Abhijit Majumdar
Deepti Gupta
Sanjay Gupta *Editors*

Functional Textiles and Clothing 2020

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Editors
Abhijit Majumdar
Department of Textile and Fibre Engineering
Indian Institute of Technology Delhi
New Delhi, Delhi, India

Deepti Gupta
Department of Textile and Fibre Engineering
Indian Institute of Technology Delhi
New Delhi, Delhi, India

Sanjay Gupta
World University of Design
Sonepat, Haryana, India

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About the Editors

Abhijit Majumdar is a Chair Professor in the Department of Textile and Fibre Engineering at Indian Institute of Technology, Delhi. He has more than 23 years of experience in industry and academia. He has published 110 research papers in refereed international journals. His research interests include protective textiles, soft body armour materials, multi-criteria decision making, soft computing, and sustainable supply chain management. He has authored 2 books and edited 3 books, and guided 11 doctoral students. He is a recipient of Outstanding Young Faculty Fellowship (2009-2014) of IIT Delhi, Teaching Excellence Award (2015) of IIT Delhi, Gandhian Young Technological Innovation Award (2017) and FITT award for the Best Industry Relevant Master's Project Supervision, IIT Delhi (2019).

Deepti Gupta is Professor in the Department of Textile and Fibre Engineering atIndian Institute of Technology Delhi. She has more than 30 years of teaching and research experience. Her research interests include ecofriendly finishing of textiles, Functional clothing design, garment sizing and fit. She is a member of various governmental, professional and industrial committees and has edited 4 books, and authored 1 book, 5 chapters and 90 research articles in refereed journals.

Sanjay Gupta is Professor and Vice Chancellor at the World University of Design, Sonepat, India, and was previously the Dean of National Institute of Fashion Technology. He obtained his Ph.D. in textile technology from Indian Institute of Technology Delhi. He was a UNDP fellow to Fashion Institute of Technology (FIT), New York and a Visiting Professor at École Nationale Supérieure des Arts et Industries Textiles (ENSAIT), France. His research interests include Functional clothing design and Development of Textile Products. He has over 100 publications and over 30 presentations in national/ international conferences and seminars.

Testing, Characterisation and Instrumentation

Objective Assessment of the Cooling Function of Textile Products Based on the Combination of WATson and Human Perception

E. Classen

1 Introduction

Comfort is one important issue for clothing. Comfort not only affects the well-being of the wearer, but also his performance and efficiency. Comfort is a complex, highly subjective quality, often defined as the absence of discomfort. The four important aspects of comfort in clothing are thermophysiological comfort, skin sensorial comfort, ergonomic comfort, and psychological comfort [1]. Wear comfort is a complex phenomenon that cannot be properly judged by the customer through simply trying the garment on in the store, nor can it define by sales representative. However, wear comfort can be measured because it is not entirely an undefined, purely subjective individual sensation. Wear comfort is a quantifiable consequence of the body-climate-clothing interaction [2].

Today, the physiological function of textiles and whole garment systems can be measured by a set of laboratory test methods (e.g., sweating guarded hotplate, thermal manikin, sweating thermal manikin). Laboratory test methods are fast and can easily determine different aspects of comfort with high reproducibility. However, the results of laboratory test methods must be correlated with human reception in wearer trials because laboratory tests do not directly measure the comfort.

Clothing with additional functions is more and more important in the field of sports but also in protective clothing. The cooling textiles should support the efficiency of athletes and workers. The cooling effect should improve the comfort and the well-being. During high activity and/or in warm environments the body core temperature can increase and human starts sweating to prevent an overheating of the body. The evaporation of liquid sweat is the most effective process to cool the body. The cooling textile should support the body to keep the body temperature constant. The cooling

E. Classen (✉)
Hohenstein Institute for Textile Innovation gGmbH, Schlosssteige 1, 74357 Boennigheim, Germany
e-mail: e.classen@hohenstein.de

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effect of textile material is not limited to the use of clothing textiles; the cooling effect is also interesting in the field of bedding, seats and technical textiles.

