

Optimising coverage, size and inclusivity of future body armour: The UK's new, innovative Tri-Service anthropometric survey

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QinetiQ has completed an up-to-date tri-service anthropometric survey of UK Armed Forces personnel. This survey, conducted on behalf of the UK Ministry of Defence is unique, as it contains new measurements specifically for optimising the coverage, size and inclusivity of future body armour.

A Stratified Sample Design was used to gather sufficient data in the following primary demographic groups: Sex, Ethnicity and Age; and in the following secondary groups: Service (e.g. Army, Royal Air Force [RAF], Royal Navy [RN]), Ranks (e.g. Officers, Others) and Service Groups (e.g. Infantry, Aircrew, Submariners). This strategy was developed to ensure statistical validity.

The main survey was preceded by a pilot survey to refine the methodology and to de-risk the main survey, conducted between October 2023 and May 2024. Two new state-of-the-art VITRONIC VITUS Bodyscan 3D Scanners were used to capture the individual measurements and used in tandem with Anthroscan software to deduce measurements.

1,886 Armed Forces personnel (1,510 males and 376 females) including 32 nationalities were measured from across 15 Army, RN and RAF bases and captured 194 measurements per person. The survey includes 20% female representation across all services, a 21% increase in females measured over the last UK anthropometric survey conducted in 2006/07. Fifty-four new measurements were captured specifically for optimising coverage, size and inclusivity of body armour. Examples include suprasternal notch to tenth rib, suprasternal notch to iliac crest and suprasternal notch to breast point (standing and sitting).

This new anthropometric survey will benefit all Users of defence equipment for the next ten to twenty years. It provides important data to immediately benefit UK Armed Forces body armour acquisition projects, particularly for women, by including 54 new measurements specifically for body armour. The 3D scanners will enable an enduring capability to measure anthropometry within the Armed Forces through longitudinal analyses.

1. INTRODUCTION

In 2024, QinetiQ completed an up-to-date tri-service anthropometric survey of UK Armed Forces personnel. This survey, conducted on behalf of the UK Ministry of Defence is unique, as it contains not only 'traditional' anthropometric measurements but also includes new measurements specifically for optimising the coverage, size and inclusivity of future body armour.

1.1 Body armour: medical coverage and anthropometry

The purpose of body armour is to prevent mortality (death) and significant long-term morbidity. It must not restrict movement as far as practicable and must not incur an unacceptable thermal or physical burden. Body armour must also provide coverage and protection to key anatomical structures. For the torso, coverage of the heart, great vessels, liver and spleen, by hard body armour plates, has been determined as essential to prevent mortality [1]. Subsequent work [2][3][4] demonstrated that the positions of internal organs and structures could be related to external anthropometric landmarks and

used to describe and optimise body armour coverage for Armed Forces personnel. For example, the arch of the aorta corresponds to the suprasternal notch, the lower border of the liver corresponds to the lower border of the ribcage (tenth rib) and the bifurcation of the aorta corresponds to the iliac crest (Figure 1).

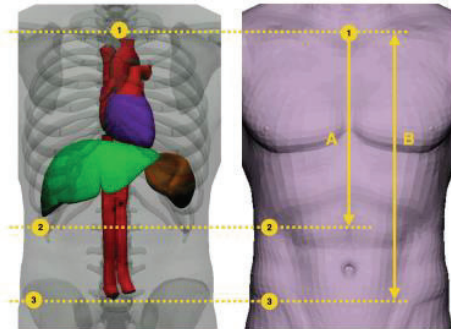


Figure 1 Anthropometric landmarks to describe coverage of the torso: (1) suprasternal notch (representing the top of aortic arch); (2) lower border of 10th rib (representing the lower border of the liver) and (3) iliac crest (representing the bifurcation of the aorta). A = Threshold Coverage (measurement of suprasternal notch to tenth rib), B = Objective Coverage (measurement of suprasternal notch to iliac crest) [3]

