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CHARACTERIZING THE SIZE OF THE ENCUMBERED SOLDIER

by
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14. ABSTRACT

This report documents work done in 2012-13 to provide a database of Soldier body measurements that would characterize the space for a fully encumbered dismounted Soldier and a driver. The Tank and Automotive Research, Development and Engineering Command (TARDEC), as part of the Occupant Centric Platform (OCP) Technology Enabled Concept Demonstration (TECD), tasked the Natick Soldier Research, Development and Engineering Center (NSRDEC) to collect and analyze the data in response to increased interest in the body size and volume of Soldiers when outfitted in their clothing and individual equipment (CIE). This interest stems from observation of fully outfitted Soldiers who were unable to fit safely and/or comfortably into the vehicle compartments or workspaces used during their daily missions. A detailed list of 42 critical anthropometric body dimensions were measured on 30 Soldiers in four of the specific duty position configurations (Driver, Rifleman/ Radioman, Squad Automatic Weapon Gunner, and Combat Medic) represented in the current nine-man dismounted squad, as well as a Semi-Nude and a Baseline configuration. The data provide, for the first time, a clear window into the increased size of a Soldier when wearing current CIE by providing specific delta values that can be added to semi-nude anthropometric databases. In general, the results strongly indicate that Soldiers wearing various combat loads are significantly taller, broader front to back, wider, and heavier than when wearing only the duty uniform. It was concluded that 1) military vehicle platforms/workstations should be re-designed to sufficiently increase Soldier space and thereby improve Soldier performance, survivability and comfort while reducing overall risk and/or 2) Soldier CIE should be sufficiently reduced so current military platforms/workstations perform as they were originally designed.

15. SUBJECT TERMS

WEIGHT FLEXIBILITY COMBAT LOAD ANTHROPOMETRY INDIVIDUAL PROTECTION COMFORT ERGONOMICS MEASUREMENT COMBAT VEHICLES PROTECTIVE CLOTHING BODY SIZE HUMAN BODY WORK STATIONS PHYSICAL WORKSPACE BODY MEASUREMENTS EQUIPMENT SPACE(ROOM) RANGE OF MOTION WORKSPACE ANALYSIS SIZES(DIMENSIONS) HUMAN FACTORS ENGINEERING DESIGN CRITERIA PERFORMANCE(HUMAN) ARMY PERSONNEL CIE(CLOTHING AND INDIVIDUAL EQUIPMENT) DISMOUNTED SOLDIERS PROTECTIVE EQUIPMENT

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PREFACE

This report documents work done to compile a database of Soldier body measurements to characterize the space for encumbered Soldiers. Measurements were collected and analyzed from Soldiers outfitted in clothing and individual equipment (CIE) for four specific duty positions. The purpose of this effort was to more fully understand the space requirements for military vehicles and workspaces. This effort was performed by the Natick Soldier Research, Development and Engineering Center (NSRDEC) Anthropometry Team between January 2012 and September 2013 under program element number 633001, project number DJ50, and work unit number R.0003427.3.6. Funding was provided by the U.S. Army Tank and Automotive Research, Development and Engineering Command (TARDEC) under the Occupant Centric Platform (OCP) Technology Enabled Concept Demonstration (TECD) Program.

The authors would like to thank the Soldiers who volunteered to be test participants for this study.

This research was supported in part by an appointment to the Postgraduate Research Participation Program at NSRDEC administered by the Oak Ridge Institute for Science and Education (ORISE) through an interagency agreement between the US Department of Energy and NSRDEC.