The cooling of a textile cannot be determined with the conventional test methods of the clothing physiology. To determine the cooling power of fabrics, the new heat release tester WATson was developed in Hohenstein. With WATson, the cooling power of cooling materials can be determined and compared. However, the measured cooling power is only a physical value. Without the correlation of these values with data of subject trials, the cooling power does not give any information about the perception of the human body and the achieved cooling effect.

2 Materials and Methods

2.1 Materials

The textile materials were commercially available fabrics for sport wear (see Table 1). The material composition was taken from the product information of the manufacturer. The mass per unit was determined according to DIN EN 12127. The thickness was determined according to DIN EN ISO 53855.

All fabric samples were washed once prior to testing on household washing, 30 °C, line drying with a standard detergent (ECE-2 Standard Detergent 1998) in accordance with ISO 6330 (procedure 4M for polyester (PES), polyamide (PA) and polypropylene and procedure N for cotton (CO)).

For sample preparation, three specimens measuring 25 cm × 25 cm were cut out. The test specimens were conditioned for 12 h prior to measurement under the climatic conditions of the testing protocol.

2.2 WATson

The test device WATson is placed in a climate chamber to ensure constant and defined ambient climate during the test run (ambient temperature (T_a) of 30 ± 0.5 °C and relative humidity of in the climate chamber (rH_a) of 70% ± 10%). The evaporative heat loss test device WATson consists of a heated plate with sweat glands and is technically and electrically designed to mimic human thermoregulation (see Fig. 1). The area of the measuring head is 400 cm^2 (20 cm × 20 cm). The heated plate is set to an average skin temperature (T_s) of 32 ± 0.1 °C. The temperature of the measuring head is held constant at the set temperature by controlled electrical heating. This electrical heating power to maintain this set temperature (i.e., the heat loss) is recorded at 1 datapoint per second (1 Hz) and is stated as "$P_{heating}$" in W.

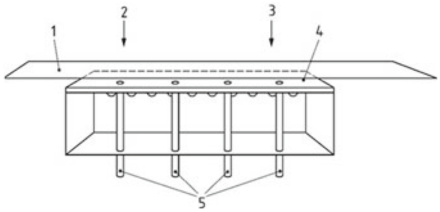
The four inner sweat glands supply deionized water (i.e., "sweat") via a peristaltic pump with a pumping rate (i.e., sweat rate) of 8 ± 0.1 g/h. Wind is one important

Tab 1 Materials and characteristic parameter

Sample	Composition*	Mass per unit (g/m^2)	Thickness (mm)	Construction
M01	PES (100)	120	0.5	Knitted, mesh
M02	PES (100)	95	2.4	Spacer fabric
M03	PA/PES/El/Lycra (54/32/14)	245	0.85	Knitted, two layers
M04	PA/PES/El/Lycra (58/26/16)	240	0.93	Knitted, two layers
M05	PA/PES/El/Lycra (58/29/13)	250	0.88	Knitted, two layers
M06	PES/Carbon (98/2)	120	0.43	Knitted
M07	PES/PES Coolmax (50/50)	120	0.75	Knitted, two layers
M08	PES/EL/Lycra (67/33)	220	0.76	Knitted
M09	PES (100)	119 120	0.69	RR double knit
M10	PES (100)	119 113	0.67	RR double knit
Fabric 1	PES (100)	**	**	Knitted
Fabric 2	PES (100)	**	**	Knitted
Fabric 3	PES (100)	**	**	Knitted

*Composition of fabric from manufacturer information; PA = polyamide, PES = polyester, EL = elastane, **fabric 1,2 and 3 show the same mass per unit and the same construction

Fig. 1 Schematic illustration of the evaporative heat loss test device WATson



1 Textile Sample
2 Wind, strictly perpendicular and centric
3 IR radiation (simulating solar radiation), not perpendicular
4 Measuring head
5 Sweat glands

parameter of the real wearer situation and for wind simulation, the test was done by a light breeze of 1 ± 0.1 m/s. The solar radiation is the second important parameter of the real wearer situation and was simulated by an IR-lamp with 13.2 ± 0.1 W. The textile sample is placed in direct contact with the heated plate.

