Women Are Not Small Men

Laird Evans[1], Robert Pringle[2] & Eluned Lewis[2]

[1]MOD Defence Equipment & Support, [2]QinetiQ

ABSTRACT

Human Factors Engineers need accurate anthropometric data to design military equipment that is safe, comfortable and enables performance under extreme operational conditions and in the most severe environments. MOD acknowledges that its current anthropometry dataset is becoming increasingly unrepresentative of today's Armed Forces personnel, particularly women and minority ethnic groups. To address this issue, MOD has launched a new, comprehensive anthropometry survey. This paper describes the requirements underpinning this survey and the planned solution.

KEYWORDS

Anthropometry, Anthropometric, Survey, Body Armour

Introduction

Human Factors Engineers need accurate anthropometry data to design equipment that is fit for purpose – i.e. equipment that is safe and comfortable, and which yields optimal and acceptable performance. This is true regardless of the domain and application being considered. It is absolutely true in the Defence domain, when designing military systems, equipment and clothing for use under extreme operational conditions and in the most severe environments. Yet Human Factors Engineers in the Defence sector are using data that are acknowledged by the Ministry of Defence (MOD) to be not fully representative of today's Armed Forces personnel. This is particularly so for women and minority ethnic groups. The following quotation is taken from the House of Commons Defence Committee, Second Report of Session 2021-22:

"We find it extraordinary that uniforms and equipment are still a problem across all services. Thousands of female Service personnel, already facing the dangers of military duty, are at greater risk of harm due to basic failures in their uniform and equipment, which can have consequences for their combat effectiveness and health. Fixing these problems is one of the simplest ways that the Forces can demonstrate they value their servicewomen."[1]

It is clear from this quotation that the safety, health, comfort and performance of service women may be being compromised, but this is true also for minority ethnic groups, small men and, arguably, for all users of military equipment. (The term "equipment" is used in a general sense to mean systems, sub-systems, individual components, clothing, Personal Protective Equipment (PPE) and even whole platforms.)

The last comprehensive anthropometry survey of UK Armed Forces personnel was conducted in 2006-07 (Pringle et al, 2011). The data gathered at that time are freely available in the MOD's Human Factors Integration (HFI) Technical Guide for Anthropometry: People Size (Cummings,

[1] Protecting those who protect us: Women in the Armed Forces from Recruitment to Civilian Life - Defence Committee - House of Commons (parliament.uk).

2022). It is principally these data that Human Factors Engineers in MOD and Industry use when designing military equipment.

To address the lack of wholly representative and up-to-date data, the MOD's Defence Ordnance Safety Group (DOSG) placed a contract with QinetiQ to conduct a new, comprehensive, tri-service anthropometry survey. This paper describes the requirements placed on QinetiQ and the solution proposed in response.

Requirements

Two workshops were conducted in 2021 to capture requirements for anthropometry data from MOD stakeholders. These workshops were organised and facilitated by Human Factors specialists in the MOD's Defence Equipment & Support (DE&S) Human Factors Integration (HFI) team. These specialists were contracted to support DOSG during the early phase of requirements gathering and remain engaged to support the conduct of the anthropometry survey.

Both workshops attracted representation from many MOD establishments and teams. Following these events, key stakeholders emerged and their requirements for data were prioritised. At the same time, principal points of contact for the three services – Army, Royal Air Force (RAF) and Royal Navy (RN) – were identified. In addition, the survey has attracted support from the highest levels in the MOD and was endorsed by Lieutenant General James Swift, Chief of Defence People (CDP); Lieutenant General Ivan Jones, Commander Field Army (CFA); Rear Admiral Jude Terry, Director Personnel and Training (RN); and Air Marshal Sir Gerry Mayhew, Deputy Commander Operations (RAF).

Body Armour Requirements

Of particular interest during the requirements gathering phase were the bodily dimensions to be measured. The 2006-07 survey had measured 92 dimensions from 2470 personnel. It was ultimately determined that all of the dimensions recorded previously should also be measured in the new survey. In addition, a significant number of new measurements are required to support the development of new body armour. It is widely acknowledged that *"women are not small men"* (Lewis, 2020) and this is never more critical than when designing body armour that will not only save lives, but which has the potential to reduce the incidence of musculoskeletal injuries, the most common cause of medical downgrading and medical discharge in both Service men and women (MOD, 2016).

