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Current Position of Equipped Anthropometric Data Research for the Australian Warfighter and Future Areas of Work – April 2017

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Defence Science and Technology Group

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ABSTRACT

Traditional anthropometric data are typically gathered from semi-nude subjects; therefore it is important, when required, to apply a correction factor to include additional size which would be introduced by the clothing or equipment worn by the subject. The Defence Science and Technology (DST) Group identified the need to supplement anthropometric data from the Australian Warfighter Anthropometric Survey (AWAS) with Personal Equipment and Clothing Correction Factors (PECCFs) to ensure a more realistic representation of the equipped soldier. A program of work has been conducted by DST Group to develop PECCFs as well as the methodology used to collect PECCFs. The intention of this document is to provide a summary of the work that has been conducted to-date and identify future areas of work/collaboration in equipped anthropometry.

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Executive Summary

Traditional anthropometric data are typically gathered from semi-nude subjects; therefore it is important, when required, to apply a correction factor to include additional size which would be introduced by the clothing or equipment worn by the subject. Defence Science and Technology (DST) Group identified the need to supplement anthropometric data from the Australian Warfighter Anthropometric Survey (AWAS) with Personal Equipment and Clothing Correction Factors (PECCFs) to ensure a more realistic representation of the equipped soldier. A program of work has been conducted by DST Group to develop PECCFs as well as the methodology used to collect PECCFs. The intention of this document is to provide a summary of the work that has been conducted to-date and identify future areas of work/collaboration in equipped anthropometry.

The work conducted comprised:

1. A meta-analysis of current clothing and equipment factor data and its relevance to the Australian Defence Force (ADF) was conducted by Land Division (LD) in 2011.
2. A pilot study was conducted by DST Group in 2012 with three aims:
    a. to derive PECCFs for immediate application to AWAS data
    b. to assess the feasibility of using 3D scanning technology to derive PECCFs
    c. to develop a robust methodology for use in future surveys.

    The PECCFs calculated from the pilot study were incorporated into the Preliminary Anthropometric Standard for Australian Army Equipment Evaluation and used to develop Digital Human Models.
3. To further the work on developing the equipped anthropometric survey methodology and derive additional PECCFs, a work package was set up with the School of Health Sciences at the University of South Australia (SA). The aims of this work were to:
    a. Recommend modifications to anthropometric measurement equipment to improve the ease and accuracy of using the equipment on equipped anthropometric measures.
    b. Develop the equipped anthropometric survey methodology based on lessons learnt from the pilot study, the modified anthropometric measurement equipment and an improved measurement collection spreadsheet.

c. Conduct a confirmation survey to test the developed methodology and gather additional, and modified, measures which were not captured in the pilot study as well as an additional Soldier Combat Ensemble (SCE) condition where a belt rig is worn.

d. Write a protocol for obtaining all defined equipped measures and subsequent PECCFs.

DST Group currently has a set of PECCFs included in the Preliminary Anthropometric Standard for Australian Army Equipment Evaluation and additional PECCFs derived through the University of SA equipped anthropometric survey should be incorporated into the next iteration of the anthropometric Technical Report/DEF(AUST). Based on the outcomes from the DST Group pilot study and the University of SA there are future areas of research surrounding sample size, modification to depth measurements, clothing thickness, T-Pose scans, constant tension girth tape, postural assessment, inter-tester TEM, DHM evaluation, and 3D scanner for compression measures.

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Sheena's expertise is in Ergonomics; she completed a Masters of Science in Human Factors (Distinction) from the University of Nottingham, UK (2008) and a four year Bachelor of Science (Hons) Degree in Psychology and Ergonomics at Loughborough University, UK (2005). As part of this degree, Sheena achieved a diploma in professional studies by completing a 1 year placement as a Human Factors Consultant at Air Affairs (UK) Ltd. Following her studies, Sheena worked for Rolls-Royce, Submarines, as a Human Factors Engineer providing support to a variety of projects for the Naval Nuclear Propulsion Program (NNPP) including extant and future class nuclear submarines. Sheena then worked as a Human Factors Consultant for Greenstreet Berman Ltd where she was required to conduct technical ergonomics work and business development activities. In January 2011, Sheena migrated to Australia to join the Land Division. Primarily her role involves providing Ergonomic expertise to the Australian Defence Force in the assessment and procurement of new equipment including back packs, helmets and combat hearing protection.