The same studies demonstrated that stature (total height) is not an accurate measure to enable sizing, fitting and scaling of body armour [2] (for example; fitting body armour using solely the traditional ‘chest circumference’ and ‘height’ measurements is not deemed adequate) therefore ‘torso height’ has been recommended as a measure instead. Torso height (defined as suprasternal notch to iliac crest) provides a more accurate measure than suprasternal notch to umbilicus (belly button), for example, as the position of the umbilicus can vary with weight loss or gain [2] or post-pregnancy [5]. Furthermore, to articulate medical coverage for new body armour acquisitions, the terms ‘Threshold Coverage’ and ‘Objective Coverage’ have been recommended [3]. Threshold coverage is defined as the ‘Absolute minimum area that must be afforded coverage by personal armour. Less than the threshold would not be considered to provide an improvement over current capabilities and is not medically recommended’. Threshold coverage relates to coverage of ‘anatomical structures (in the torso) that if injured would result in life-threatening haemorrhage and lead to death within 60min without surgical intervention’ [3]. The surface (anthropometric) landmarks used to determine ‘Threshold coverage’ are Suprasternal notch to lower border of ribcage (10th rib). Similarly, the landmarks used to determine ‘Objective Coverage’ are Suprasternal notch to superior border of the iliac crest [3] (shown in Figure 1).

1.2 Previous UK Anthropometry Survey and the need for updated data

The last comprehensive anthropometry survey of UK Armed Forces personnel was conducted in 2006–07 [6] with the survey data freely available in the MOD’s Human Factors Integration (HFI) Technical Guide for Anthropometry: People Size [7]. The data gathered were predominantly based on white Caucasian, male Armed Forces personnel; 2470 personnel were sampled, 88% were white Caucasian and 87% were male. Whilst this may have been appropriate in 2007, this is no longer the case, as the composition of the UK Armed Forces has changed significantly in the past 18 years [5]. Since late 2018, for example, all roles in the UK Armed Forces have been opened to women, including Ground Close Combat roles [4] and hence the number of women, as a percentage of the total number of Armed Forces personnel, has increased. Opening up all roles to women has meant that all equipment, including body armour, must be usable by both men and women [5]. Women in the Armed Forces have been wearing hard body armour plates that were optimised for large men, partly because specific anthropometric measures, that are now known to be required, were not included in previous anthropometry surveys. Suprasternal notch to iliac crest, therefore, is only one of the new measures incorporated into this new, updated anthropometry survey¹ as a result of recommendations from previous work[2][3][4][5]. Other specific measures are also required to enable the optimisation of the torso body armour system, as well

¹ NB. Suprasternal notch to umbilicus is also included as a measure in this study

as specific measures for the optimisation of armour for the extremities, such as arm protection and pelvic protection. Furthermore, new measurements are required to optimise body armour sizing and fitting regimes, particularly acknowledging the differences between male and female Armed Forces personnel as well as for other minorities. Without new underpinning data, it is not possible to quantify the differences between sexes, but also not possible to implement any meaningful changes to body armour coverage, sizing and fitting. Up-to-date anthropometric data has the potential to revolutionise all military equipment, but for body armour, it also has the potential to increase the number of sizes to optimise the medical coverage and fit, particularly for women. One size does not fit all when it comes to armour and women are not small men, hence increasing the range of sizes and shapes will impact on fit, form, function, interoperability, integration and reduce mass of body armour. Body armour not only saves lives, its optimisation will reduce the incidence of musculoskeletal injuries which are the most common cause of medical downgrading and medical discharge in both Service men and women [9].

2. METHODS AND EQUIPMENT

2.1 Internal and external anthropometry requirements

MOD's intent was to procure new, innovative 3D scanners to conduct a new, tri-service, anthropometric survey of UK Armed Forces personnel (to capture 'external' anthropometric measures), coupled with using Magnetic Resonance Imaging (MRI) scanners to capture 'internal' organ boundary and anthropometric data [9]. This paper's focus is the 'external' anthropometry survey only.

