. Correlation with the height of worker's body. The second is to experimentally test the sizing of the garment according to EN 13402 [2] and compare it with the manufacturer's recommendations. It is expected that with different proportions of the target

audience there are both fit and grading problems, as well as the wear-ability of clothing and the performance of the most characteristic work positions [8].

2. METHODOLOGY

This study was endorsed by the need for a new grading, sizing and fit system for work-wear. One hundred and fifty workers (males) participated in this study. Participants were between 19 and 52 years of age, with different physical fitness and daily activity. In the face-to-face observation it was concluded that some of the participants have increased fat volume, some even obese. Participants were selected to maximize the body size range and check their potential impact on grading, sizing and fit. Each participant signed a consent form to participate in the study, to provide data protection (according to GDPR), and non-dissemination of individual participants' data.

The study covered non-contact anthropometrics in two positions – standard standing position (see Fig. 1_A) and posture characteristic for workers, e.g. climbing (step-up) position (see Fig. 1_C) with the right leg (right leg raised and bent). Standard position measurements include body height and right leg measurements. The climbing position uses the Vitus Smart XXL® built-in seat set in height at 53.5 cm. For the repeatability of the experiment, both the base and the bench are marked with footmarks (see Fig. 1_B).

A   B   C
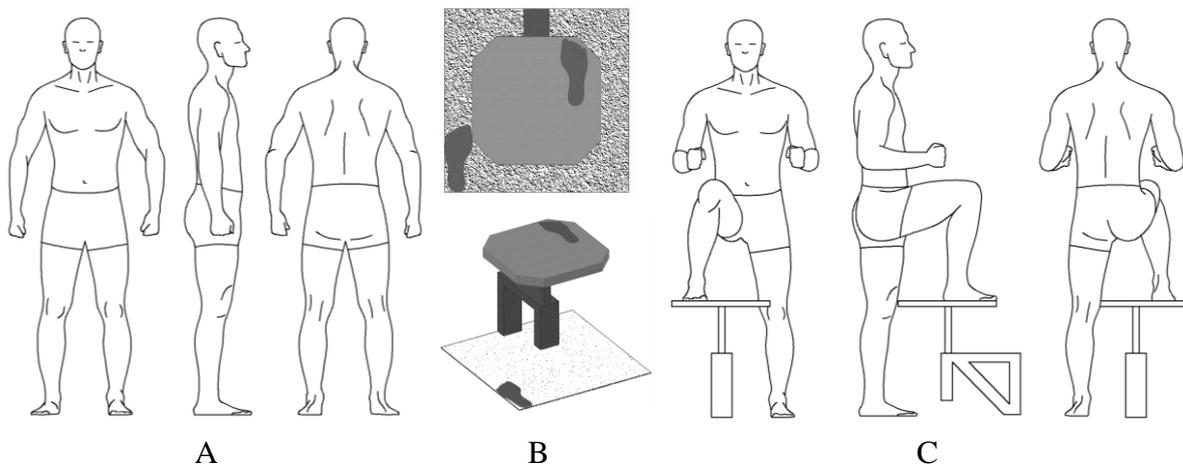
Figure 1. Scanning positions (A and C) and footmarks (B)

Each shot was scanned in two steps, first dressed in tight underwear and then dressed in work-wear trousers. Untreated scans were processed with Vitus Smart XXL (Human Solutions Group GmbH) built-in software for measurements AnthroScan. All subjects' ability to perform the required positions and 3D displays along with the measure tables were saved in the program database.

2.1 Anthropometrics

In this study, several anthropometric parameters of body size were used: body height, waist and buttock girth, right lower limb measurements, and additional step-up measurement. As well, as measured and compared right leg bending angles in step-up position. Direct body measurements have been used from automatically obtainable (embedded in AnthroScan software), adjusting

their measurement methodology, if necessary (measurement of subjects with large masses should be adjusted more often). Body height is defined as the distance between the plantar surface and the cranial top. Waist circumference is defined as the horizontal perimeter of the body between the lower part of a rib and a gut. Buttock girth - hip circumference at the most prominent point of the seat. Side seam was defined as the distance between the waist and the plantar surface. The statistics of samples of anthropometric parameters are given in Table 1.