As a link to reality, this heating power equates the heat loss of the skin (identical with the heat loss of the fabric) due to the evaporation of sweat and can be described as the ability to lose evaporative heat when wearing this kind of clothing. So, the higher this heating power, the higher is the physiological cooling effect, that is, the cooler the fabric is perceived on the skin.

2.3 Wearer Trials

To determine the influence of cooling textiles on human thermoregulation and temperature perception wear trials with subjects were performed. Test design followed ethical rules and written informed consent was obtained from all participants.

Five male subjects (28.8 ± 3.2 years, 178.8 ± 7.3 cm, BMI 23.6 ± 1.1) performed a standardized activity protocol in a climatic chamber (temperature T_a = 25 °C, relative humidity RH_a = 50% rh). Subjects were running on a treadmill with different speeds: 4 and 6 km/h. They were wearing cooling shirts and additional standard clothing (short pants, socks, shoes). Samples for the cooling shirts were chosen by the results of the heat release tester. Every subject performed three trials with one t-shirt. Samples were pre-acclimatized for at least two hours. Trial duration was 120 min with a activity and rest program (0–20 min: sitting on a chair (rest); 20–60 min walking with a speed of 4 km/h; 61–80 min: sitting on a chair (rest) and 81–120 min walking with a speed of 6 km/h.

T-shirts were made from three different cooling textiles with different cooling behavior (fabric 1, 2 and 3). To produce the T-shirts of the wearer trials enough material had to be available; this was only the case of the fabric 1, 2 and 3. All other investigated materials were ready-made products and could not use in the wearer trials. For a fit of the T-shirts, the size and shape of the test subjects were determined with 3D-Scanning to achieve the body data for the sewing of well-fitted T-shirts. To achieve a high cooling effect the T-shirt must be worn closed to the body of the test subjects. Objective data of the test subjects (e.g., heart rate, core temperature, skin temperature and humidity, weight loss) with sensors and data logger and subjective feedback were recorded during and after the subject trials.

3 Results and Discussion

Figure 2 shows the results of 10 investigated products from the market with the heat release tester. The samples were put on the WATson measuring head in the dry state. Sweating was switched on at t = 10 min and performed until a constant heating power was achieved again (i.e., heat loss in wet state). Then sweating was turned off (t = 70 min) and the test was performed until the samples were dry again (i.e., drying time, the decay of heat loss over time).