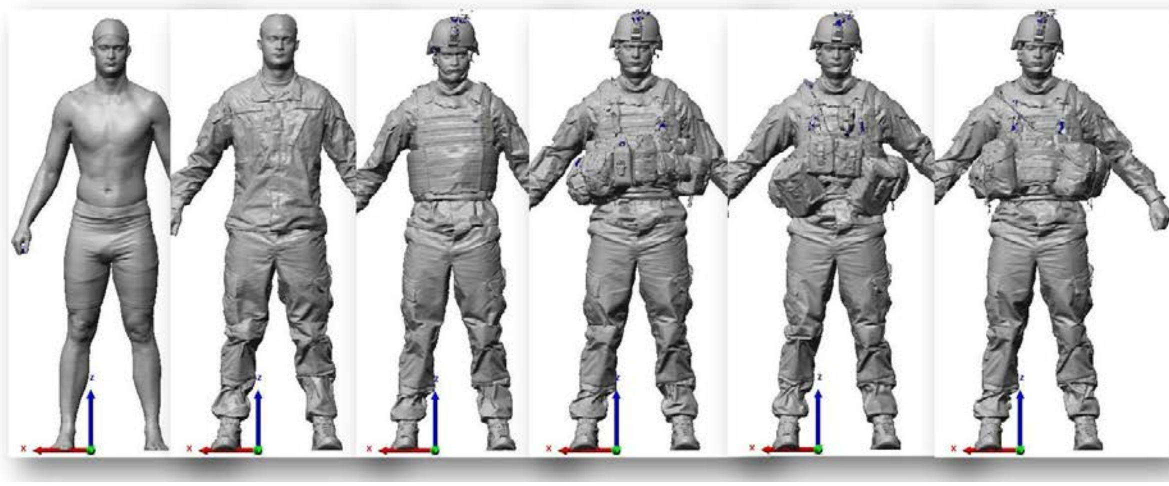
EXECUTIVE SUMMARY

The Tank and Automotive Research, Development and Engineering Command (TARDEC), as part of the Occupant Centric Platform (OCP) Technology Enabled Concept Demonstrator (TECD), tasked the Natick Soldier Research, Development and Engineering Command (NSRDEC) Anthropometry Team to provide a database of Soldier body measurements that would characterize the space for a fully encumbered dismounted Soldier(s) and a driver. This study, which was performed between January 2012 and September 2013, highlighted a detailed, but not exhaustive, list of 42 critical anthropometric body dimensions from 30 test participants (TPs) in five different encumbered configurations to characterize Soldier space and thereby better represent the current nine-man dismounted squad, including the driver.

This study was the result of increased interest in the characterization of Soldier body size and volume when outfitted in clothing and individual equipment (CIE). This interest stems from observations of fully outfitted Soldiers who were not able to fit safely and/or comfortably into vehicle compartments or workspaces used during their daily missions (see Figure ES-1). One of the reasons for this is that many of the current military vehicle platforms and workspaces were originally designed based on minimally clad body dimensions.

Figure ES-1: Example of the encumbered Soldier

Characterization of the fully outfitted Soldier is not straightforward, as the nature and length of military missions and the varied Military Occupational Specialties (MOSs) introduce a myriad of clothing and equipment that can be investigated. A detailed literature review and several user focus groups by McNamara (2012) provided a snapshot of what constitutes a realistic Soldier kit for a nine-man squad and a driver. This information from McNamara's work was the basis for selection of four specific duty positions that were investigated in the current project: 1) Driver, 2) Rifleman/Radioman, 3) SAW Gunner, and 4) Medic. In addition, two other configurations, Semi-Nude and Baseline, were included to aid in calculating delta values (i.e., the differences between configurations) for each of the four specific duty configurations relative to the minimally clad condition that was the design basis for many current military vehicle platforms and workspaces (Figure ES-2).



(a) (b) (c) (d) (e) (f)

Figure ES-2: Distribution of configurations for this study.
(a) Semi-Nude, (b) Baseline, (c) Driver, (d) Rifleman, (e) SAW Gunner, (f) Combat Medic

The findings from this study should assist other researchers and engineers in determining design changes that may improve military vehicle platforms and other Soldier workstations in order to improve Soldier performance, safety, and comfort. They provide, for the first time, a clear window into the increased size of a Soldier relative to the bulk and weight of current CIE by providing specific delta values that can be added to Semi-Nude anthropometric databases, such as the recently collected Army Anthropometric Survey (ANSUR II) (Gordon et al., 2014).