Table 1. Sample statistics of anthropometric parameters (cm)

N=150	Body height	Waist girth	Buttock girth	Inseam right	Side seam right	Side seam 3D waistband right	Side seam at waist right	Height to patella (bent leg) right
Average	180.6	91.1	104.0	80.6	104.3	104.5	114.2	109.9
SD	7.03	10.78	6.71	4.68	5.05	5.08	5.27	2.93
Min	160.3	73.3	91.2	68.3	91.7	91.7	100.5	100.4
Max	195.5	138.0	133.7	89.3	114.9	114.8	125.6	117.0

Anthropometrics shows large differences between measurements. Waist girth shows largest standard deviation (SD). In addition, the maximum waist circumference is greater than the highest buttock girth value, which indicates excessive fat in the abdomen. This distribution of measurements suggests that it is difficult to classify the sample of population (participants). Supply for this group proper and well-fitted work-wear is esteemed to be difficult, especially because the current grading systems are based on non-actual measurements (mostly former Soviet Union standards [9]) which are now considered outdated because of human population variability, acceleration. and migration. Alternatively, the grading system is created on tables made by collaborators of enterprise, which do not always correspond to the particular group of subjects to be dressed and work-wear supplied.

2.2 Measurements of step-up position

Additional measurements were made to supplement and broaden the standard anthropometric measurements. Height from the plantar plane to the knee tip (patella) was set for all participants in the step-up position. It is a vertical distance measurement determined by a tool built into the AnthroScan system (see Fig. 3_A). In addition to this measurement, the measurement of the angles of leg position - the angle between the knee point (see Fig. 3_B) and the point of leg cuff (see Fig. 3_C) was performed for each subject. A leg sagittal plane (see Fig. 3_D) was performed to locate the leg position and uniformity among all participants.

Height	160		164		168		172		176		180		184		188		192		196	
Range	158	162	162	166	166	170	170	174	174	178	178	182	182	186	186	190	190	194	194	198
Amount	1		2		10		17		23		31		30		25		9		2	
	1%		1%		7%		11%		15%		21%		20%		17%		6%		1%	

Figure 2. Distribution of participants by height according to EN 13402

In order to compare the values obtained, the classification of participants by body height according to EN 13402 [2] was performed. As shown in table (see Fig. 2), distribution of participants tends to be according normal distribution.
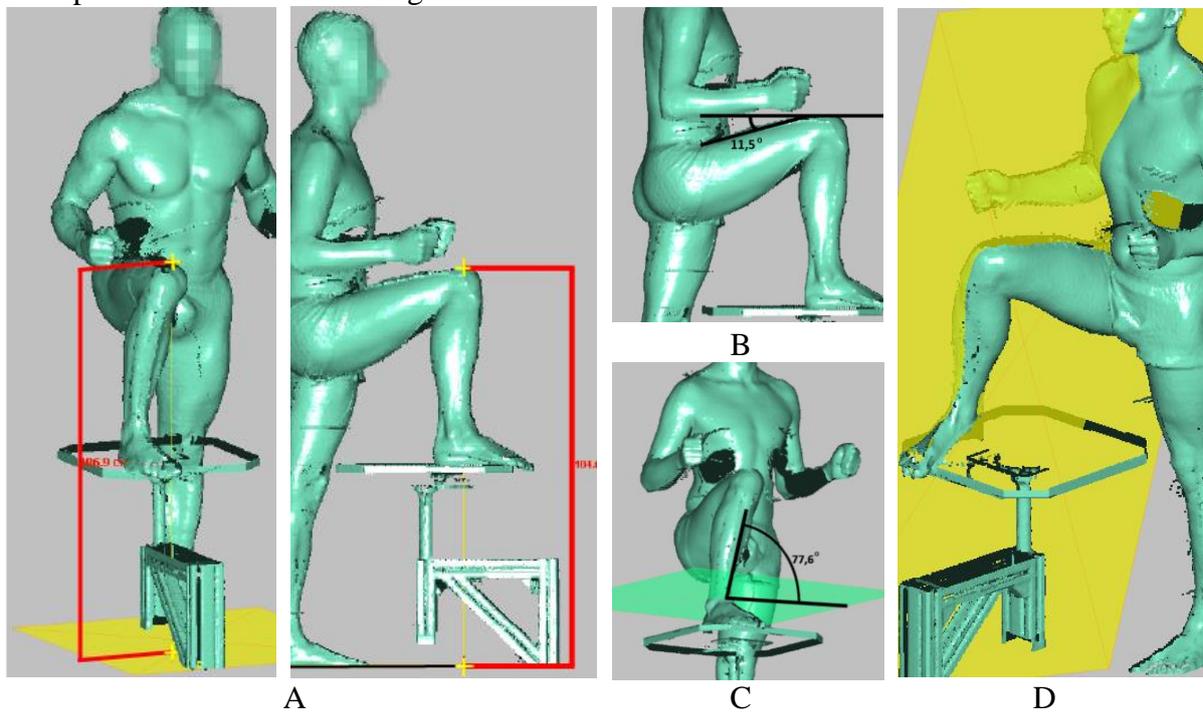
Figure 3. Special measurements of step-up position:
Height to patella (A), Knee angle (B), Ankle angle (C), Leg position (D)