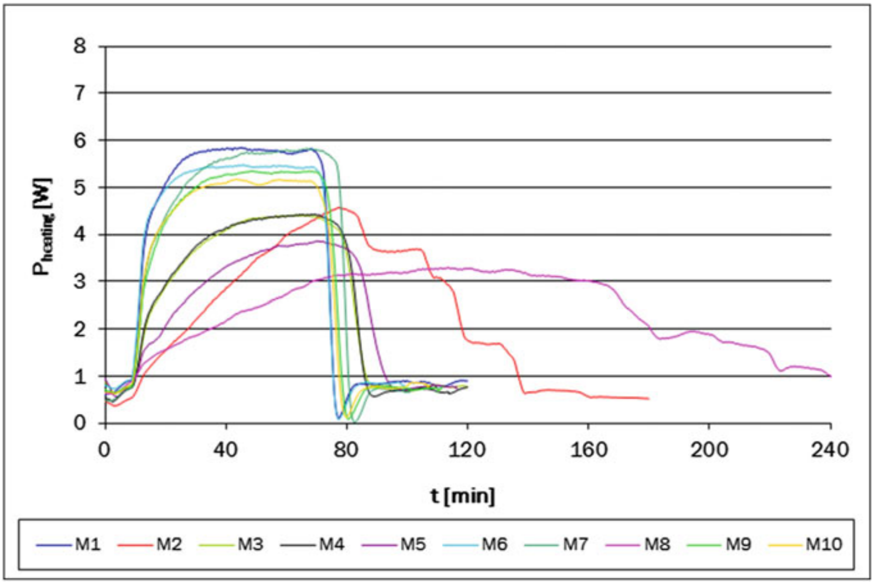


Fig. 2 Heating power of cooling textiles M1–M10, (WATson results)

The ten investigated textiles show different curves. Fabric M1, M6, M7, M9 and M10 show a fast increase in the heating power and reach the maximum cooling power fast. The drying period starts also very fast at the end of sweating and the fabrics show a similar drying behavior. The other fabrics show a low increase of the cooling power in the first 20 min, a lower maximum cooling power and the drying phase is very various. Fabric M2 and M8 show the longest drying times. Important for the cooling is a fast increase of the cooling power after the start of sweating and the reached maximum cooling power. For a better comparison, the heating power at certain periods was investigated and the results show that certain time periods for the cooling behavior are important: the wicking power, the cooling power and the drying behavior. These aspects are shown in Figs. 3 and 4.

Figure 3 shows the so-called wicking power and the cooling power of the different fabrics. After analysis of the data, the wicking power can be expressed as the momentary value of the heating power $P_{heating}$ at t = 20 min.

$$P_{wicking} = P_{heating}(t = 20) \tag{1}$$

The cooling power is the average of $P_{heating}$ between t = 60 min and t = 70 min.

$$P_{cooling} = \frac{\sum_{i=1}^{n} P_{heating,i}}{n} \tag{2}$$

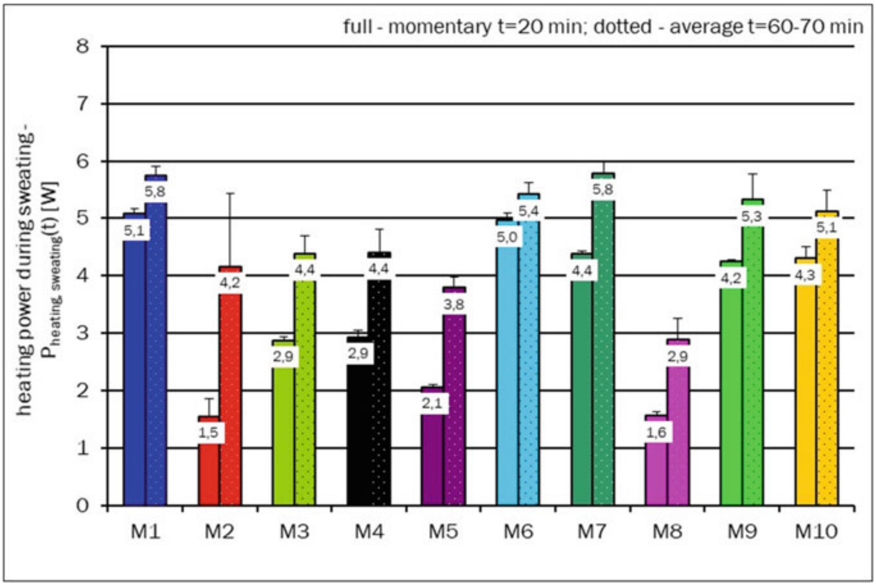


Fig. 3 Heating power of different cooling textiles, at 20 min and average value over 10 min between 60 and 70 min (results WATson)