Methods

The TPs for this study were 30 active duty Army personnel, both male (n=25) and female (n=5), who were screened based on their predicted Improved Outer Tactical Vest (IOTV) size and distributed in the study based on their best fitting IOTV size. This sampling method provided the opportunity to distribute the sample size through a range of five body sizes that closely matched the overall distribution of the larger Army anthropometric database, based on ANSUR II.

Procedures

The TPs completed a demographic questionnaire. They then changed into garments for the Semi-Nude measurements (i.e., spandex shorts for the males and spandex shorts and sports tops for the females). A total of eight body landmarks (Acromion, Buttock, Chest, Deltoid, Waist at Omphalion, Suprapatella, and First and Fifth Metatarsophalangeal protrusions) were palpated and/or located and marked on the right side of the body. The marks were then transferred to the front, back, and left sides of the body, where applicable, and the dimensions were measured. The marks were then transferred to each successive configuration, when donned, for measurement. A total of 42 anthropometric dimensions were measured. Twenty of them were measured in all six configurations, as the increment due to CIE was expected to change depending on the equipment configuration. A total of 13 dimensions, including head and foot measurements, were measured in only two configurations because no CIE was added to those locations in any of the other configurations studied. Eight specific maximum dimensions were measured in only the four target configurations (Driver, Rifleman, SAW Gunner, and Combat Medic) because the reference landmarks for these dimensions were located at specific maximum protrusions on the IOTV and had no related Semi-Nude or Baseline landmarks. The maximum measurements were related to three specific body locations where TP CIE appeared to be broader and wider at a different waist level than at the standard Omphalion location. The height was recorded, and Maximum Waist Breadth, Maximum Waist Circumference and Maximum Waist Depth were measured, both standing and seated. The other dimension, Maximum Chest Circumference, was measured only in the SAW Gunner configuration due to the additional grenade located on the chest in the Saw Gunner configuration.

After each set of TP dimensions was measured, the TPs were directed to move to the Cyberware WB4 3D whole body scanner where they were scanned in two standing postures and one seated posture to obtain 3D whole body digital images for use in potential future modeling and simulation efforts. In addition, TPs were scanned in the Driver configuration using the Cyberware 3D head scanner to capture a digital image of their heads without any covering and while wearing a helmet. In total, a set of 21 digital images is associated with each TP across all of the encumbered configurations (not analyzed in this study).

Analysis

Before the data from the anthropometric dimension measurements were analyzed, analyses of observer error and gender differences were conducted. The observer error analysis was conducted to develop an initial reference guide on the allowable error ranges for encumbered anthropometric data for use in the analysis of the data from this study and, if successful, for use in future studies. The analysis for gender differences was conducted to investigate the dimensional differences of encumbered anthropometric torso data between male and female Soldiers to determine whether male and female encumbered torso data should be separated or combined within the same IOTV size categories.

The collection of a reliable dataset is the most critical goal in any anthropometric study, and a number of quality control procedures were required for this study to be successful. One way measurement error was minimized was by using the same measurement team comprised of two trained anthropometrists throughout to collect and record measurement values. In addition, a subset of the TPs was re-measured to calculate inter-observer error and to assist in development of reference data for allowable error ranges of encumbered anthropometric dimensions.

Results from this analysis indicated that the mean absolute differences (MADs) were close to the allowable error ranges of Semi-Nude individuals found in ANSUR and ANSUR II, except in four cases where the Semi-Nude MADs in this study were slightly larger than allowable. These small differences are not likely functionally or operationally relevant and may have resulted from

TP fatigue as a result of being re-measured after a 3-hour encumbered measurement session. In addition, and not unexpectedly, several of the encumbered MADs were larger than current Semi-Nude allowable errors. To address the issue of larger MADs for encumbered measurements, ANSUR and ANSUR II allowable error ranges were adjusted proportionally so they better reflected the increased variability found when conducting encumbered measurements. These error range adjustments were not radically different from many of the Semi-Nude allowable errors, but were shifted slightly higher, as expected. For this study, then, it can be concluded that the data generated by the two anthropometrists was repeatable and reliable.