Clearly, body height and inseam measurements have a close relationship and a correlation coefficient of 0.753, a similar tendency is with the knee height measurement, but with a lesser correlation of 0.666. In addition, the minimum and maximum limits for each body height group are not similar. In contrast, the knee height has no unequivocal tendency to grow with height increase. The low correlation coefficients for angular measurements - 0.312 (knee) and 0.0682 (ankle) - also indicate that each participant has differentiated the step-up position. Examining the sagittal planes shows that position of foot varies greatly among participants, their contour depends on the physical abilities of the worker and personal skill that does not correlate with body height or body mass index.
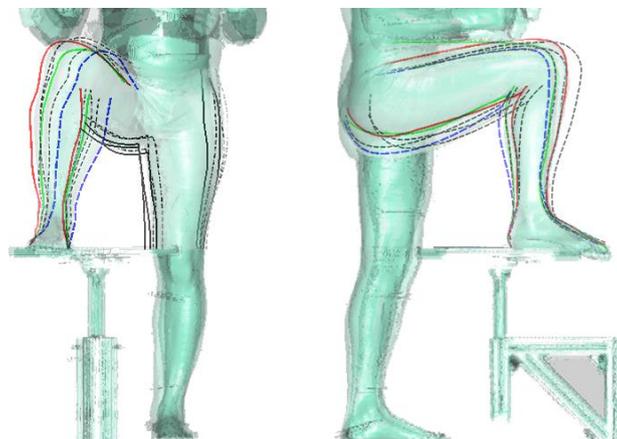
Figure 4. Superimposed pictures for step-up position analysis

By superimposing one group (for example in body height group 180, see Fig. 4), leg position in the step-up position is very different (superimposed 31 wearers included in the group, marked marginal/extreme positions), workers try to place their leg so that it would be comfortable, while following the marked feet-marks.

3. RESULTS AND DISCUSSION

The aim of the study was to test the suitability of work-wear for workers. Already in statistics of basic anthropometry it was observed that the measures were very deviated (see Table 1). The diversity of workers is also characterized by a variety of measurements. However, the biggest grading, sizing and fit problem is the lack of a unified approach and proper measurements of population. The measure tables used by the work-wear manufacturing companies are outdated, the approach is not appropriate to meet the needs of the particular sample group. Considering a body set after body height classified according to EN 13402 (see Fig. 2), it can be seen that their distribution approximates to normal distribution. However, large deviations in other measurements show that classifying a particular group of workers is not an easy task. Summing up the measures used in lower body garment according to EN 13402, it can be seen that the dispersion around the selected dimensions is very large (see Fig. 5). EN 13402 is stated that the dimensions used for trouser design and sizing are waist girth and hip girth. These sizes require a very large number of labeled items (sizing items), and to produce a very small number of trousers for each size. It makes it difficult to produce (it is not easy to produce different proportions for the uniformed work-wear), but also to supply the workers with a high fit PPE.