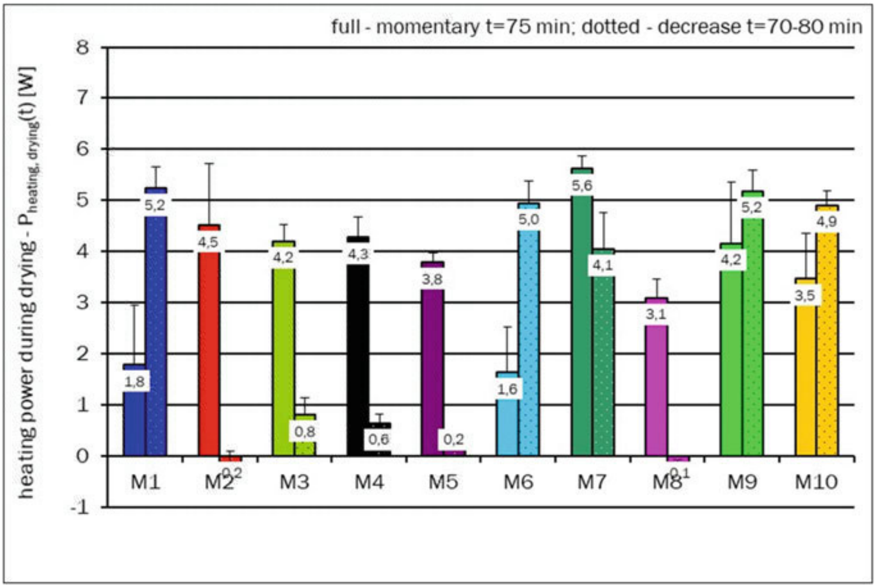


Fig. 4 Heating power of different cooling textiles, at 75 min and average value over 10 min between 70 and 80 min (results WATson)

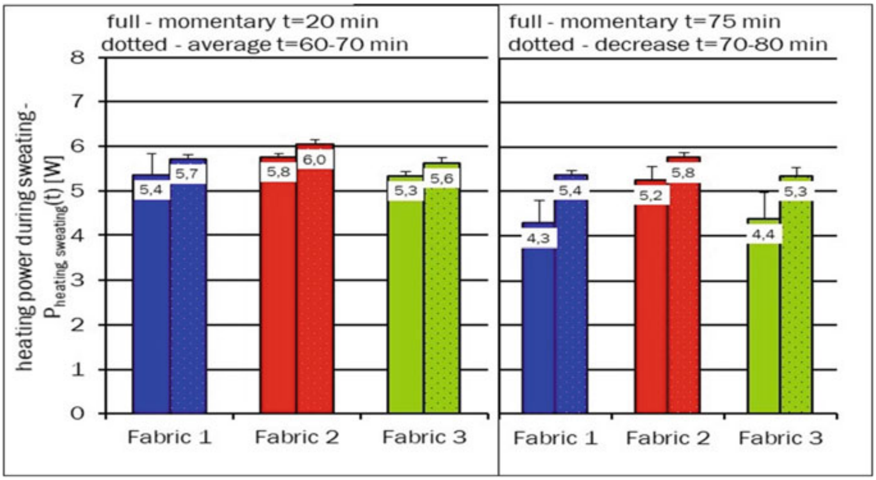


Fig. 5 Heating power of fabric 1, 2 and 3, at 20 min and average value over 10 min between 60 and 70 min (sweating phase) and at 75 min and average value over 10 min between 70 and 80 min (drying phase)

n is the number of measurements, that is, n = 600 for measurements in a time interval of 10 min, if $P_{heating}$ is measured every second.

The highest heating power at the beginning of the sweating (t = 20 min) shows the fabric M1, followed by fabric M6, M7, M9 and M10. The highest cooling power (t = 60–70 min) shows the Fabric M1, followed by fabric M7, M6, M9 and M10. Fabric M2 shows the lowest heating power, in the beginning, followed by fabric M8, M5, and M3 and M4. The highest cooling power show fabric M3 and M4, followed by fabric M2, M5 and M8. Fabric M9 and M10 show the same material composition and construction; however the cooling behavior show differences. The reason for the different cooling behavior could be, for example, the different fiber shape of the PES fibers. Further investigation is necessary to clarify the reason for different cooling behavior.