Results from the gender evaluation showed that the only statistical differences between male and female torso dimensions in the Semi-Nude configuration were for Chest Circumference, where males were on the whole larger. When the same TPs were measured wearing the IOTV in the Driver configuration, there were no differences in any torso measurements between males and females, although as expected the delta values for Chest Circumference remained different. This finding suggests that once the IOTV is donned gender differences disappear in the torso region and that the specific CIE (i.e., IOTV) is the strongest factor causing the differences between different encumbered configurations.

Given the gender analysis result, the data for the female TPs were not used in the analysis of the anthropometric measurements to provide an even distribution of TPs among IOTV sizes. Descriptive statistics, including the mean, median, minimum, maximum, range (as well as 25th percentile and 75th percentile), and standard deviation, were calculated for the 25 male TPs for 36 of the 42 measured anthropometric dimensions. In addition, the mean delta value for each configuration with the percent increment due to CIE relative to the Semi-Nude configuration was calculated for those TPs for the 23 of those 36 dimensions that were measured in all four IOTV configurations. Because no Semi-Nude landmarks were available to calculate deltas at the maximum height locations for the three Maximum Waist dimensions, the Waist (Omphalion) location standing was used as a surrogate for calculating standing delta values. Deltas were not calculated for the maximum height dimension or the same seated maximum dimensions. Pairwise evaluations of the measurement differences within the different IOTV sizes were also conducted.

Anthropometric Results and Discussion

In general, all of the delta calculations for the standing and sitting dimensions (Table ES-1) from the IOTV configurations were statistically larger than the Baseline configuration deltas (i.e., Baseline minus Semi-Nude). This is not a surprise, as the Baseline configuration consisted of the TPs wearing their own duty uniform and duty boots. More importantly, the mean deltas generally increased relative to the CIE for the different configurations, although the only meaningful differences were that the dimensions of the three loaded configurations (the Rifleman, the SAW Gunner, and the Combat Medic) were, on the whole, larger than those of the Driver configuration. This too was expected, as the TPs in the Driver configuration wore only their IOTVs and no additional CIE. The only exception to this was for Mid-Shoulder Height, where the Driver had the largest delta, which was likely related to the greater weight of the loaded configurations pushing the shoulders down. Overall, Stature and Sitting Height showed no statistical differences among the four IOTV configurations, as all four included the Advanced Combat Helmet (ACH). Although dependent on specific body dimensions, the three loaded configurations were often very similar to each other even though they consisted of different gear components as defined by McNamara (2012). This trend was present for many body dimensions, and while several dimensions revealed statistically significant differences they were small and are likely not operationally relevant. For example, the SAW Gunner configuration showed significant differences at some of the measurements around the chest region compared to the Rifleman and the Combat Medic configurations, which were primarily a result of SAW Gunner equipment, including the presence of a grenade pouch, at this location. Moving the equipment elsewhere on the torso could have reduced these differences.

Table ES-1: Mean and maximum delta values for measured standing and sitting dimensions for five encumbered configurations relative to Semi-Nude configuration