The development of body armour is a complex undertaking, involving significant engineering trade-offs. Not only must the armour protect the wearer, but it must do so in a manner that reduces restriction of movement to a minimum and does not incur unacceptable thermal or physical discomfort. Most importantly, the armour must offer protection to the critical areas of the body. A study by Breeze *et al*. (2016) identified protection of the heart, great vessels[2], liver and spleen to be of paramount importance if death or significant long-term morbidity is to be avoided. Therefore, to enable new body armour to be designed and optimised to protect these organs, 53 new dimensions are required to be measured. Examples of two of these critical dimensions are illustrated in Figure 1. These are:

A. Suprasternal notch to tenth rib
B. Suprasternal notch to iliac crest

[2] The large arteries and veins directly connected with the heart are termed the great vessels, consisting of the inferior vena cava, superior vena cava, pulmonary arteries, pulmonary veins, and root of the aorta.

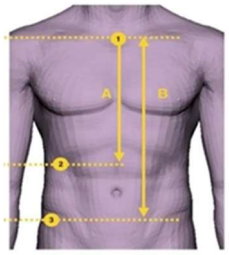


Figure 1: Critical Dimensions (A & B) from Breeze *et al*, 2016

In addition to the measurement of new external dimensions, the development of body armour to protect the anticipated user population – male and female, across all services – requires the measurement of the sizes and positions of the critical internal organs. A separate but related study, also initiated and funded by DOSG, was launched to acquire the necessary data. This study is being led by the Defence Science and Technology Laboratory (Dstl) and will utilise a Magnetic Resonance Imaging (MRI) scanner based at the University of Nottingham. Therefore, an additional requirement is for QinetiQ to collaborate with Dstl to ensure that the two studies yield complementary data, such that the combined dataset meets the requirements for new body armour.

Data Analysis Tool

It is important to note that the requirements placed on QinetiQ do not include a requirement to develop a new anthropometry data analysis tool. This is not in scope of the current contract but will be addressed separately. However, as a first step to realising a new analysis tool, QinetiQ was contracted to identify User and System requirements, and to deliver a Data Analysis Tool Requirements document, which will form a foundation for the development of an analysis tool.

Transition Plan

An important aspect of the overall requirement is the development of a Transition Plan. It is MOD's intention to transition the capability to measure anthropometry to the three services – Army, RN and RAF[3]. Ideally, each of the three services will have the same hardware and software and follow the same protocols in terms of measuring personnel. In this way, it is hoped that an enduring capability will be developed and as a consequence, the measuring of service personnel will become 'business as usual'. In other words, the database will be continually updated and maintained and MOD will never again find itself in the same position as today – having to embark upon another comprehensive tri-service anthropometry survey.

Solution

In response to the requirements identified by MOD, QinetiQ has developed a programme of work, which is currently underway. Key elements of this work programme are described below.

Sampling Strategy

An analysis of the MOD's requirements concluded that a total of 163 body dimensions were required to be measured. These comprised the 92 dimensions measured in the 2006-07 survey plus 53 dimensions required to meet the requirements for new body armour, 12 dimensions required for compatibility with the JACK[4] digital human modelling tool, plus an additional 6 body dimensions

[3] The RAF Centre for Aviation Medicine (RAFCAM) already has a capability and DE&S is indebted to RAFCAM for the support and guidance it has provided to the Tri-service Anthropometry Survey.
[4] JACK is a human modelling tool owned by Siemens with UK distributors SIMSOL Ltd

that were deemed necessary, e.g. Buttock-heel length whilst seated. As 30 dimensions were replicated to provide left and right-hand values, the total requirement resulted in 193 measurements.

Given the requirement to record 193 measurements, QinetiQ calculated that it will be possible to sample 2,875 personnel within the constraints of the available time and funding.