The analysis of the drying behavior shows that two periods are important for the comparison of the cooling power: the heating power at 75 min and the average heating power between 70 and 80 min. The drying time is the time starting from t = 70 min until t = x min; x is reached when $P_{heating}$ reaches the same value as at t = 10 min. The drying performance/drying time of a tested sample was displayed as a momentary value at the 75th min of the experiment (i.e., 5 min after the end of sweating) and the average over the first 10 min of drying phase-out of the sample (Fig. 4). The lower the value at the 75th minute and the higher the average value between 70 and 80th minute the quicker the fabric dries (quick-drying fabrics). The higher the value at the 75th minute and the lower the average value between 70 and 80th minute the longer the fabric dries (slow-drying fabrics).

Figure 5 shows the different characteristics parameter of the fabric 1, 2 and 3 measured with the heat release tester WATson. These fabrics were used in the subject trials. The fabrics show high values of the wicking power and the cooling power and the average value over a certain time period. The three fabrics show good cooling behavior.

The test persons rate the perception (temperature, humidity and comfort) on a rating box during the subject trials. The subjective temperature is rated by a modified seven-point Bedfort scale [3]: 1 too cold, 2 cold, 3 slightly cold, 4 neutral, 5 warm, 6 hot and 7 too hot. For humidity, a four-level scale is used: 1 dry, 2 slightly moist, 3 moist and 4 wet. The details of this analysis are reported in the project report [4]. The analysis of all data which are received from the wearer trials show that fabric 2 tends to be the best during and in the end the activity program in the temperature and humidity perception. These results were confirmed by the results of the questionnaires after every subject trial and the results of the objective data. Fabric 2 shows also the best values in the investigation with WATson.

4 Conclusion

Differences between cooling textiles could be shown by means of heat release tester WATson and wear trials. WATson test design can show differences in the heating power of different cooling textiles during the test program. The test program simulates the human sweating during activities in warm conditions (temperature 25 °C, relative humidity 50 %) and the time after activities. The first 10 min simulates the non-sweating phase (pre-exercise state) representative for low metabolic rates without sweating. After 10 min, the sweating is starting for 1 h. This represents high metabolic rates with liquid sweat occurring and equates the evaporative heat loss of the human skin covered with the wet test specimen. After 70 min, the sweating is stopped, and this represents the activity by rest with low metabolic rates. This equates the wet heat loss of the human skin covered with the test specimen in wet to dry transition and the drying time of the test specimen on the human skin. The evaporative cooling power of a tested sample in the sweating phase can be displayed as a total average over the sweating phase and as a steady-state average over the last 10 min of the sweating phase. The closer these 2 bars are together the quicker the build-up of the maximum evaporative cooling power is. The further these 2 bars are apart the longer it takes to build up the maximum evaporative cooling power. The drying performance after activity can be displayed as a momentary value at the 75th min of the test and the average over the first 10 min of drying out of the sample. The lower the value at the 75th minute and the higher the average value between 70 and 80th minute the quicker the fabric dries. The higher the value at the 75th minute and the lower the average value between 70 and 80th minute the longer the fabric dries. The wearer trials of three different garments show that the results of objective and subjective parameters of the tested garments are similar and fabric 2 is judged as the best one which is seen in the WATson test. Because the three tested fabrics have similar properties further wearer trials with cooling textiles will be performed in the future to correlate the data of wearer trials.