2.2 Stratified sample design for the main survey

For the main external anthropometry survey, a Stratified Sample Design (SSD) was devised by MOD statisticians, provided to QinetiQ, and used to gather sufficient data in the following primary demographic groups: Sex, Ethnicity and Age; and in the following secondary groups: Service, Ranks, and Service Groups (see 2.5). This strategy was developed to ensure statistical validity [5]. An SSD was selected for the Tri-Service anthropometric survey, rather than a simple random sample, for the following reasons: (a) A simple random sample may not include sufficient members from minority groups for accurate parameter estimation; (b) The data was required to be of a known precision for the strata; and (c) Stratified sampling produces lower variance estimates for the whole population.

The Stratified Sample was based on Serving Military Population data from the Defence Statistics, Joint Personnel Administration system (JPA), (from Jan. 2021 to Jan. 2022) and the 2006/2007 Tri Service Anthropometry Survey data [6]. Following the calculation of strata sample size the JPA data was subsequently used to identify UK military locations that provided the greatest coverage across all strata. This approach aimed to provide a current Anthropometry dataset that is proportional to the demographic of the entire Armed Forces. The number of participants required for each strata sample was calculated using a method derived from BS EN ISO 15535-2012 [10], which also suggests a similar approach, stating that the source for the variance should be that of a previous anthropometric measurement with the highest Coefficient of Variation (CoV). The variable selected from analysis of the 2006/2007 Survey data [6] was "Weight". From these calculations, the generated strata sample sizes were produced and predicted to be sufficient to estimate the average weight for each strata to +/- 4 kg with 90% confidence.

2.3 Selection and descriptors of individual measurements

Stakeholder workshops were conducted with a range of MOD disciplines and functions represented, to capture requirements for anthropometry data [5]. After careful consideration and investigating the art of the possible within the programme bounds, 194 measurements were selected, and a new, more descriptive style of naming the anthropometry measurements was adopted e.g. left/right, sitting position, midpoint, maximum prominence, vertical height or contour etc. to add clarity to the measurement definitions.

2.3 Survey parameters

The survey design and execution included: (a) Demographic information from the participants; (b) Equipment required to take the measurements; (c) Postures in which the participants were scanned (in

the 3D scanner); (d) Manual measurements taken from the participants; (e) Measurements to be extracted from the scan data; and (f) Landmarks needed in the measurement process (scan or manual). The parameters described in (a) – (f) were subsequently used to define the measurement process both physically (manual measurements taken directly from the participant) and virtually (by automatically extracting located landmarks or by manually picking landmarks from the 3D scans) [11].

2.5 Demographic information

Demographic data was collected from participants as part of the consenting process for participating in the anthropometric survey and in accordance with the requirements of the MOD Research Ethics Committee (MODREC) stipulations. The demographic data collected comprised of: Participant Number, First Name, Middle Name, Surname, Service Number, Service, Rank, Officer (Yes/No), Date of Birth, Sex (Now), Sex (At Birth), Ethnicity, Nationality, Role, Pilot (Yes/No), Aircrew (Yes/No), Submariner (Yes/No), Association, Length of Service, Handedness and any Physical impairments were recorded [11]. All data produced by the Survey after the initial collection were anonymised with the Participant Number being the only reference used to identify an individual. Anthropometry databases created by MOD will not contain the names and dates of birth of individuals.

2.6 Equipment Used

2.6.1 3D Whole body scanners

Two new state-of-the-art VITRONIC VITUS Bodyscan 3D Scanners [11] were procured for this survey, used to capture the individual measurements and used in tandem with Anthroscan software to deduce measurements [11]. The VITRONIC VITUS Bodyscan 3D Scanners comprise of an aluminium box section structure onto which are mounted four sensor sleds. The sensor sleds are made up of two cameras and use optical triangulation with an eye-safe infrared laser light. These sleds are on a motorised carriage that move them in a vertical motion from top to bottom to capture imagery of the participant. The scanner specifications are shown in Table 1. Data is transferred from the scanning head to a control Personal Computer (PC) via a Wi-Fi Router [11].

