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Anthropometric Measure Extraction and Offset Calculation for 3D Body Scan Data, Obtained from an Epidemiological Health Study

Dominik BONIN[a,1], Sascha WISCHNIEWSKI[a], Markus PETERS[a] and Dörte RADKE[b]
[a] *Federal Institute for Occupational Safety and Health (BAuA), 44149 Dortmund, Germany*
[b] *Institute for Community Medicine - SHIP/KEF, University Medicine Greifswald, 17489 Greifswald, Germany*

Abstract. Digital Human Modeling Systems (DHM´s) benefit from detailed up to date anthropometric data. Whereas the clothing industry focuses on anthropometric measures according to ISO-18825-2, ergonomic- and safety- related measures are defined in ISO 7250-1. For the current research project, body scan data was collected as part of an epidemiological study (Study of Health in Pomerania, SHIP). ISO 20685-1 recommends a validation study for the comparison of manual vs. 3D body scan data from at least 40 persons, if the data should be considered in anthropometric databases. The current study evaluated data of 44 participants. The scans and the manual measurements for each participant were taken successively at the same day. The definition of anatomical landmarks differed for some parameters between the ISO 7250-1 standard and the standard operating procedures (SOP´s) of the SHIP study. As it was not possible to change the methods of the SHIP study, the authors performed a relative offset calculation. With few exceptions, the validation measures exceeded the maximum error allowances from ISO 20685-1:2018. The paper discusses possible root causes of the evaluated differences.

Keywords. Manual Anthropometry, 3D Body Scanning, Data Comparison

1. Introduction

Digital Human Modeling Systems offer the possibility to consider individual, or population based anthropometric data for a human centered product and work system design. To be reliable for a specific population, and to account for multivariate coherences, the anthropometric database needs to be exceptionally detailed. For the German population, percentile based anthropometric data exists, for example within the standards ISO/TR 7250-2 [1] and DIN 33402-2:2005-12 [2]. Other anthropometric databases, with higher level of detail, or with access to raw measures for the German population, are not easy to access as they were collected in a proprietary, commercial setting and are not publicly free available. The manual collection of anthropometric data is time consuming and expensive, therefore the use of 3D body scan devices increased,

[1] Corresponding Author, Email: bonin.dominik@baua.bund.de.

as the scanning procedure is capable of saving time and offering numerous opportunities for further applications. Especially in the clothing industry 3D body scan data is commonly used, even own standards for the vocabulary and terminology used for attributes of the virtual human body exist, e.g. ISO 18825-2:2016 [3]. For ergonomic and safety related applications, the relevant standard is ISO 7250-1:2017 [4]. As there are several differences between classic anthropometry and scan derived anthropometry, ISO 20685-1:2018 [5] provides a standard for internationally comparable anthropometric databases and an evaluation protocol for body dimensions extracted from 3D body scans.

In 2013, the authors got the possibility to establish a cooperation for the collection of 3D body scans within an epidemiological study. The already existing infrastructure offered the possibility, to extract anthropometric measures according to ISO 7250-1:2017, with only little changes in the study protocol. The method, standard operating procedures and the certification process for the examiners and the readers who performed the post processing of the data, have already been published [6]. The main focus of the present paper is to show the results from a validation study according to ISO 20685-1, for the comparison of ISO 7250-1:2017 measures derived from 3D body scan data with manual measures taken with anthropometer, beam caliper and measuring tape.

2. Method

The study was performed as part of a joint project between the Federal Institute for Occupational Safety and Health, Dortmund, Germany (BAuA) and the Institute for Community Medicine - SHIP/KEF, University Medicine Greifswald, Germany. Within the epidemiological Study of Health in Pomerania [7], 4.107 3D body scans were collected within the study waves SHIP-3 (2014 - 2016) and SHIP-Trend-1 (2016 - 2019). The scanning device used was a Vitronic Vitus Smart XXL bodyscanner (Human Solutions, Kaiserslautern, Germany), which fulfills the requirements for anthropometric whole body scanning according to ISO 20685-2:2015 [8, 9]. The measures according to ISO 7250-1 were extracted in a post processing, where human readers manually identified 44 anatomical landmarks on the 3D images of two scan positions, sitting and standing, respectively.