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Validation and Reliability of Sizestream 3D Scanner for Human Body Measurement

Manoj Tiwari and Noopur Anand

1 Introduction

Knowledge of anthropometric body dimensions, size, shape, movement, etc., is of much use in many fields. Traditionally, such data have been obtained through manual techniques of measuring the body through hand-held instruments like anthropometer, measuring tapes, spreading caliper, etc., which is time-consuming, labor-intensive and hence expensive. It further becomes more challenging when a data has to be collected on a larger scale from many participants like in national sizing surveys. Additionally, the data such collected (manually) is error-prone and hence unreliable. This is the reason why there has been a significant increase in the utilization of 3D body scanning technologies worldwide for such purposes. More than 19 countries since 1980s have undertaken their national anthropometric surveys using 3D scanning technology for example the USA, the UK, Germany, France, Japan, Korea, and China, etc. The 3D scanning has applications in a number of fields such as automobiles, medical sciences, aviation, architecture, and of course apparel where it is extensively used for mass customization for an improved fit.

M. Tiwari (✉)
Department of Fashion Technology, National Institute of Fashion Technology, Jodhpur 342037, Rajasthan, India
e-mail: manoj.tiwari@nift.ac.in

N. Anand
Department of Fashion Technology, National Institute of Fashion Technology, New Delhi 110016, India

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2 Background

Since the collection of anthropometric data automatically through 3D whole-body scanning technology is getting favored over traditional manual measurement method, it becomes vital to establish the accuracy of the new technology-driven system in comparison to the traditional manual system for establishing acceptability and appropriateness of the data generated. It is important to understand how the scanner extracted measurements are concurring with the measurements taken manually for the same dimensions [1]. The validity and reliability assessment of 3D body scanner is one critical area in order to establish the accuracy of the data collected. There have been a number of researches conducted in this aspect of 3D scanning which is further supported by ISO. Further, there have been recommended standard procedures to establish 3D scanner performance in terms of reliability and accuracy, in different ISO documents as well. ISO 20685:2005 guides on 3D scanning methodologies for internationally compatible anthropometric databases [2] while ISO 20685:2015 discusses about the evaluation protocol of surface shape and repeatability of relative landmark positions [3]. This study is aimed at establishing the validity and reliability of 3D whole-body scanners to carry out an anthropometric survey.

3 Methodology

3.1 Procedure and Equipment

Sample. Fifty (50 in no.) subjects (25 males and 25 female subjects) of different body shapes/body types were measured manually as well as using 3D whole-body scanners.

Anthropometric measurements were manually collected through traditional techniques by measurers. In total twelve (12) body dimensions comprising of height, girth (small and big), body depths were shortlisted to be measured as part of the study namely, Stature, Waist back height, Shoulder height, Inside leg-length, Waist height, Across-shoulder width, Chest girth, Waist girth, Hip girth, Neck girth, Thigh girth, and Chest. It was ensured that at least one dimension was included from the ISO 20685:2005 prescribed measurement type [2]. It may be noted that dimensions related to head, hand and foot were not in the scope of this study, hence were not included in the scanner validation exercise.

The manual body measurements were taken manually by the expert having experience of anthropometry. There were two (02) measurers to measure male and female subjects. Each of the measurer measured every subject twice independently following the standard definition and measurement procedure as prescribed in ISO 8559:1989. The manual body measurements (lengthwise) were taken using an anthropometer and the sliding stadiometer of length 210 cm and least count 1.0 mm. While for the girth related measurements, a certified flexible non-stretchable steel tape (Length

200 cm and least count 1.0 mm) was used. A mirror behind the subject was fitted on the wall to ensure the correct landmark positioning and placement of measuring tape. The entire exercise of taking manual body measurements was conducted under the guidance of an observer having more than 20 years of experience in anthropometry and anthropology.

Anthropometric measurements are automatically collected through the use of 3D whole-body scanning technology. The technology used was infrared technology by SS14 3D Body scanning Sizestream. The protocol followed while 3D scanning was as per ISO20685:2005. The scanner was duly calibrated at the start of the exercise on each day as per the procedure prescribed by the manufacturer. Each of the subject was measured thrice using 3D Scanning (1 scanner scanned each of the subject 3 times). To ensure precise 3D body measurement while scanning, each of the subjects were provided specially designed scan suits made of a material with enough stretch to avoid any body compression as well as any kind of slackness or looseness from the body. During 3D scanning process, the subjects were asked to maintain the posture by holding their breath in an exhaled position as prescribed in ISO 20685:2010-11.