Measurement principle	Optical double triangulation
Number of sensor sleds	4
Interface	USB port and LAN
Measurement accuracy	Average max. circumference errors significantly < 1 mm
Scan time	approx. 6 to 10s
Point density	~300 points / cm ²

Table 1 Specifications for the VITRONIC VITUS Bodyscan 3D (Whole Body Scanner)

2.6.2 Traditional measurement tools

‘Traditional’ measurement tools were also used, such as tape (used to take circumferences or lengths along the body surface), small callipers (used to take measurements from point to point, e.g. the head and hand length), a stadiometer (used to measure heights from the ground), a measuring rod (used for measuring fingertip to fingertip span), a pupilometer (used for measuring interpupillary distance), scales (Withings Bodyscale) (used for measuring the weight of the participants, can also be used as a BMI/Body fat device) and a foot box (used for measuring foot length and breadth). Suitably qualified personnel took all measurements and the data entered directly into a PC [11].

2.6.3 Anthroscan software

The Anthroscan software provided with the VITRONIC VITUS Bodyscan system has the functionality to automatically extract (‘auto extraction’) a number of measurements. These measurements are calculated from scans in a standardised pose by mathematically identifying a series of landmarks, which are then combined to extract the measurements. Anthroscan can also be programmed to assist the operator in identifying landmarks on screen by automatically selecting the correct scan posture, zooming into the approximate area of the body where the landmark is to be placed and providing tools for modifying or editing landmark position. Following landmarking, measurements can be defined as point to point (3D line distance), height/length, breadth and depths (single axis measurements), contours across the body surface or circumferences (virtual tape measures) [11].

2.7 Pilot Studies

Two Pilot Studies were conducted to ensure that the scanners and the associated software could capture 3D data from participants and extract the required measurements accurately, consistently and with sufficient fidelity. The Pilot Studies also sought to assess and optimise all aspects of the measurement protocol, including the accuracy and reliability of manual measurements – both within and between those taking the measurements [5][11].

2.8 Main Survey

The main survey was conducted between October 2023 and May 2024 across 15 different Army, Navy and Royal Air Force bases [12] [13]. The 2006–07 survey measured 92 dimensions from 2470 personnel [6], and all of these dimensions were included in the new survey. Fifty-four new measurements were specifically added to support the development of new body armour. Twelve extra measurements were included to support 3D modelling systems e.g. Knee-ankle length and a further seven ‘new’ useful measurements were added that had not been captured previously e.g. Buttock-heel length, Sitting.

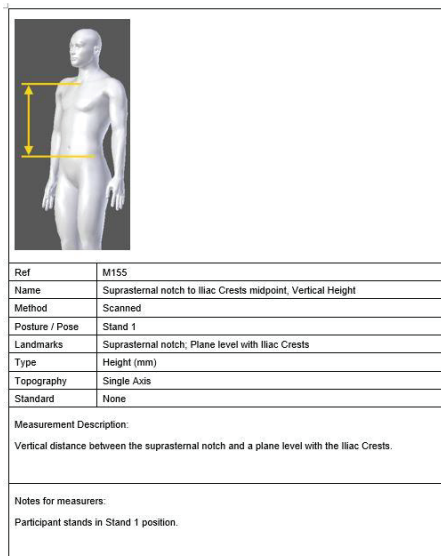


Figure 2 Measurement definition for ‘Suprasternal notch to Iliac Crests midpoint, Vertical Height’ [11]



Figure 3 VITRONIC VITUS Bodyscan system [5]

3. RESULTS

3.1 Survey headlines

3.1.1 Numbers and demographics

One thousand, eight hundred and eighty-six (1,886) Armed Forces personnel, including 32 different nationalities, were measured from across 15 Army, Royal Navy (RN) and Royal Air Force (RAF) bases over a period of 20 weeks. This included 1,510 male (M) and 376 female (F) participants: 793 Army ((141 F, 652 M), 587 Army Male [excluding Nepalese], 65 Army Nepalese), 627 RAF (147 F, 480 M), 329 RN (77 F, 252 M), 137 Royal Marines (RM) (11 F [band members], 126M) [12]. One hundred and ninety-four measurements were captured per person [12] [13]. The survey includes 20% female representation across all services, a 21% increase in females measured over the last UK anthropometric survey conducted in 2006/07 [6].