2.1. Validation Study

One prerequisite for the evaluation of anthropometric data derived from body scans is a validation study, which compares the extracted digital measures with manual measure extraction. ISO 20685-1:2018 recommends a minimum of 40 participants, to ensure a 95 % confidence. The present validation study was performed with 44 participants (n = 25 female and n = 19 male). The participants were regular participants of the SHIP-Trend-1 study and volunteered to participate in the extra manual measuring procedure. The participants were provided with an extra expense allowance of 10 € per hour. To avoid examiner or reader effects, all measurements, digital as well as manual, were carried out by one single examiner. The examiner was trained and certified for both methods. The manual measurements were performed at the same day, immediately after the body scan. The measures were calculated using the statistical software tool R [10]. Mean bias and standard deviation were calculated for each measure, combined for female and male. The corresponding 95% confidence interval was calculated using the method according to ISO 20685-1:2018 (see Eq. (1), N = number of participants).

$$95\ \%\ \text{confidence interval} = mean\ \pm\ sd \cdot \frac{1.96}{\sqrt{N}} \qquad (1)$$

2.2. Methodological differences and offset calculation

Two predefined landmark definitions of the SHIP body scan standard operating procedure (SHIP-SOP) showed systematic differences to the ISO 7250-1:2017 landmark definitions. These were the landmarks of the acromion and the olecranon (differences see Figure 1).

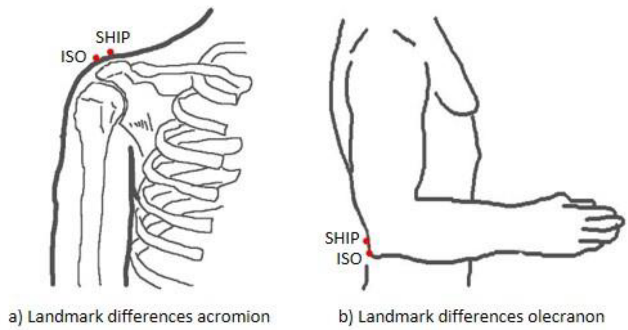

Figure 1. Example (not true to scale) as rough visualization for the landmark location offsets (drawing modified from [4]).

The different landmark locations had an impact to the following measures:

- biacromial breadth,
- shoulder height sitting,
- shoulder height standing,
- shoulder elbow length,
- forearm fingertip length.

As it was not possible to change the study design of the running SHIP evaluation, and to keep the comparability to previous examinations, the authors decided to measure these parameters twice: The first time according to the landmark definition of ISO 7250-1:2017, the second time according to the landmark definition of the SHIP-SOP. As a result, the calculation of a systematic offset was possible. To account for different body sizes (e.g. between fifth percentile female and ninety-fifth percentile male) the offsets were calculated as the relative difference between the two landmarks, taking the mean bias as reference, combined for female and male (see Table 2). Within the validation study, only the SHIP-SOP landmark locations were taken as reference for the comparison.

The parameter crotch height was excluded from the examination, as the landmark definition differed between the SHIP-SOP and the ISO 7250-1:2017 definition in a non-systematic, non-quantifiable manner. As the original landmark location is masked in the body scan images, the SHIP-SOP indexes the lowest visible point between the legs within the sagittal plane, which in turn is highly influenced by gender as well as type and fitting of the underwear.

Further, the parameter body-depth was excluded due to quality-relevant irregularities on the 3D body scan image and obviously observable differences in body posture (standing upright leaning against a wall vs. standing upright in the body scan without supportive wall).