Dimension	Baseline (mm)		Driver (mm)		Rifleman (mm)		SAW Gunner (mm)		Combat Medic (mm)	
	Mean	Max	Mean	Max	Mean	Max	Mean	Max	Mean	Max
Standing										
Weight	4	5	18	22	28	32	33	37	26	30
Stature	39	52	63	78	62	87	61	94	60	92
Mid-Shoulder Height	46	57	71	86	61	77	54	75	60	94
Shoulder Circumference	65	101	171	217	239	286	280	336	244	295
Chest Circumference	34	65	260	318	345	402	375	434	341	398
Waist (OMP) Circumference	37	74	336	460	865	996	863	989	887	1028
Vertical Trunk (USA) Circumference	56	128	167	230	298	415	299	441	237	351
Chest Depth	8	25	93	117	181	256	199	255	176	221
Waist Depth	10	24	129	180	304	357	294	339	309	339
Chest Breadth	10	43	41	70	50	79	47	81	47	77
Waist Breadth	4	32	73	106	287	328	300	337	280	339
Sitting										
Sitting Height	1	14	29	59	31	57	27	53	28	53
Waist Height	4	72	38	107	45	88	50	116	46	99
Buttock-Knee Length	8	25	64	96	144	176	148	186	137	185
Buttock-Popliteal Length	-2	23	57	96	136	172	140	171	127	158
Biacromial Breadth	5	29	9	38	13	54	12	63	13	62
Bideltoid Breadth	25	57	36	60	50	90	51	85	49	93
Forearm-Forearm Breadth	51	121	83	164	151	252	160	250	140	217
Hip Breadth	19	38	22	55	139	256	153	253	131	253
Elbow Circumference	116	252	270	361	539	686	607	783	619	739

In general, there were no significant differences in deltas between IOTV sizes for the different configurations. Exceptions to this included Waist (Omphalion) Breadth, Waist (Omphalion) Circumference, Weight, Maximum Waist Breadth, and Maximum Waist Depth. This seems to generally reflect more difficulty in tightening the adjustment straps because the side ballistic

plates pushed up against the edge of the front and back plates, preventing the full tightening of the IOTV. Because the TP could not tighten the adjustment straps, the IOTV could not be fully tightened to the torso, creating a kind of "bell effect", potentially leading to larger deltas for these dimensions in the smaller sized vests. In addition, the Tactical Assault Panel (TAP) is a one-size-fits-all item that when donned generally follows the curvature of the IOTV. On the smaller-size IOTVs, it can be more difficult to completely tighten the TAP, leaving the potential for slight gapping between the surface of the IOTV and the TAP. This could also account for slightly larger delta values in these variables for TPs wearing the smaller-size IOTVs.
For head and foot anthropometry the only differences were related to wearing a helmet on the head and the Army combat boots on the feet. Overall, the delta values for the three loaded configurations were generally similar to each other for each of the three maximum dimensions that were calculated, but they were all significantly larger than those for Driver configuration.

Conclusions

The results from this study strongly indicate that Soldiers wearing various combat loads are significantly taller, broader front to back, wider, and heavier than when they are in their duty uniform alone. When Soldiers donned their uniforms, an increase in body weight of approximately 4 kg (8.8 lb) was observed. When they donned the IOTV and ACH, an additional increase of approximately 18 kg (39.6 lb) was observed. On average, the delta values for body weight in the three loaded configurations ranged from 26 kg (57.2 lb) to 33 kg (72.6 lb). In addition, all four IOTV configurations are loaded on or around the torso area. This resulted in substantial increases for delta values on the Breadths, Depths, and Circumferences around the Chest and Waist regions, as can be seen in Table ES-1. The results of this work show that the space occupied by a Soldier wearing an IOTV with any associated gear, sitting or standing, is considerably larger than when wearing only his/her duty uniform. Given that the space in many current military vehicle platforms and/or work stations was designed using Baseline or Semi-Nude measurements, it is clearly not satisfactory for Soldiers wearing mission specific equipment. Based on these results, it can be concluded that 1) military vehicle platforms/workstations should be re-designed to sufficiently increase Soldier space and thereby improve Soldier performance, survivability, and comfort while reducing overall risk and/or 2) Soldier CIE should be sufficiently reduced so that current military platforms/workstations perform as they were originally designed.

In addition to providing for the first time a clear window into the increased size of the Soldier caused by CIE, this study was the first to use modern digital 3D whole body and head imaging technology to record individual body scans in all six configurations, both in a standing and seated position resulting in a database of over 600 raw digital images ready for post processing and analysis. Although beyond the scope of this study, these digital data are available and can assist computer modelers in generating simulation and virtual models of the encumbered Soldier.