3.1.2 Measurement methods

For the total 194 measurements per person; two ‘standing’ scans captured 115 measurements, three ‘sitting’ scans captured 53 measurements, 23 manual measurements were taken and three measurements

were derived by calculations (e.g. Sitting/Standing ratio). The Anthroscan software was used to create each of the scanned measurements. Twenty-two of the Anthroscan automated measurements [13] were used and another 146 measurements were coded within the software (e.g. applying functions for Virtual Height calculations and Virtual tape measures used for contours).

3.2 New measurements captured for optimising body armour

Fifty-four (54) new measurements were captured specifically for optimising coverage, size and inclusivity of body armour [12]. The full list is provided in Table 2.

#	ID	Measurement Type
1	M022	Axilla height, anterior, Sitting
2	M023	Axilla height, posterior, Left
3	M024	Axilla height, posterior, Sitting, Left
4	M042	Cervicale (C7) height, Sitting
5	M045	Cervicale (C7) to Iliac crests midpoint, Contour
6	M046	Cervicale (C7) to Iliac crests midpoint, Vertical Height
7	M047	Cervicale (C7) to Iliac crests midpoint, Sitting, Contour
8	M048	Cervicale (C7) to Iliac crests midpoint, Sitting, Vertical Height
9	M049	Cervicale (C7) to posterior Axillae midpoint, Contour
10	M050	Cervicale (C7) to posterior Axillae midpoint, Vertical Height
11	M051	Cervicale (C7) to posterior Axillae midpoint, Sitting, Contour
12	M052	Cervicale (C7) to posterior Axillae midpoint, Sitting, Vertical Height
13	M053	Cervicale (C7) to level with top of Thigh, Sitting, Left, Contour
14	M054	Cervicale (C7) to level with top of Thigh, Sitting, Left, Vertical Height
15	M055	Cervicale (C7) to level with Umbilicus, Top, Contour
16	M056	Cervicale (C7) to level with Umbilicus, Top, Vertical Height
17	M057	Cervicale (C7) to level with Umbilicus, Top, Sitting, Contour
18	M058	Cervicale (C7) to level with Umbilicus, Top, Sitting, Vertical Height
19	M059	Cervicale (C7) to Tenth ribs midpoint, Anterior, Contour
20	M060	Cervicale (C7) to Tenth ribs midpoint, Anterior, Vertical Height
21	M061	Cervicale (C7) to Tenth ribs midpoint, Anterior, Sitting, Contour
22	M062	Cervicale (C7) to Tenth ribs midpoint, Anterior, Sitting, Vertical Height
23	M194	Chest breadth
24	M105	Iliac crest height, Left
25	M106	Iliac crest height, Sitting, Left
26	M107	Iliac crests midpoint to Umbilicus, Top, Contour
27	M108	Iliac crests midpoint to Umbilicus, Top, Vertical Height
28	M109	Iliac crests midpoint to Umbilicus, Top, Sitting, Contour
29	M110	Iliac crests midpoint to Umbilicus, Top, Sitting, Vertical Height
30	M150	Suprasternal notch height
31	M151	Suprasternal notch height, Sitting
32	M152	Suprasternal notch to Breast point, Left, Contour
33	M153	Suprasternal notch to Breast point, Left, Vertical Height
34	M154	Suprasternal notch to Breast point, Sitting, Left, Vertical Height
35	M155	Suprasternal notch to Iliac crests midpoint, Vertical Height
36	M156	Suprasternal notch to Iliac crests midpoint, Sitting, Contour
37	M157	Suprasternal notch to Iliac crests midpoint, Sitting, Vertical Height
38	M158	Suprasternal notch to level with anterior Axillae midpoint, Contour
39	M159	Suprasternal notch to level with anterior Axillae midpoint, Vertical Height
40	M160	Suprasternal notch to level with anterior Axillae midpoint, Sitting, Contour
41	M161	Suprasternal notch to level with anterior Axillae midpoint, Sitting, Vertical Height
42	M162	Suprasternal notch to level with Tenth ribs midpoint, Contour
43	M163	Suprasternal notch to level with Tenth ribs midpoint, Vertical Height
44	M164	Suprasternal notch to level with Tenth ribs midpoint, Sitting, Contour
45	M165	Suprasternal notch to level with Tenth ribs midpoint, Sitting, Vertical Height
46	M166	Suprasternal notch to level with top of Thigh, Sitting, Left, Contour
47	M167	Suprasternal notch to level with top of Thigh, Sitting, Left, Vertical Height
48	M168	Suprasternal notch to Top of Umbilicus, Contour