3. Results

Table 1 shows the mean bias, standard deviation, standard error and 95% confidence interval of the comparison scan measure – manual measure, combined for female and male. MB = Mean Bias, SD = Standard Deviation, SE = Standard Error, - 95% = lower limit of confidence interval, + 95 % = upper limit of confidence interval.

Table 1. Results from the validation study manual vs. body scan, unit: [cm].

Parameter	N	MB	SD	SE	-95%	+95%
bsiso_sta_stature	43	0.28	0.78	0.23	0.05	0.51
bsiso_sta_eye_height	44	-1.11	1.06	0.31	-1.42	-0.80
bsiso_sta_shoulder_height	44	0.12	0.91	0.27	-0.15	0.39
bsiso_sta_tibial_height	44	-0.8	1.5	0.44	-1.24	-0.36
bsiso_sta_grip_axis_height	44	-1.47	1.8	0.53	-2.00	-0.94
bsiso_sta_elbow_height	44	0.1	1.27	0.38	-0.28	0.48
bsiso_sta_iliac_spine_height	44	-1.61	2.36	0.70	-2.31	-0.91
bsiso_sta_hip_breadth	44	0.73	0.67	0.20	0.53	0.93
bsiso_sta_chest_breadth	44	1.11	1.07	0.32	0.79	1.43
bsiso_sit_thigh_clearance	44	-1.81	1.13	0.33	-2.14	-1.48
bsiso_sit_knee_height	44	-0.06	1.04	0.31	-0.37	0.25
bsiso_sit_height	43	-0.29	1.14	0.34	-0.63	0.05
bsiso_sit_cervicale_height	44	-0.69	1.1	0.33	-1.02	-0.36
bsiso_sit_eye_height	44	-1.11	1.31	0.39	-1.50	-0.72
bsiso_sit_shoulder_height	44	-0.41	1.39	0.41	-0.82	0.00
bsiso_sit_elbow_height	44	-0.53	1.79	0.53	-1.06	0.00
bsiso_sit_popliteal_height	44	-0.02	3.34	0.99	-1.01	0.97
bsiso_sit_buttock_poplit_len	44	-0.5	1.85	0.55	-1.05	0.05
bsiso_sit_buttock_knee_len	44	-0.17	1.96	0.58	-0.75	0.41
bsiso_sit_butt_abdomen_depth	44	1.65	1.49	0.44	1.21	2.09
bsiso_sit_abdominal_depth	44	1.1	1.18	0.35	0.75	1.45
bsiso_elbow_grip_len	44	-0.95	1.07	0.32	-1.27	-0.63
bsiso_elbow_wrist_len	44	0.12	0.76	0.22	-0.10	0.34
bsiso_forearm_fingertip_len	44	0.45	0.58	0.17	0.28	0.62
bsiso_shoulder_elbow_len	44	0.01	1.05	0.31	-0.30	0.32
bsiso_biacromial_breadth	44	0.05	1.74	0.51	-0.46	0.56
bsiso_bideltoid_breadth	44	1.21	0.95	0.28	0.93	1.49
bsiso_elbow_to_elbow_breadth	44	3.87	3.87	1.14	2.73	5.01
bsiso_sit_hip_breadth	43	-0.06	1.3	0.39	-0.45	0.33
bsiso_neck_circumference	42	0.49	0.84	0.25	0.24	0.74

Table 2 shows the calculated relative offsets for those parameters, which were affected by SHIP-study specific systematic differences to the ISO 7250-1:2017 landmark locations of the acromion and the olecranon (see Section 2.2).

Table 2. Calculated relative offsets for SHIP-study specific differences to ISO 7250-1:2017 measures. _F = Female, _M = Male, unit: [%].

