Determination of the Air Gap Thickness underneath the Garment for Lower Body Using 3D Body Scanning

Emel MERT[1,2], Sonja BÖHNISCH[1,3], Agnes PSIKUTA*[1], Marie-Ange BUENO[2], Rene M. ROSSI[1]
1 Empa, Swiss Federal Laboratories for Materials Science and Technology, Laboratory for Protection and Physiology, St. Gallen, Switzerland; 2 Univ. de Haute Alsace, Laboratoire de Physique et Mécanique Textiles, Ecole Nationale Supérieure d'Ingénieurs Sud Alsace, Mulhouse, France; 3 Hochschule Albstadt-Sigmaringen, Germany

DOI: 10.15221/15.114 http://dx.doi.org/10.15221/15.114

Abstract

The heat and mass transfer between the human body and its surroundings is affected not only by the properties of the fabrics, but also by the shape and the thickness of the air layer between the garment and the human body due to the low conductivity of the stagnant air. Therefore, it is important to accurately determine the thickness of air layers between the body and the garment. The aim of this study was to accurately evaluate the change in the air gap thickness at the lower body for different garment fit (tight, regular and loose) and style (3/1 twill woven trousers and single jersey sweatpants). A standing stationary manikin, the highly accurate 3D body scanning and post-processing method developed in previous studies were used to determine the thickness of the air layers between the body and the garment. The results showed that the regional body sections had the strongest effect on the air layers beneath the garment. The garment fit had stronger effects on the air layers at the legs than the pelvis area due to body geometry and the garment style. This finding is useful for clothing modelling and design, and it implies that the modelling of air layers at the pelvis and the legs is possible, since the observed trends were unambiguous. The results of this study can contribute to an improved design of protective clothing and active sport garments. Furthermore, it will help to improve the simulations of the heat and mass transfer for lower body garments in various fit and design.

Keywords: air gap, 3D body scanning, lower body, heat and mass transfer in clothing

1. Introduction

The clothing is an important interface between the body and its surroundings for protection against external hazards and harsh environmental conditions. It provides a microclimate, in which the human body attempts to keep its wellbeing. The heat and mass transfer between the human body and its surroundings is affected not only by the properties of the fabrics, but also by the shape and the thickness of the air layer between the garment and the human body due to the low conductivity of the stagnant air [1, 2].

The garment properties have an effect on the distribution of air gap thickness over the body. In previous studies, the distribution of the air gap thickness and the effect of the garment properties (fit and style) on the air layers have been investigated for upper body [3, 4]. However, none of the studies focused on the distribution of the air layers for the lower body garments and the interaction between the lower body geometry and the garment properties. To understand the similarities or to distinguish the differences between the distribution of the air layers for upper and lower body garments, it is necessary to have a systematic study for lower body garments in different fit and style.

In the presented study, the distribution of the air gap thickness at different garment fits, such as tight, regular and loose fit, and styles, such as trousers and sweatpants, were determined on the motionless male manikin using advanced 3D scanning and post-processing method developed in previous study. The results of this study can contribute to an improved design of protective clothing and active sport garments. Furthermore, it will help to improve the simulations of the heat and mass transfer for lower body garments in various fit and design.

2. Method

2.1. Fabrics and garments

In the presented study, plain jersey knitted fabric, which contained 95% of cotton (CO) and 5% of spandex fibre (SP), was used to sew the sweatpants. Additionally, 3/1 twill woven fabric, which consists of 100% cotton, was used to confection the trousers (Table 1). The Fabrics were washed with gentle washing program at 40°C and dried to remove any foreign material, such as dust, soil, dye waste and the tensions of the manufacturing process from the fabric [5].

* agnes.psikuta@empa.ch, phone: +41 58 765 76 73, Fax: +41 58 765 77 62

Table 1 Properties of the fabrics used in the study

Fabric	Fibre Content	Mass (g/m^2) [6]	Thickness (mm) [7]	Drape Coefficient (DC) (%) [8]
Single Jersey	98CO / 2SP	188	0.87	41
3/1 Twill weave	100 CO	179	0.67	63

Casual sweatpants made of jersey fabric was confectioned to represent indoor clothing and the trousers made of 3/1 twill woven fabric was prepared to represent the outdoor clothing. The patterns of the garments were done in tight, regular and loose fit (Figure 1). Ease allowances of the garment were calculated by subtracting the girth of manikin body from the girth of the garment at relevant body landmarks are presented in the Table 2.