A personnel sampling strategy has been devised to gather sufficient data points in the following primary demographic groups: Sex, Ethnicity and Age; and in the following secondary groups: Service (e.g. Army, RAF, RN), Ranks (e.g. Officers, Others) and Service Groups (e.g. Infantry, Aircrew, Submariners). This strategy was developed by statisticians in the MOD's Defence Statistics organisation and DOSG.

The devised strategy is referred to as a 'Stratified Sample Design'[5]. This requires equal variance in each selected sub-strata[6] for at least one critical parameter. Following guidance in ISO 15535:2012, the coefficient of variance was calculated to select this parameter. Weight was determined to be the critical parameter, as this varied more than any other dimension in the 2006-07 survey. The statistical analysis demonstrated that, if the numbers of participants shown in Table 1 are achieved, all sub-strata have a variance of +/- 4 kg, yielding a 90% level of confidence.

	Total Population	Selected Population	Selected Percent	Sample size	% of sample	% of population
Army	114819	22145	19.3%	1091	37.9%	61.1%
Navy	29937	6899	23.0%	722	25.1%	15.9%
Royal Air Force	35556	10354	29.1%	736	25.6%	18.9%
Royal Marines	7604	1589	20.9%	326	11.3%	4.0%
	187916	40987		2875	100.0%	100.0%
Officer	35885	7221	20.1%	1070	37.2%	19.1%
Other Ranks	152031	33766	22.2%	1805	62.8%	80.9%
	187916	40987		2875	100.0%	100.0%
Male	165991	36265	21.8%	1995	69.4%	88.3%
Female	21925	4722	21.5%	880	30.6%	11.7%
	187916	40987		2875	100.0%	100.0%
17-24	43883	11410	26.0%	898	31.2%	23.4%
25-44	117828	24866	21.1%	1144	39.8%	62.7%
45+	26205	4711	18.0%	833	29.0%	13.9%
	187916	40987		2875	100.0%	100.0%
Infantry	38396	10030	26.1%	711	24.7%	20.4%
Aircrew	4085	1358	33.2%	363	12.6%	2.2%
Submariners	3911	438	11.2%	214	7.4%	2.1%
Other	141524	29161	20.6%	1587	55.2%	75.3%
	187916	40987		2875	100.0%	100.0%
BAME	13334	3023	22.7%	632	22.0%	7.1%
White	168052	36423	21.7%	1875	65.2%	89.4%
Gurkha	4576	991	21.7%	86	3.0%	2.4%
Fijian	1954	550	28.1%	282	9.8%	1.0%
	187916	40987		2875	100.0%	100.0%

Table 1: Stratified Sample Design

During the 2006-07 survey, the overall percentage of females measured was 12.6%, with the relevant services representation being Army (7.7%), RAF (20.9%), and RN (16.5%). Following the stratified sample design will generate substantial percentage increases compared with the previous survey: Overall (30.8%), Army (29.8%), RAF (36.7%) and RN (33.5%).

[5] The 2006-07 anthropometry survey employed a more traditional Simple Random Sample (SRS) design.

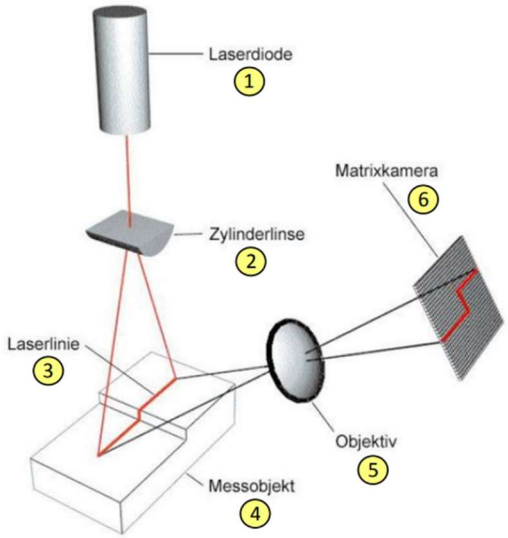
[6] Sub-strata are the primary and secondary groups identified in the previous paragraph.