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Glossary

ADF	Australian Defence Force
AWAS	Australian Warfigher Anthropometry Survey
CV	Coefficient of Variation
CWC	Cold Weather Clothing
DCC	Dismounted Close Combatant
DHM	Digital Human Manikin/Modelling
DST Group	Defence Science and Technology Group
LD	Land Division
NVGs	Night Vision Goggles
PECCF	Personal Equipment and Clothing Correction Factor(s)
SA	South Australia
SCE	Soldier Combat Ensemble
TBAS	Tiered Body Armour System
TEM	Technical Error of Measurement

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1. Introduction

1.1 Equipped Anthropometry

Traditional anthropometric data are typically gathered from semi-nude subjects; therefore it is important, when required, to apply a correction factor to include additional size which would be introduced by the clothing or equipment worn by the subject. For example, when determining the width of a seat in an armoured vehicle it is important to use the relevant anthropometric measurements, such as hip breadth, from the intended user population. To ensure satisfactory human integration with the system, it is important to identify the personal equipment and clothing that the intended user population will wear whilst seated in the vehicle. The 'thickness' of the equipment and clothing can then be added to the anthropometric measurement(s), in this case the hip breadth, to give a total equipped anthropometric measurement which can then be used in the design of the seat.

Such correction factors, known as Personal Equipment and Clothing Correction Factors (PECCF) do not just apply to items of clothing, but to items including ballistic and fragmentation protection, load carriage rigs, hydration packs and ammunition belts. Relying solely on anthropometric data in a military environment where the user population is required to wear significant amounts of equipment results in vehicles, airframes and equipment which are not fit for purpose.

1.2 DST Group Research

The Defence Science and Technology (DST) Group identified the need to supplement anthropometric data from the Australian Warfighter Anthropometric Survey (AWAS) with PECCFs to ensure a more realistic representation of the equipped soldier. A program of work has been conducted by DST Group to develop PECCFs as well as the methodology used to collect PECCFs. The intention of this document is to provide a summary of the work that has been conducted to-date and identify future areas of work/collaboration in equipped anthropometry.

2. Background

2.1 Meta-Analysis

A meta-analysis of current clothing and equipment factor data (Ref 1 - 9) and its relevance to the Australian Defence Force (ADF) was conducted by Land Division (LD) in 2011 (then the Human Performance and Protection Division). The meta-analysis identified that all datasets had one or more shortcomings related to sample size and inclusion of females in the sample, configuration and applicability to the ADF, and/or measurement method and validity. Based on the shortcomings identified from the data-sets, the conclusion of the

meta-analysis was that there were no datasets applicable to the ADF and that methods used and lessons learned from the previous studies should be considered to develop an ADF specific equipped anthropometric pilot study.

3. Pilot Study

3.1 Aims

A pilot study was conducted by DST Group in 2012 (Ref 10) with three aims:

1. To derive PECCFs for immediate application to AWAS data.
2. To assess the feasibility of using 3D scanning technology to derive PECCFs.
3. To develop a robust methodology for use in future surveys.

3.2 Method

The AWAS dataset comprises 83 measurements but, as equipped anthropometric data are required to determine occupant packaging or space claims, not all measures are required. Only those measures identified as being required in digital human modelling (DHM) environments, occupant packaging (fit and clearance), workstation and pedal operation and access in gloves were considered in the pilot study. Five male and five female participants were measured in the pilot study with data collected on four configurations: Dismounted Close Combatant (DCC), vehicle crewman, DCC in cold weather clothing (CWC) and vehicle crewman in CWC.

Manual and 3D scanned data were captured and, in addition to deriving the PECCFs, analysis of the data to identify intra-tester Technical Error Measurement (TEM), calculate required sample size for future equipped surveys, identify percentage Increase from semi-nude to equipped condition and explore re-dress variation was conducted. The additional analysis helped to provide confidence in the methodology used and identify areas for further consideration.

3.3 Results and Recommendations

The PECCFs calculated from the pilot study were incorporated into the Preliminary Anthropometric Standard for Australian Army Equipment Evaluation (Ref 11), which is being developed into a DEF(AUST), and used to develop Digital Human Models (Ref 12). Data from the survey, such as measures with higher TEM values as well as methodological issues identified during the conduct of the pilot study, were reviewed to identify recommendations for future methodological research and for future equipped anthropometric surveys. These recommendations are listed below.