Fig. 1. Photos of trousers and sweatpants in tight, regular and loose fits for front and back view

Table 2 Ease allowances between girths of the nude manikin and the sampled garments used in the present study

Garments	Fit	Ease allowances (cm) [9]		
		Hip	Thigh	Calf
Sweatpants	Tight	6	3	-3
	Regular	6	6	5
	Loose	9	10	12.5
Trousers	Tight	6	3	3.5
	Regular	6	6	7.5
	Loose	9	10	12.5

2.2. Measurement protocol

In the presented study, a motionless male manikin was used with the height of 190 cm, waist girth of 74 cm, hip girth of 94 cm, thigh girth of 53 cm and calf girth of 35.5 cm. These anthropometric measurements were done in the standing straight upright position according to ISO 8559:1989 [9] and used as a basis for the patterns of the garments.

The manikin was stable in the fixed standing straight position with arms slightly extended to the front and fixed with the additional locks during the measurements. The manikin was scanned nude and clothed with relevant garments using Artec MHT 3D body scanner (Artec Group, USA). Due to the small view area (536x371 mm) of the hand-held scanner, it has to be moved around the manikin to be able to scan the large size of the manikin using a special driver.

The 3D scans were post-processed using dedicated software Geomagic Control 2014 (3D Systems®, SC, USA) to derive the thickness of the air layer and the magnitude of the contact area. Scanning and the post-processing procedure consist of the following steps which were developed in the previous studies [10, 11]:

- Scanning the dressed manikin's lower body (6 repetitions to have variability of draping) in fixed standing straight posture,
- Scanning the nude manikin's lower body,
- Cleaning the surface of the 3D scans by removing the artefacts and closing the surfaces with deficiencies,
- Super-imposing of the nude and dressed 3D scans of the manikin using uncovered body parts as a reference,
- Slicing the super-imposed manikins into body parts to evaluate the sought parameters individually for each body part (Figure 2),
- Geometrical determination of the distance between super-imposed surfaces recognized as air gap thickness.

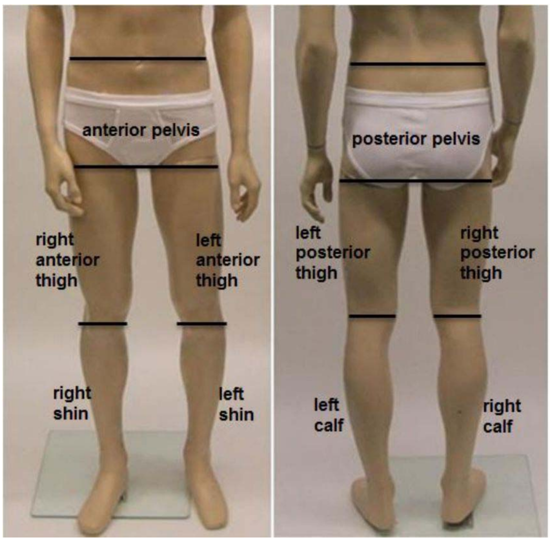

Fig. 2. Division of the lower body into individual body parts for which the air gap thickness and the contact area were determined

The air gap thickness was calculated individually for the body regions. It was calculated by deriving the average distance between the superimposed surfaces of the scans of the nude manikin body and the clothed manikin body.

3. Results

Figure 3 shows the exemplary colour maps of post-processed 3D scans of trousers and sweatpants confectioned in tight, regular and loose fits, where the air gap is indicated in red and yellow.