Furthermore, the newly adjusted error ranges developed and used during this study can be used for future encumbered anthropometric studies. Likewise, based on the gender analysis performed during this study, male and female encumbered torso data can potentially be combined in future studies once torso protective CIE is donned; however, it is recommended that a larger number of TPs in different sized IOTVs be similarly tested.

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CHARACTERIZING THE SIZE OF THE ENCUMBERED SOLDIER

1. INTRODUCTION

This report documents efforts to critically characterize the space claim resulting from encumbered Soldiers in order to assist other researchers and engineers in determining design changes that may improve military vehicle platforms and other Soldier workstations, thereby enhancing Soldier performance, safety, and comfort. This work was performed between January 2012 and September 2013 by the Natick Soldier Research, Development and Engineering Center (NSRDEC) in response to increased interest in recent years in the characterization of Soldier body size and volume when outfitted in clothing and individual equipment (CIE).

This interest stems from observations of fully outfitted Soldiers who are not able to fit safely and/or comfortably into the vehicle compartments or workspaces used during their daily missions. One of the reasons for this is that many of the current military vehicle platforms and workspaces were originally designed based on minimally clad body dimensions, i.e. individuals measured in shorts and t-shirts or lightweight duty uniforms (Clauser et al., 1972; Churchill et al., 1977; Gordon et al., 1989). In addition, the body size and composition of the current US Army Soldier population has changed over time (see Gordon et al., 2014) along with the introduction of bulkier personal protective equipment (PPE), such as rigid body armor with front, back, and side plates. All of these factors have significantly increased the space that is needed by each individual Soldier. Only a few studies on Soldiers wearing military CIE have been conducted, and they utilized very small samples, did not standardize their measurement procedures, and/or included military equipment that is now outdated compared to current military CIE (see Paquette et al., 1999; Johnson 1984).

The Tank and Automotive Research, Development and Engineering Command (TARDEC), as part of the Occupant Centric Platform (OCP) Technology Enabled Concept Demonstration (TECD), tasked the Anthropometry Team at NSRDEC to provide a database of Soldier body measurements that would characterize the space of a fully encumbered dismounted Soldier and driver. Unfortunately, this characterization is not straightforward. The nature and length of military missions and varied Military Occupational Specialties (MOS) introduce many CIE combinations that can vary from unit to unit based on leadership decisions. Each of these combinations has a unique influence on Soldier space, and because of the resources involved, attempting to characterize each of these many combinations in a single study is not feasible. The encumbered anthropometry effort undertaken by NSRDEC was based on the work of Paquette et al., (1999). In addition, as part of the overall TARDEC effort, McNamara (2012) conducted a detailed literature review and several user focus groups in an attempt to clearly define a realistic Soldier kit for a nine-man squad that included a driver. From his work, representative Soldier kits outlining what Soldiers actually wear in field conditions, rather than kits based on doctrine, for four specific duty positions were identified and agreed upon by the OCP TECD. These four encumbered configurations were characterized in the NSRDEC study described here: 1) Driver, 2) Rifleman/ Radioman, 3) Squad Automatic Weapon (SAW) Gunner, and 4) Combat Medic. Characterization of the space that these Soldier kits represent will contribute to improving the designs of future military vehicle platforms and workspaces, CIE, and human performance models. Two additional configurations were included in this study: Semi-Nude and Baseline.

2. MATERIALS AND METHODS

Semi-Nude and Baseline configurations were critical for calculating the required delta values (i.e., the differences between configurations) for each of the four specific duty configurations relative to the minimally clad condition that was the design basis for current military vehicle platforms and workspaces. In the Semi-Nude configuration (only shorts for the males and shorts and a sports top for females), the individual Soldiers were landmarked and measured to collect unclothed data for comparison to the encumbered configurations. In the Baseline configuration, the Semi-Nude measurements were transferred to the duty uniform prior to the Soldier donning duty boots. These landmarks were then transferred to each of the remaining encumbered configurations to calculate incremental differences between the Semi-Nude and each clothed configuration. The sections in this chapter outline the (2.1) test items, (2.2) test equipment, (2.3) test participants (TPs), (2.4) test and body measurement procedures, and (2.5) analysis of the data collected.