3.3.1 Methodological Recommendations for Future Equipped Anthropometric Surveys

Data Recording

Recommendation 1a: For future surveys the Excel spreadsheet used to collect the measurements should be iterated to make the spreadsheet useful for collection of equipped measures. This would include, but is not limited to, the immediate calculation of the relevant PECCF (equipped measure minus semi-nude measure), identifying if the difference between the first and second PECCF is acceptable or if a third measure is required and a sanity check to determine if the PECCF is realistic. The development of the spreadsheet will require the identification of acceptable percentages of difference between the first and second measures. This will allow for real-time exploration of any outliers and, hopefully, reduce the level of variance seen in the results of the pilot survey.

SCE Size Allocation

Recommendation 1b: Future surveys should ensure that all possible sizes of equipment and clothing are available and that allocation of the items to subject is based on the manufacturers' sizing guides and adequate fitting.

Reliability Testing

Recommendation 1c: It is recommended that, when future surveys are conducted, a greater number of participants are measured and analysis, such as Bland-Altman Analysis is conducted to allow for more in-depth analysis of the results. Bland-Altman Analysis, and other similar analyses, could not be reliably conducted on the data with only ten participants.

Additional Measures

Recommendation 1d: The analysis conducted has identified that there are a number of measures, which were not taken as part of this survey, which would be beneficial to take in future surveys. These measures are:

- Waist Breadth to determine the widest breadth on the torso
- Heel Height to determine the offset for how high the heel is from the floor
- Forefoot Height to determine the offset for how high the forefoot is from the pedal
- Helmet with NVG and counterweights to determine the offset around either side of the head when NVGs are worn.

Modification to Measures

Recommendation 1e: There are a number of measures which require modification in future surveys. Prior to use in future surveys, the modifications should be piloted to ensure that they are producing accurate and reliable results. These are:

- **Chest Depth** requires total, front and rear PECCF for DHM evaluation;
- **Abdominal Extension Depth, Sitting** requires total, front and rear PECCF for DHM evaluation;

- **Sitting Height** requires normal Sitting Height plus Sitting Height without helmet for DHM evaluation;
- **Buttock-Knee Length** requires normal Buttock-Knee Length plus clothed Buttock-Semi-Nude Knee for DHM evaluation;
- **Acromion Height, Sitting** requires normal Acromion Height, Sitting plus Acromion Height with only clothed lower body and semi-nude acromion landmarks for DHM evaluation; and
- **Ankle Height** requires a more effective landmark sticker for identification in 3D scans.

Measuring Equipment Modification

Recommendation 1f: The measuring equipment used to measure Stature, seated statures and breadths, such as Forearm-Forearm Breadth, required modification to improve the ease of taking those measures. To improve the accuracy of measuring Stature, it is recommended that a more secure, sturdy stadiometer is used and consideration given to moving the base of the stadiometer forward to allow the participant to stand straight (the increase in lateral, posterior bulk on the back of the participant caused by the wearing of body armour does not allow the participant to stand straight). To improve the accuracy of measuring seated height it is recommended that an anthropometric box with a larger surface area and an anthropometer with longer measuring arms be developed. Consideration should also be given to modifying the measuring equipment to help increase the accuracy of Acromion Height (standing and seated) for example, weighting the anthropometer to apply a consistent level of pressure to compress the clothing may be a solution.

3.3.2 Recommendations for Future Areas of Work Relating to Equipped Anthropometry

Postural Change

Recommendation 2a: Due to the load which participants are required to wear during some of the equipped conditions and the requirement to maintain a specific posture it was identified that they may be subject to postural fatigue and unintentionally alter their posture during measuring. This would lead to differences in the data. Although some anomalies in the data could be due to postural change, the results were not conclusive and so it is recommended that separate work be conducted, possibly including motion capture, to identify if postural fatigue impacts on equipped anthropometric data collection.

TEM

Recommendation 2b: It is recommended that equipped anthropmetric data be collected using multiple measurers and intra-measurer TEM is calculated and analysed to assess the reliability of such measures when using multiple measurers.

Compare Scans to Manual Measures

Recommendation 2c: One of the factors which impacted on the decision as to whether to take a measure manually or in the 3D scanner was whether compression was required. Wherever compression was required, the measure was taken manually. As taking

measures from 3D scans reduces the amount of time a participant is required to wear the ensembles and observe specific postures it is beneficial to take as many measures as possible. It is, therefore, recommended that analysis be conducted to extract all those measures taken manually from the 3D scans and compare them. Should the results prove favourable then it may be possible to take more measures via the 3D scanner in future surveys.