49	M169	Suprasternal notch to Top of Umbilicus, Sitting, Contour
50	M170	Suprasternal notch to Top of Umbilicus, Sitting, Vertical Height
51	M171	Suprasternal notch to Top of Umbilicus, Vertical Height
52	M172	Tenth rib height, Left
53	M173	Tenth rib height, Sitting, Left
54	M179	Thigh height, Sitting, Left

Table 2 The Fifty-four (54) new measurements captured specifically for optimising coverage, size and inclusivity of body armour, from [12]

3.3 Initial comparison of some new measurements

Three of the fifty-four (54) new measurements captured specifically for optimising coverage, size and inclusivity of body armour are included in Table 3. This compares the measurements for ‘Chest Breadth’, ‘Suprasternal notch to tenth rib’ and ‘Suprasternal notch to iliac crest’ for the 1st, 5th, 25th, 50th, 95th and 99th percentiles for All (all Female and all Male combined), All Female, All Male, Army Female, Army Male, RAF Female, RAF Male, Royal Navy Female and Royal Navy Male.

Measurement & ID (see Table 2)	%ile	All mm	All Female (F) mm	All Male (M) mm	Army (F) mm	Army (M) mm	RAF (F) mm	RAF (M) mm	RN (F) mm	RN (M) mm
<i>Sample size (n)</i>		<i>n=1880</i>	<i>n=375</i>	<i>n=1505</i>	<i>n=141</i>	<i>n=649</i>	<i>n=147</i>	<i>n=478</i>	<i>n=76</i>	<i>n=252</i>
Chest Breadth (M194)	1 st	270	261	280	258	273	267	285	267	290
	5 th	288	272	296	272	293	278	297	274	298
	50 th	338	309	344	306	341	313	347	306	339
	95 th	394	362	396	350	394	366	397	362	407
	99 th	413	387	405	381	410	372	421	398	427
<i>Sample size (n)</i>		<i>n=1876</i>	<i>n=375</i>	<i>n=1501</i>	<i>n=141</i>	<i>n=646</i>	<i>n=147</i>	<i>n=479</i>	<i>n=76</i>	<i>n=250</i>
SSN to 10th rib (M163)	1 st	251	247	255	246	253	255	255	249	261
	5 th	267	258	271	254	270	262	273	260	278
	50 th	305	289	310	289	310	288	308	292	310
	95 th	346	323	350	325	352	322	345	316	348
	99 th	364	336	356	335	366	335	365	329	364
<i>Sample size (n)</i>		<i>n=1878</i>	<i>n=375</i>	<i>n=1503</i>	<i>n=141</i>	<i>n=649</i>	<i>n=147</i>	<i>n=478</i>	<i>n=76</i>	<i>n=250</i>
SSN to IC (M155)	1 st	319	306	336	309	340	321	333	292	340
	5 th	339	324	353	321	354	329	354	314	352
	50 th	390	362	396	362	399	363	397	362	395
	95 th	444	409	448	404	450	410	447	406	449
	99 th	473	424	474	423	475	423	462	426	490