This resulted in a total of seven (07) data points for each of the body dimension (03 data points from 3D scanning as each of the subject was scanned thrice, and 04 data points from manual scanning, wherein each of the subject was manually measured twice by each of the two measurers).

3.2 Data Preparation

Step 1. 3D scans (done thrice) for each of the subject.

Step 2. Manual measurements (done twice by each of the two measurers) for each of the subject.

Step 3. Recording and storing 3D scan data and manual measurement data of each subject (for all the prescribed dimensions) in the MS Excel sheet/SPSS file.

3.3 Data Analysis

Step 1. Differences between the 3 measures derived from the scanner and 4 measures provided by the manual measures were computed. There are 12 combinations of the same for each measure and for a particular subject. The mean difference was calculated by averaging all the differences between the scanner measurements and the average measurements taken manually [1]. The differences were checked using the test methods given in Clause 5 of ISO 20685:2005 [2, 4].

Standard Deviation (SD) of the difference between scanner measurements and the manual measurements to check the comparability of the two measurement techniques was calculated [5].

Step 2. Error limits were calculated using the mean of the differences (between scanner measurement and manual measurement) for all the subjects and reported with its associated standard deviation, sample size and 95% confidence Interval. If the 95% confidence interval for the mean of scan-minus-manual measure differences is within the plus or minus interval defined by the ISO 20685:2005 values, then the 3D scanning system can be considered as acceptable as per the International standards [6].

$$\text{95\% Standard Error} = 1.96 * \text{std. Deviation of difference/SQRT(N)}$$
$$\text{Upper Limit} = \text{Mean difference}(+)\text{95\% Standard Error}$$
$$\text{Lower Limit} = \text{Mean difference}(-)\text{95\% Standard Error}$$

Please refer Table 1 for the scanner validation analysis on the actual extracted measurements from the scanner. Table 1 illustrates the summary statistics for scan measurements-manual measurements for different body dimensions measured during the scanner validation exercise. The upper limit and lower limits of the differences as derived by following the process mentioned in step 2 were compared to the ISO 20685:2005 standard values for the permissible error. The result of the comparison of error values obtained from scanner measurements to the ISO 20685:2005 permissible error is shown as "Outcome" with P for Pass or F for Fail. It can be observed that the upper and lower limit of all the differences were observed beyond the permissible limit except WBL (Waist back length) and WH (Waist height), where the lower limit and the upper limit was observed within the permissible range for WBL (Waist back length) and WH (Waist height), respectively.

To accept the scanner extracted measurements, both the upper value and lower value should be within the ISO 20685:2005 prescribed limit. For example, for Stature the upper limit and lower limit are 1.42 and 1.17 cm, respectively, while the ISO 20685:2005 permissible error value is ± 0.4 cm. Here both the values of the upper limit and lower limit are beyond the ISO 20685:2005 permissible error value, hence all the scanner extracted measurements were considered as "FAIL".

Further, the same procedure was followed while checking the accuracy as per ISO 8559:1989 standard by comparing the difference between scanner measurements and manual measurement to the ISO 8559:1989 values (an accuracy of ± 1% or ± 5.0 m, whichever is the smaller) [7]. As indicated in Table 1, While comparing the mean difference of scanner measurement – manual measurements to the ISO 8559:1989 prescribed error limits, it was observed that all the differences were observed beyond the permissible limit. However for the WH (Waist height), the upper limit was observed in the ISO Range (Error of −0.43 against standard acceptable error value of −0.497) and a lower limit was observed out of the ISO Range (Error of −1.02 against standard acceptable error value of −0.497), hence all the scanner extracted measurements were considered as "FAIL".