Range of Motion

Recommendation 2d: Range of motion data is important and should be collected in a separate study as there are additional considerations and measurement methods to consider which could not be addressed in the pilot survey.

Additional SCE Conditions

Recommendation 2e: Due to the nature of a pilot survey it was not possible to test all SCE. Indeed, it will never be possible to test all SCE variations but work should be conducted to gather more data sets on other SCE which are likely to impact on occupant packaging. A key condition would be to test a DCC in a belt rig (i.e. Tier 0 Heavy, Belt). As the focus of operations is moving from being Afghanistan focused to near region (i.e. the jungle), the type of Load Carriage Equipment (LCE) and body armour is likely to change to more hip borne rather than shoulder/torso borne. Hip belts will have a large impact on occupant packaging and so should be subject to an equipped anthropometric survey. Other SCE requirements should be considered and may include, although are not limited to:

- Gunners
- Chemical and Biological (CB) Suits
- Medics
- Signallers.

Sample Size

Recommendation 2f: A survey should be conducted with a much larger participant group and comparison between the results from the large group with the pilot survey data should be conducted to identify if there is a significant difference. This will help to determine what the required sample size is for future surveys.

4. University of South Australia Work Package

4.1 Aims

To further work on developing the equipped anthropometric survey methodology and derive additional PECCFs as recommended in Ref 10, a work package was set up with the School of Health Sciences at the University of South Australia (SA). The aims of this work were to:

1. Recommend modifications to anthropometric measurement equipment to improve the ease and accuracy of using the equipment on equipped anthropometric measures.
2. Develop the equipped anthropometric survey methodology based on lessons learnt from the pilot study, the modified anthropometric measurement equipment and an improved measurement collection spreadsheet.
3. Conduct a confirmation survey to test the developed methodology and gather additional, and modified, measures which were not captured in the pilot study as well as an additional SCE condition where a belt rig is worn.
4. Write a protocol for obtaining all defined equipped measures and subsequent PECCFs.

4.2 Deliverables

The work was completed in 2014 and provided the following deliverables:

a. recommendations for modified anthropometric measuring equipment (which were used in the confirmation survey)
b. equipped anthropometry measurement data collection worksheet
c. equipped Anthropometric Landmarking and Measurement Manual (Ref 13 and Appendix A)
d. report detailing each stage of the work package, findings, PECCFs and recommendations for future work (Appendix B).

4.3 Key Findings and Outcomes

4.3.1 PECCFs

The University of SA confirmation study considered three conditions;

1. DCC with belt rig only
2. DCC with Tiered Body Armour System (TBAS) Tier 2 vest (cleanskin) & belt rig

3. DCC with belt rig only and CWC. Equipped measures of the belt rig were key as this condition was not assessed in the DST Group pilot study. Eight males and four females participated in the survey.

Twenty six additional measures and segmented measures, required for DHM evaluation, were derived from the University of SA confirmation study resulting in a total of 57 PECCFs across three SCE conditions.

4.3.2 DHM Measures

Data was gathered in the DST Group pilot survey specifically for use in DHM modelling of vehicle environments. Application of these data into *Human Solutions –GmbH RAMSIS* software identified the need to modify some measures and obtain additional measured for future DHM modelling. The key modification was for measurements to be split into anterior and posterior measurements to enable the PECCFs to be applied to either the front of the vehicle occupant or the back of the occupant. For example, knowing the total correction factor for Chest Depth does not provide information on how much an occupants Chest Depth increases anteriorly, or posteriorly and estimating what percentage to apply to either the front or back could introduce error to an evaluation.
Head measurements with NVGs, Forefoot Height, Helmet Offset, and Knee Offset were all derived and the method recommended for use in future surveys, although a larger sample size is recommended.

Segmented measurements (obtaining anterior and posterior measures) were derived but caveated with limitations relating to a lack of compression, high variability attributed to inability to maintain posture and defining regions. A recommendation was made to consider alternative methodologies for obtaining segmented measures in future surveys.

Buttock Offset had a high variability and it was recommended that applying a standard PECCF based on the thickness of the clothing would be a more accurate measure.

4.3.3 Space Claim

Boundary circumferences were taken for the first time in the University of SA confirmation study. Boundary circumferences are taken by 3D scans to quantify the worst case ‘space claim’ of either the chest, abdominal or hip circumference as shown in Figure 1.