Table 3 Key measurements for torso body armour, ‘Chest Breadth’, ‘Suprasternal notch (SSN) to 10th rib’, ‘SSN to Iliac crest (IC)’ comparing between (some of the) datasets. ‘n’ = numbers measured [12]

4. DISCUSSION

4.1 Opportunities for data analysis

There is a vast amount of analysis possible from this updated dataset; from the comparison with the previous UK survey dataset to gain an understanding of the secular change and improvements in the accuracy of data collection methods, to the specific data comparisons between male and female data, between ethnicities, between services and between internationally available datasets. Furthermore, there are 54 new measures specifically for the optimisation of body armour that require in-depth analysis to determine the optimum coverage, fit and number of sizes of hard ballistic plates, soft body armour vests, arm protection, neck protection and pelvic protection for both men and women in the UK Armed Forces population. It has been impossible therefore, to present all these data permutations within this one paper. It is also important to highlight that as well as the opportunity to analyse the data tables, it is also possible to further interrogate the 3D scans themselves to obtain even more specific data, should there be a particular measurement required now or in the future. For example, at an MOD/QinetiQ Working Group,

(held in August 2024, and subsequent to the completion of the main survey), two new measurements were added to the dataset: M195 – Axilla to Iliac Crest and M196 – Chest Depth (sternum to vertebrae). The measurement dataset should, therefore, be seen as dynamic, and updated as and when an anthropometric need arises.

This new data can be exploited into new equipment programmes; accurate internal data can be used to underpin realistic virtual battlefield simulation and surgical training; and could inform personalised, individual survivability modelling and simulation. Other applications include aircrew cockpit sizing, vehicle crew compartments and blast survivability modelling. The full range of exploitation pathways for anthropometric data has yet to be discovered [9].

4.1 Overall differences between this survey and last survey

Some statistically significant differences were identified between data gathered during the 2023/2024 study [12] [13] and the previous 2006/2007 tri-service anthropometric survey [6]. These differences can be attributed to a number of factors including secular change, changes in data collection methods, the removal of deduced measures and improvements in the accuracy of three-dimensional scanners [14]. A summary of the key differences identified between the surveys is provided in [14] but include Hip Breadth, Waist Circumference, Chest Depth, Thigh Clearance Height and Buttock-Popliteal length. It is not possible to compare data of new measurements (the 54 measures specifically for body armour) as the data was simply not gathered in the previous 2006/2007 anthropometric survey [6].

4.2 (Some) new measurements captured specifically for optimising coverage, size and inclusivity of body armour

One size does not fit all when it comes to body armour plates and this new anthropometric data further reinforces that a range of plate sizes would better fit the UK Armed Forces population compared to a single sized front and rear plate [2][3][4]. Whilst it is not possible to compare data of the 54 measures specifically for body armour with the previous 2006/2007 anthropometric survey [6], it is possible to make a simple comparison with previously published male [2] and female Computed Tomography (CT) scan data [4] for two key measurements: Suprasternal notch to 10th rib ('Threshold coverage') and suprasternal notch to iliac crest ('Objective coverage'). Table 4, for example, shows the 50th percentile data for these studies. For reference, the length of the existing front UK hard ballistic plate is 334mm; which is longer than the Suprasternal notch to 10th rib measurements ('Threshold coverage'), for over half of today's Armed Forces population.

Measurement	Percentile	All F [12] <i>n</i> =375 (mm)	All M [12] <i>n</i> =1501-1503 (mm)	CT (F) [4] <i>n</i> =45 (mm)	CT (M) [2] <i>n</i> =120 (mm)
SSN to 10 th rib	50 th	289	310	290	300
SSN to IC	50 th	362	396	355	371

Table 4 50th percentile data for 'SSN to 10th rib' and 'SSN to IC' for 'All females' and 'All males' [12] compared with CT scan data of UK Armed Forces females [4] and males [2]

Whilst the CT data in Table 4 were captured with the subjects supine (lying down), this is not thought to affect the measurements of the (bone) anthropometric landmarks, but may affect internal organ positions and boundaries [1] [15]. Further work is underway as part of the initial MOD requirement that is collecting internal organ anthropometric data from (standing and supine) MRI scans of UK Armed Forces personnel.