Parameter	mean_F	sd_F	mean_M	sd_M
bsiso_biacromial_breadth	17.0647	3.5153	16.8904	3.4158
bsiso_forearm_fingertip_len	-3.9810	1.3520	-2.1383	0.9281
bsiso_shoulder_elbow_len	-5.2477	1.9240	-5.1487	1.6193
bsiso_sit_shoulder_height	-2.0419	0.9774	-2.4088	1.2966
bsiso_sta_shoulder_height	-0.9055	0.3194	-1.0168	0.4462

4. Discussion & Conclusion

The present paper showed the methods and results of a body scan evaluation, which was performed as part of an epidemiological study. Some recent research projects already addressed the comparison of manual anthropometry vs. algorithm-based assessment of anthropometric data, e.g. [11-15]. The peculiarity of the present study was the post-processing with manual identification of ISO 7250-1:2017 landmarks on the scan image by a human reader.

Interpretation of the validation study results

ISO 20685-1:2018 allows a maximum mean error between the scan derived data and manual data of 5 mm for segment lengths and body depths, 4 mm for body heights, breadths and small girth, and 9 mm for large girth measurements. The maximum allowable error needs to be smaller than the calculated limits of the 95 % confidence interval. Only four parameters (shoulder height standing, knee height sitting, elbow-wrist length and shoulder-elbow length) fulfilled these requirements. Taking the upper and lower confidence limit as references, six parameter were below 0.5 cm error, eight parameter between 0.5 cm and 1 cm error, eleven parameter between 1 cm and 1.5 cm, four parameter between 1.5 cm and 2.3 cm and one parameter (elbow-to-elbow-breadth) exceeded these values with a confidence interval ranging from 2.73 cm to 5.01 cm (see all values in Table 1). These findings are in line with other comparative studies [12, 16], which also documented higher deviation values, than the above listed maximum error allowances.

As the inter- and intrarater reliability were on a high level within the certification procedure for the manual reading of the present study [6] and the body scanner passed the technical requirements according to ISO 20685-2:2015 [8, 9], it is likely that the root cause for the evaluated differences derive from other influencing factors. One issue might have been differences in landmarking, as landmarking errors are known to have a major influence on the comparability [17]. The scanner used was not capable of detecting manually added landmarks on the participants skin, and a preparation with reflective physical markers on the participant's skin was not possible, due to the limited time frame within the ongoing study procedure. This mainly effects those parameters, where a clear landmark identification on the scan image is difficult (e.g. thigh-clearance, iliac-spine-height or buttock-abdomen-depth).

Nine out of ten parameter with a negative comparison mean error and a -95 % lower limit of the confidence interval bigger than -1 cm were height measures. This leads to the assumption that the body posture, and especially the placement of the feet might have differed between the trials. This is in line with the results and assumptions of [12], but contrary to other comparison studies that evaluated higher values derived from the 3D body scanner, presumably because of compressed hair underneath the used bathing cap [13, 15, 16].

The parameters with a positive comparison error and a 95 % upper limit of the confidence interval bigger than 1 cm were breadth and depth measures. The parameters elbow-to-elbow breadth, bideltoidal-breadth and chest-breadth seem to suffer from a special sensitiveness to breathing, body composition and arm placement. For the manual measurement of the buttock-abdomen-depth, a buttock plate was placed at the most posterior point of the buttock to ensure a good reference point for the anthropometer. Therefore, a tissue compression at the contact areas from the buttock plate to the participants surface might be a possible reason for the evaluated difference.

Overall, when taking the given methodically difficulties into account, the evaluated differences were in an expected and credible range.

Conclusion

The idea of capturing body scans as part of an epidemiological study is a promising approach to gather a big amount of anthropometric datasets in a comparably short time. Despite a comprehensive quality assurance, the maximum error allowances from ISO 20685-1:2018 for validation studies were hard to achieve, due to several methodically differences. Nevertheless, the values were within a reasonable range and appear to be acceptable for numerous use cases.

However, for the subsequent use of the derived data, it is advisable to take the inter- and intrarater errors of the reader certification as well as the observed errors of the validation study into account. When adding a security supplement, and reporting the source of the data, the authors suggest that it should be possible to use such data, also as a supplement for existing anthropometric databases – which, of course, needs to be discussed with the relevant technical committees.

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