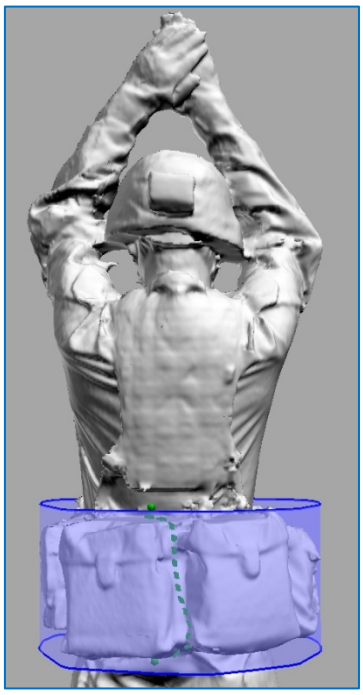

Figure 1: EM54 Hip Boundary Circumference, the maximum circumference within the hip region including the belt rig.

Four additional postures (seven in total) were used to obtain 'space claim' and depth measurements from 3D scan data. Five boundary measures were taken (Chest Boundary Circumference, Chest Boundary Circumference [Arms Raised], Abdominal Circumference, Abdominal Circumference [Arms Raised], and Hip Boundary Circumference.

It was recommended that boundary measures be included in future equipped anthropometric surveys.

4.3.4 Recommendations

4.3.4.1 Recommendations for Future Equipped Anthropometry Surveys

Modification to depth measurements

Recommendation 1a: This pilot survey trialled a number of depth measurements (EM39-49) in order to quantify what percentage of PECCFs should be allocated to the anterior and posterior aspects of the body. Although these worked reasonably well there were very high levels of variability. Alternative methodologies that could be trialled include:

1. If the belt rig is not being worn use the Trochanterion as a reference point as it is a more stable landmark than Acromion, Right.
2. Have all possible sizes of equipment and clothing available to ensure that limited sizing is not increasing variability.

Reach and range of motion assessment

Recommendation 1b: Neither of the two pilot surveys assessed measurements associated with reach. It is recommended that a future survey quantifies the anthropometric measurements associated with reach. It would be practical to assess the impact equipped conditions have on range of motion in the same survey. Range of motion is an important factor that should be considered in DHM evaluation.

4.3.4.2 Recommendations for Future Work/Collaboration

Clothing thickness

Recommendation 2a: Further testing should be completed to determine whether adding the thickness of clothing to semi-nude measurements is a valid method for PECCFs. This would be applicable to measurements where clothing alone is the main contributor to a change in the measurement between semi-nude and an equipped condition, for example, Acromion Height and Eye Height, Sitting. Changes in these measurements are relatively small and using clothing thickness would remove variables that impact on physically taking a measurement such as landmark identification, postural changes, measurement techniques and so forth.

T-Pose Scans

Recommendation 2b: Two boundary circumferences were assessed in posture *P06 Anthropometric Standing, Arms Raised*. It is recommended that further testing be completed to determine if having the arms in a T-pose (horizontal) increases the validity and reliability of the measurement.

Constant tension girth tape

Recommendation 2c: One difficulty with taking circumferences on an equipped participant is to apply a constant and repeatable tension to the girth tape across all participants (and with different ensembles). It is recommended that further testing be completed to determine if a constant tension tape can standardise the measurement process and reduce error.

Other future areas of work

There were a number of other recommendations that were made in the first survey report which are yet to be addressed. These include:

- Ensuring all possible sizes of clothing and equipment are made available
- Increasing the sample size to assess reliability
- Assessing inter-measurer TEM to assess the reliability of these measurements when using multiple measurers
- Determining whether the 3D scanner can be used for some measurements that require compression.

5. Current Position

5.1 Introduction

DST Group currently has a set of PECCFs included in the Preliminary Anthropometric Standard for Australian Army Equipment Evaluation (ref 11) and additional PECCFs derived through the University of SA equipped anthropometric survey should be incorporated into the next iteration of the anthropometric Technical Report/DEF(AUST) (**Action 1**).

Based on the outcomes from the DST Group pilot study and the University of SA there are areas required attention to determine 1) if the sample size of both studies was sufficient to have confidence in the derived PECCFs and 2) to develop the methodology for future surveys.