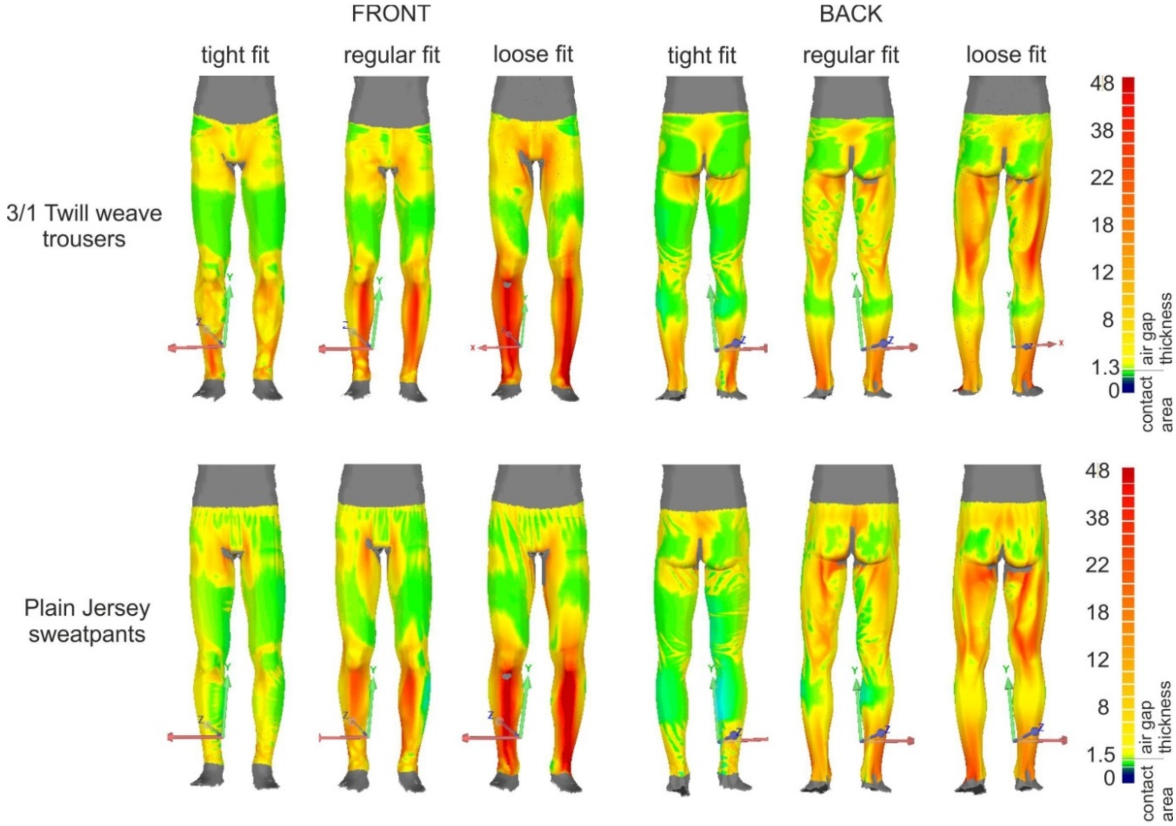

Fig. 3. Colour maps of post-processed exemplary single 3D scans of trousers and sweatpants in tight, regular and loose fits for front and back view

Figure 4 shows the mean air gap thickness of six scans and their standard deviations for sweatpants and trousers. The air gap thickness was plotted against to the ease allowances of the tight, regular and loose fitted garments.

4. Discussion

The results of the presented study show that the change in the air gap thickness depended on the body region (Figure 4). Moreover, the findings indicate that the change in the air gap thickness due to garment fit was higher for the legs than the pelvis area. At the pelvis, the garment fell on the buttocks owing to its own weight and conformed to this body region due to the flexibility of the textile material (green areas on the buttocks in Figure 3). Below the buttocks which is the most protruding body part on the lower body the garment hung downwards with a certain distance to the posterior thigh and created relatively larger air layers. Similar effect was observed at the shin with the knee which is the second protruding body part (Figure 4). The effect of fit was clearer at the concave body parts (posterior thigh and the shin), where the distance between the body and the garment was large enough to see the differences in air gap thickness at this landmark, than at their counterparts (anterior thigh and calf). Moreover, the results for right and left legs were similar due to the symmetrical body shape of the manikin fir its left and right side. This result suggests that the modelling of the air gap thickness at the legs and pelvis is possible, since the observed trends are unambiguous. Consequently, for the future mathematical modelling of air layers, the effect of garment style should be considered.