	Waist girth ↓																	
	62	66	70	74	78	82	86	90	95	100	105	110	115	120	125	130	135	
	60 64	64 68	68 72	72 76	76 80	80 84	84 88	88 93	93 98	98 103	103 108	108 113	113 118	118 123	123 128	128 133	133 138	
Hip girth →	74	77	80	83	86	89	92	95	98	101	104	107	110	113	116	119	122	
	73 76	76 79	79 82	82 85	85 88	88 91	91 94	94 97	97 100	100 103	103 106	106 109	109 112	112 115	115 118	118 121	121 124	
5									2	1	1	1						3%
Hip girth →	76	79	82	85	88	91	94	97	100	103	106	109	112	115	118	121	124	
	75 78	78 81	81 84	84 87	87 90	90 93	93 96	96 99	99 102	102 105	105 108	108 111	111 114	114 117	117 120	120 123	123 126	
10								1	4	1	2	1	1					7%
Hip girth →	78	81	84	87	90	93	96	99	102	105	108	111	114	117	120	123	126	
	77 80	80 83	83 86	86 89	89 92	92 95	95 98	98 101	101 104	104 107	107 110	110 113	113 116	116 119	119 122	122 125	125 128	
19					1	3	2	1	4	6			1		1			13%
Hip girth →	80	83	86	89	92	95	98	101	104	107	110	113	116	119	122	125	128	
	79 82	82 85	85 88	88 91	91 94	94 97	97 100	100 103	103 106	106 109	109 112	112 115	115 118	118 121	121 124	124 127	127 130	
14					1	1	2	2	3	1	3			1				9%
Hip girth →	82	85	88	91	94	97	100	103	106	109	112	115	118	121	124	127	130	
	81 84	84 87	87 90	90 93	93 96	96 99	99 102	102 105	105 108	108 111	111 114	114 117	117 120	120 123	123 126	126 129	129 132	
34					2	8	8	5	6	4			1					23%
Hip girth →	84	87	90	93	96	99	102	105	108	111	114	117	120	123	126	129	132	
	83 86	86 89	89 92	92 95	95 98	98 101	101 104	104 107	107 110	110 113	113 116	116 119	119 122	122 125	125 128	128 131	131 134	
30			2		2	8	6	6	3	1			1				1	20%
Hip girth →	86	89	92	95	98	101	104	107	110	113	116	119	122	125	128	131	134	
	85 88	88 91	91 94	94 97	97 100	100 103	103 106	106 109	109 112	112 115	115 118	118 121	121 124	124 127	127 130	130 133	133 136	
27			2		4	8	5	2	2		2	1	1					18%
Hip girth →	89	92	95	98	101	104	107	110	113	116	119	122	125	128	131	134	137	
	88 91	91 94	94 97	97 100	100 103	103 106	106 109	109 112	112 115	115 118	118 121	121 124	124 127	127 130	130 133	133 136	136 139	
10						3	3	1	1	1	1							7%
Hip girth →	92	95	98	101	104	107	110	113	116	119	122	125	128	131	134	137	140	
	91 94	94 97	97 100	100 103	103 106	106 109	109 112	112 115	115 118	118 121	121 124	124 127	127 130	130 133	133 136	136 139	139 141	
1							1											1%

Figure 5. Sizing of trousers for sample selection according to EN 13402

150 men involved in the study are so varied that the classification proposed in the standard [2] does not cover the entire set. In order to introduce additional size designation, a corresponding row is added (see last row in Fig. 5). Manufacturer's used sizing tables do not provide grading over different hip girth. The manufacturers grading is guided by body height and waist girth, thus ignoring the different proportions of wearers in this group of participants.

4. CONCLUSIONS

Grading and sizing is a complicated task. Creating appropriate measurement and measure tables is a labor-intensive and resource-intensive process. In order to be able to produce population-based measurement and grading tables, it is necessary to conduct an in-depth and expanded nationwide survey. Since contactless measurement methods offer fast and high-quality measurements, if a manufacturer needs to produce work-wear for a relatively small group of wearers, it is possible to perform a complete survey of the entire group. The classification made after these measurements is appropriate for the direct development of this group of PPE. The current set metrics indicate that according to EN 13402 [2] there are 58 different clothing sizes for this group (150 male workers). Producer uses only 31 sizes which are related to body height and waist girth. This does not take into account different proportions and leads to ill-fitted work-wear trousers.

Overall, it is very difficult to ensure a good fit and a range of movement in non-stretch working clothes. To provide freedom of movement, it is recommended to insert the folds or darts of the trouser leg at the knee, wedge insert into crotch area and adjust the waist band. To ensure a better fit and reduce amount of sizes included in sizing range, the manufacturer is recommended to replace size designation from waist girth to buttock girth. This would reduce the number of sizes required. At the same time, an adjustable waist band could be introduced to provide a good fit for wearers of different proportions.

5. REFERENCES

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