Table 3 in the 'Results' section shows the comparison between 'Chest Breadth' percentile data. This measure was initially not included in the list of measurements (although 'Chest Breadth (maximum prominence), Contour' was included) but was later added as a key measure for optimising body armour and provides a useful comparator to other published work [15].

4.3 New Standardised Measurement Set

Significant effort went into creating the master list of individual measurements [11]; taking great care to standardise the descriptions of each measurement into a template (Figure 2). It was important to create this 'master list' to enable consistency of measurement and nomenclature and to clearly differentiate

between other (similar-sounding) measures. This is a key milestone in the development of national and international standards of measurement descriptions for future anthropometric surveys.

4.4 Transition Plan

MOD's intention is to transition the capability to measure anthropometry to the three services – Army, RN and RAF. QinetiQ delivered a Transition Plan [13] with nineteen key associated documents addressing not only the hardware and software required by the three Services but also identifying the establishments to locate the equipment to best support further anthropometric studies. The training required by those responsible for the equipment is outlined as well as the protocols (e.g. to measure personnel and manage their data) to follow to ensure that data are recorded in a consistent manner by each Service; ensuring reliability and validity of data measurements and management. An enduring capability is being implemented based on this Transition Plan, with the 3D scanners procured for this survey already transferred to SoldierWorks for the Army and The Institute of Naval Medicine (INM) for the Royal Navy; complementing the 3D scanner in the Royal Air Force, based at the Centre of Aviation Medicine (RAFCAM). It is anticipated that this will result in the measuring of Armed Forces personnel becoming 'business as usual', dynamic, responsive and populating a 'living anthropometric database'.

5. CONCLUSIONS

This is the first Tri-Service anthropometric survey of the UK Armed Forces to be conducted in the UK in 18 years. One hundred and ninety-four measurements were captured per person from 1,510 males and 376 females and from 32 nationalities. The data are applicable across Defence and include 54 new measurements specifically for body armour optimisation, 12 extra measurements required for 3D modelling packages and a further 7 measurements deemed useful that were not captured in previous anthropometric surveys.

The 3D body scanners procured for this survey have already transitioned to their permanent locations, to meet the MOD's aspiration for measuring Armed Forces personnel as part of 'business as usual' and populating a 'living database'.

The HFI Technical Guide for Anthropometry, TG1.1 V6 [14] has been updated by MOD to include some of the new data and is freely available to all via the MOD's Defence Gateway portal.

At the time of writing, a database solution containing all the new data is still in development by MOD. In the future, it is anticipated that this new anthropometric database tool will be made available through the MOD's Defence Gateway portal.

6. RECOMMENDATIONS

All future UK military equipment should be developed using this up-to-date, representative and relevant anthropometric data, thereby ensuring that Defence is diverse, inclusive and consistent in its approach to equipment acquisition, whilst at the same time maximising the likelihood that defence equipment is safe, comfortable and usable under extreme operational conditions and in the most severe environments.

Logistics and resources did not allow the scope of this project to include Reservists. It is recommended that with the transition of the 3D scanners to military establishments, this will provide the opportunity to measure this population.

It is recommended that other nations and User groups (such as Police and Security) adopt the additional 54 measurements to optimise their body armour systems.

It is recommended that the measurement definitions, postures and measurement protocols created for this anthropometry survey are adopted internationally and in new standards e.g. ISOs and NATO standards.

It is recommended that this new anthropometry data is shared freely and widely by MOD to maximise exploitation opportunities.

There is an opportunity to further exploit the current dataset; this should be seen as dynamic and updated as and when an anthropometric need arises. For other specific defence research, applications and equipment, several measurements could be further analysed/deduced from the captured 3D scans to optimise equipment design and workplace integration. Furthermore, the 3D scanning capability provides the ability to measure all types of User-borne equipment ensembles in situ for future research and trials.

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