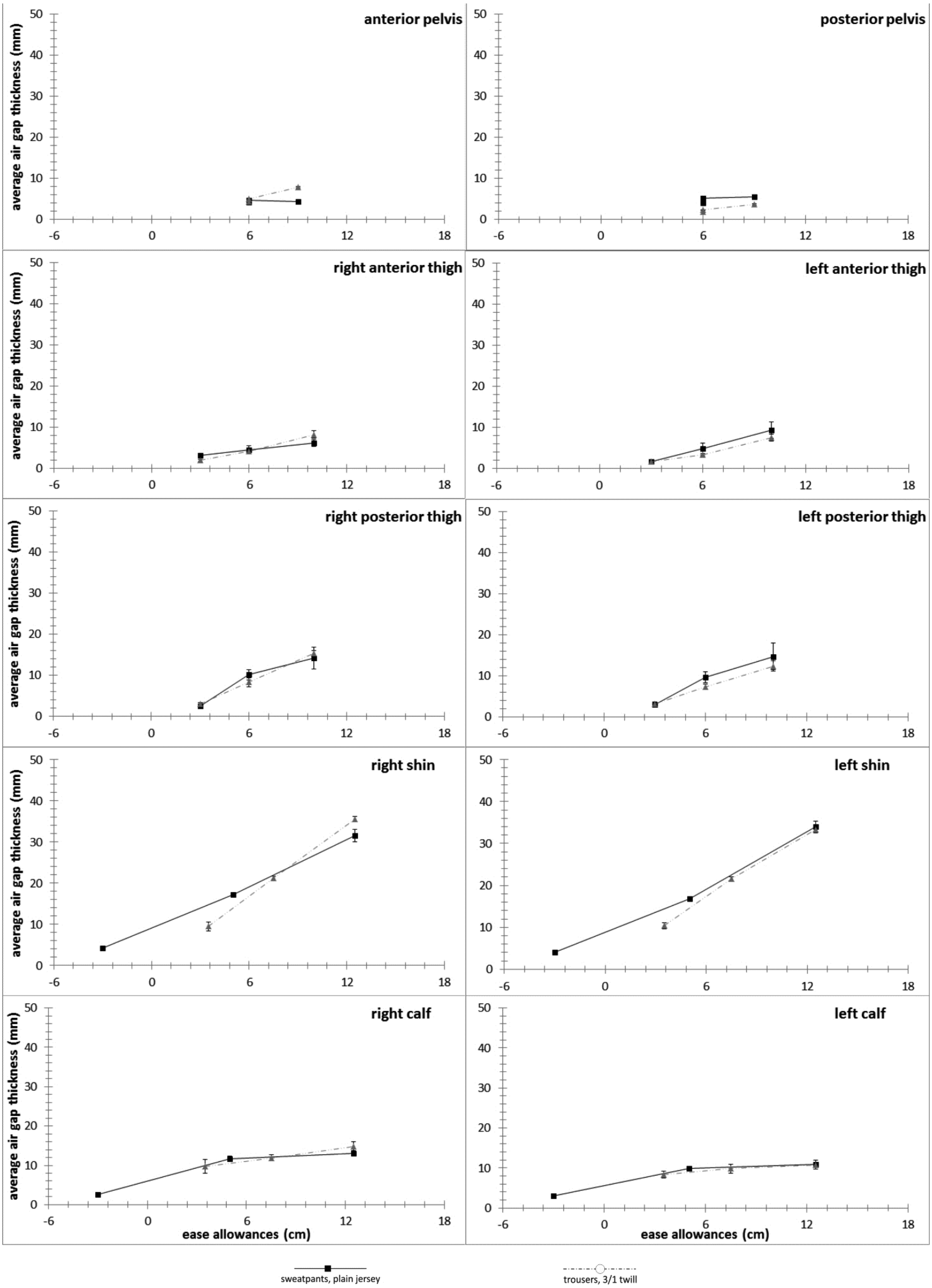

Fig. 4. Average air gap thickness and its standard deviation plotted against ease allowance in the trousers and sweatpants presented for individually body regions

The garment style had only effect on the air gap thickness at the pelvis and the lower legs, even though the trousers were designed to have larger ease allowances at some landmarks than the sweatpants. On one hand, at the shin, trousers had lower air gap thickness than the sweatpants at tight fit (Figure 4), whereas at the calf, the effect of increasing air gap thickness can be seen only for sweatpants. The reason for these differences in the air gap thickness for the shin and calf could be either the pattern construction of the sample garments or the fabric type. The sweatpants were designed with one side seam at the inner leg and made of one pattern piece, whereas the trousers were designed with two side seams. Having more seams on the trousers had an effect on the drape of the garment due to the increased fabric thickness and stiffness [12]. On the other hand, due to the differences in design of the waist of both trousers and sweatpants, the trousers showed lower air gap thickness at the posterior pelvis than the sweatpants. The elastic band that was used for the sweatpants to adjust the size of the waist of the sweatpants to the hip of the manikin, whereby a button, a zipper and a yoke was used to confection the trousers to have better wearing comfort and better fit to the pelvis area. As a result, elastic band caused more folds on the pelvis area in the case of the sweatpants, whereas the trousers conformed to the shape of the posterior pelvis due to the yoke and belt (Figure 3).

5. Conclusion

In the presented study, the distribution of the air gap thickness in relation to the garment fit (tight, regular and loose), the garment style (sweatpants and trousers) and the fabric properties (3/1 twill woven and jersey knitted fabric) were evaluated. The results showed that regardless the garment fit the air gap thickness stayed unaffected at the pelvis area, whilst the pronounced effect was observed at the legs. Moreover, the garment style had only an effect on the pelvis area and the lower legs.

The outcome of the study showed that the comfort level of the human body for a given purpose can be adjusted by selection of fabric type and the design of ease allowances in the garment individually for body regions. Moreover, the air gap thickness derived in this study can be used in the clothing mathematical models to estimate the heat and mass transfer through the lower body garments, and hence, the outcome of the simulations will be improved for different garment fits and styles.

Acknowledgements

The authors wish to thank Christiane Luible and Madaleine Ribeiro (HEAD, Geneva, Switzerland) for designing and confectioning the sample garments used in the presented study.

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