VITRONICS VITUS Bodyscan 3D Scanners

Two VITRONICS VITUS Bodyscan 3D Scanners have been purchased by MOD. These complement an existing scanner purchased by RAFCAM and will be given to the Army and the RN on the conclusion of this study, thus enabling MOD's transition of the capability to measure anthropometry within the three services.

Figure 2: VITUS Bodyscan 3D Scanner (VITRONIC, 2016)

Figure 2 shows the VITRONICS VITUS Bodyscan 3D Scanner assembled; for scale, the main enclosure is approximately 3m in height. The participant is placed in the centre of the enclosure, the doors are closed to eliminate direct natural light and four scanning sensor heads, one in each corner of the enclosure, travel from the ceiling to the floor taking data measurements. The total scanning process takes approximately 10 seconds.



1	Laser diode	4	Measurement object
2	Cylindrical lens	5	Lens
3	Laser line	6	Matrix camera

Figure 3: VITUS Bodyscan 3D Scanner Laser Light-Section (VITRONIC, 2016)

The data is captured by projecting a horizontal structured light (limited wavelength content, in this case eye-safe near infrared) line onto the body, which is then viewed by a camera system offset from the axis of the illuminating line. The line is seen by the camera as a profile, as seen in Figure 3. Utilising data from a calibration process, the distance of each pixel on the camera from a set datum is converted to an x,y co-ordinate from the central axis of the scanner. The z component is referenced to the floor and acquired from an encoder on the traverse system moving the scanning heads from floor to ceiling. Each scanning head therefore captures a vertical (z) stack of 2D lines described by a series x,y coordinates. The data from the four scanning heads are then combined to provide the complete 3D point cloud describing the surface of the participant, the resultant grid being with a spacing of approximately 1.5mm x 1.5mm between points.

Anthroscan Software

To accompany the purchase of the two scanners, Anthroscan software has been procured for the study. This software allows the capture of pixelated meshes; from very simple ones to highly accurate full figure ones, see Figure 4. A cloud of 3D data points (approx. 1.5 million) is produced and a colour photographic textured map. If MOD wishes to measure some further dimensions, after the study has concluded, these may be captured from the stored meshes.

Figure 4: Anthroscan Photographic Textured Map Image

The main use of the Anthroscan software is to create algorithms which extract all the required measurement types from the five 3D scans that will be taken of each participant (2 standing and 3 seated). These will be coded using landmarks and functions within the software to extract specific measurements e.g. breadths, circumferences, contours, heights, lengths, vertical heights, etc., so that all 163 study dimensions are captured.

The Anthroscan software also contains a RAMSIS[7] measurements export wizard for easy export to a Computer Aided Design (CAD) package. Therefore the anthropometry data recorded in this study will support at least two of the main human modelling tools currently available (Jack and RAMSIS).

[7] RAMSIS is a human modelling tool owned by Humanetics Innovative Solutions, Inc.

Military Establishments

After the sampling strategy was derived, an assessment of where the required military personnel were located was performed. The following military establishments were chosen to achieve the numbers required for the study.

British Army	Royal Navy	Royal Air Force
Aldershot	Lympstone	Brize Norton
Andover	Portsmouth	Coningsby
Catterick	Torpoint	Cranwell
Colchester	Yeovil	Halton
Tidworth		Honington
Wattisham		

Table 2: Planned Military Establishment Visits

The number of participants measured is expected to be 75 per scanner per week. Generally, the scanners will be located at the same establishment, though occasionally they will be at two separate bases. A total of 20 weeks' worth of measuring is expected at the 15 establishments. Table 3 illustrates a typical weekly schedule where the scanners are taken to a base and installed.

Monday		Tuesday		Wednesday		Thursday		Friday	
AM	PM	AM	PM	AM	PM	AM	PM	AM	PM
Travel	Setup	Calibration (0.5hrs) Measure	Measure	Measure	Measure	Measure	Measure	Measure	Breakdown Travel

Table 3: Scanner Weekly Schedule

MODREC Protocol

An ethics protocol for the anthropometry survey was developed in conjunction with, and approved by, the Army Scientific Assessment Committee. This protocol was forwarded to the MOD Research Ethics Committee (MODREC). A letter of favourable opinion was received from the MODREC Chief Secretary on January 9th 2023 to enable a Pilot Study to commence.