5.2 Recommendations for Future Work/Collaboration

Sample Size

Recommendation 1: Both the DST Group pilot study and the University of SA were conducted with a small sample size and both recommend that a survey be conducted with a much larger participant group. This would allow for analysis of data from a larger sample group and comparison between the results from the large group with the pilot survey data to identify if there is a significant difference. This will help to determine the minimum required sample size is for future surveys and determine confidence in the already derived PECCFs.

Modification to Depth Measurements

Recommendation 2: The University of SA survey trialled a number of depth measurements (EM39-49; see 0) in order to quantify what percentage of PECCFs should be allocated to the anterior and posterior aspects of the body. Although these worked reasonably well there were very high levels of variability. Alternative methodologies that could be trialled include:

1. If the belt rig is not being worn use the Trochanterion as a reference point as it is a more stable landmark than Acromion, Right.
2. Have all possible sizes of equipment and clothing available to ensure that limited sizing is not increasing variability.

Clothing Thickness

Recommendation 3: Further testing should be completed to determine whether adding the thickness of clothing to semi-nude measurements is a valid method for PECCF derivation. This would be applicable to measurements where clothing alone is the main contributor to a change in the measurement between semi-nude and an equipped condition, for example, Acromion Height and Eye Height, Sitting. Changes in these measurements are relatively small and using clothing thickness would remove variables

that impact on physically taking a measurement such as landmark identification, postural changes, measurement techniques and so forth.

T-Pose Scans

Recommendation 4: Two boundary circumferences were assessed in posture *P06 Anthropometric Standing, Arms Raised*. It is recommended that further testing be completed to determine if having the arms in a T-pose (horizontal) increases the validity and reliability of the measurement.

Constant Tension Girth Tape

Recommendation 5: One difficulty with taking circumferences on an equipped participant is to apply a constant and repeatable tension to the girth tape across all participants (and with different ensembles). It is recommended that further testing be completed to determine if a constant tension tape can standardise the measurement process and reduce error.

Postural Assessment

Recommendation 6: Due to the load which participants are required to wear during some of the equipped conditions and the requirement to maintain a specific posture it was identified that they may be subject to postural fatigue and unintentionally alter their posture during measuring. This would lead to differences in the data. Although some anomalies in the data could be due to postural change, the results were not conclusive and so it is recommended that separate work be conducted, possibly including motion capture, to identify if postural fatigue impacts on equipped anthropometric data collection.

Recommendation 7: The postures in which anthropometric data are obtained are specified to aid collection of measurements and are not representative of postures that users would obtain in a vehicle or dismounted environment. Consideration should be given to defining operational postures and how anthropometric/equipped anthropometric data can be obtained from these postures.

Inter-Tester TEM

Recommendation 8: The manual measurements in both the DST Group pilot study and the University of SA were taken by one researcher and so only intra-measurer TEM was able to be calculated and analysed. It is recommended that equipped anthropometric data be collected using multiple measurers and inter-measurer TEM is calculated and analysed to assess the reliability of such measures when using multiple measurers

DHM Evaluation

Recommendation 9: The University of SA specifically considered the development of modified PECCFs to aid DHM evaluation. An assessment of the utility of the new measures, any gaps and any requirements for additional/modified measures should be conducted to identify requirements for that can be assessed in future equipped anthropometric surveys.

3D Scanner for Compression Measures

Recommendation 10: An evaluation to determine whether the 3D scanner can be used for some measurements that require compression would be beneficial. 3D scans are currently

avoided when compression of clothing/equipment is required as compression can only be applied through manual measures. However, for some, or all, of the measures that appear to require compression can be taken with the 3D scanner then measurements time can be reduced.

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Appendix A Equipped Anthropometric Measurements Manual

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Appendix B University of South Australia Deliverable

Uni SA - Encumbered
Pilot Report - Nov 20

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Current Position of Equipped Anthropometric Data Research for the Australian Warfighter and Future Areas of Work – April 2017

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19. ABSTRACT Traditional anthropometric data are typically gathered from semi-nude subjects; therefore it is important, when required, to apply a correction factor to include additional size which would be introduced by the clothing or equipment worn by the subject. The Defence Science and Technology Group (DST Group) identified the need to supplement anthropometric data from the Australian Warfighter Anthropometric Survey (AWAS) with Personal Equipment and Clothing Correction Factors (PECCFs) to ensure a more realistic representation of the equipped soldier. A program of work has been conducted by DST Group to develop PECCFs as well as the methodology used to collect PECCFs. The intention of this document is to provide a summary of the work that has been conducted to-date and identify future areas of work/collaboration in equipped anthropometry.			