General Data Protection Regulation (GDPR) and Data Protection Impact Assessment (DPIA)

A DPIA submission provided a comprehensive account of the types of data to be recorded in the study and the uses to which these data will be put. The activity is authorised in law through the explicit consent of participants to have their personal data, which includes information around ethnicity, biometrics and health, collected. Suitable mitigations are required through the use of specialised data storage, data encryption, and pseudonymisation of the data and organisational (contractual clauses, training, vetting) artefacts to achieve security by design and default.

The DPIA was formally approved by the MOD Data Protection Office on January 20th 2023.

Pilot Study

A Pilot Study has been designed to ensure that the scanners and any associated software can capture 3D data from participants and extract the measurements required accurately and consistently and

with sufficient fidelity. The study will determine the limits of the Vitus Bodyscan system and Anthroscan software. During the pilot study different materials (colour and reflectivity) will be scanned to determine whether there are any special requirements for underwear (for participants to be scanned in). It has been broken down into two stages:

Firstly, taking traditional measurements of all of the dimensions, to provide a 1-1 correlation between scanned and traditional measures. The techniques stated within ISO 20685-2018 will be used to assess the accuracy of the scanned measurements against the equivalent manual measurements to ensure they are sufficiently close to progress to the second part of the Pilot Study and subsequently, to the Main Survey.

Secondly, a small study of the whole scanning process will be carried out with ten QinetiQ staff, to ensure the end-to-end procedure is understood and any issues are identified early and rectified. The ten participants will therefore be processed by the scan teams (each consisting of four personnel, including at least one female), several times, in a manner (clothing, equipment and procedure) that is identical to the expected Main Survey procedure.

Conclusion

At the time of writing the anthropometry survey is underway, the Pilot Study is due to start in February 2023 with the main survey expected to start in April 2023. It is anticipated that new data to support the development of improved and inclusive body armour will be available in September 2023 and that all data gathering will have completed by the end of 2023. It is planned that the HFI Technical Guide for Anthropometry (Cummings, 2022) will be updated to include the new data in 2024. This will be freely available to all via the MOD's Defence Gateway portal. It is further anticipated that a new anthropometry data analysis tool will be developed and that this will also be freely available to all, although how this will be achieved and when it will be available are yet to be determined.

References

Cummings, R. (2022). Human Factors Integration Technical Guide for Anthropometry: People Size. Version 4.4.

Breeze, J., Lewis, E. A., Fryer, R. (2016). Determining the dimensions of essential medical coverage required by military body armour plates utilising Computed Tomography. International Journal of the Care of the Injured, Vol. 47: 1932-1938.

Breeze, J., Lewis, E. A., Fryer, R., Hepper, A. E., Mahoney, P. F., and Clasper, J. C. (2016). Defining the essential anatomical coverage provided by military body armour against high energy projectiles. Journal of the Royal Army Medical Corps, Vol. 162, Issue 4.

ISO 15535:2012 – General requirements for establishing anthropometric databases (Annex A - Method for estimating the number of subjects needed on a sample).

ISO 20685-1:2018 3-D scanning methodologies for internationally compatible anthropometric databases.

Lewis, E. (2020). Digital mannequins for our diverse Armed Forces. Application for Defence Innovation Fund TLB Ideas Scheme (Round 9) – FY20/21. 27 October 2020.

MOD (2016). Interim Report on the Health Risks to Women in Ground Close Combat Roles WGCC/Interim-Report/10/2016.

Pringle, R. H., Puxley, A. J., Puxley, K. P., Turner, G. M, and Tyrrell, A. K. (2011). Anthropometry Survey of UK Military Personnel 2006-7 (Issue 3). QINETIQ/07/01821/3.0.

Protecting those who protect us: Women in the Armed Forces from Recruitment to Civilian Life - Defence Committee - House of Commons (parliament.uk).

VITRONIC (2016). VITUS Bodyscan Operating Manual Version 1.4 - 22.01.2016.