2.1 Test Items

The Improved Outer Tactical Vest (IOTV) was used as the body armor system for all four specific duty configurations, in sizes X-small through X-large (regular length). The IOTV was worn with front and back enhanced small arms protective inserts (ESAPI) and both enhanced side ballistic inserts (ESBI) and yokes (see Figure 1). Figures 2 through 7 show the six test configurations and describe the specific equipment that was identified from McNamara (2012).

Figure 1: IOTV with front, back, and side ballistic inserts

- Compression shorts (males); compression shorts and a sports top (females)

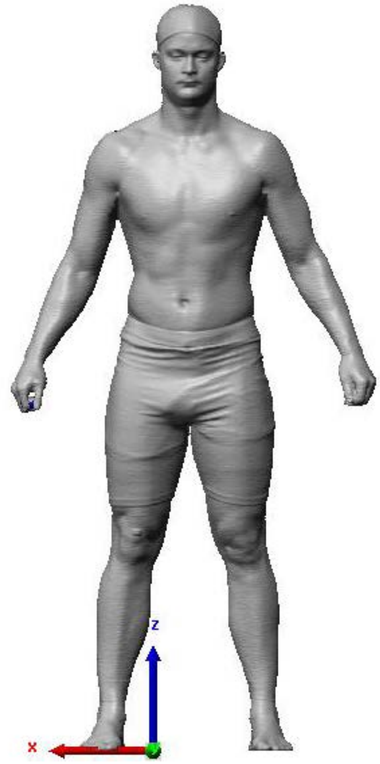


Figure 2: Semi-Nude configuration for obtaining Baseline anthropometric dimensions

- Personal undergarment
- Army issued t-shirt
- Army Combat Uniform (ACU) - duty uniform
- Riggers belt
- Army issued warm weather combat boots donned after heights were transferred to the duty uniform
- No IOTV or equipment worn

Figure 3: Baseline configuration for landmark transfer and encumbered anthropometric dimensions

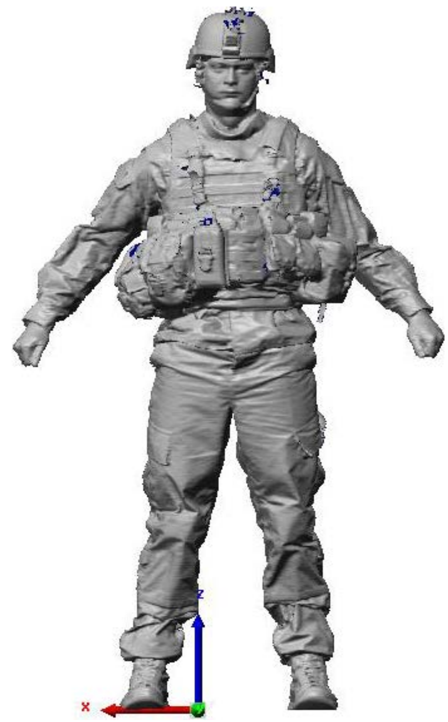
Baseline configuration plus:

- IOTV with front, back, and side plates and yoke
- Advanced Combat Helmet (ACH)/Combat Vehicle Crewman (CVC) helmet
- AN/PVS 14 with helmet mount and arm (worn only for anthropometric weights)

Figure 4: Driver Configuration for obtaining encumbered anthropometric dimensions

Driver configuration plus Rifleman Tactical Assault Panel (TAP):

- Eight M4 30-round magazines
- Canteen pouch with cup worn on right side used as a night vision device (NVD) pouch (A)
- Canteen Pouch used a miscellaneous pouch (B)
- Multi-Band Inter/Intra Team Radio (MBITR) and pouch (C)
- Fragmentation grenade and pouch (D)
- Individual First Aid Kit (IFAK) worn on left side (E)
- Camelbak hydration bladder and pouch (filled) (F)
- One M67 (baseball grenade) (D)



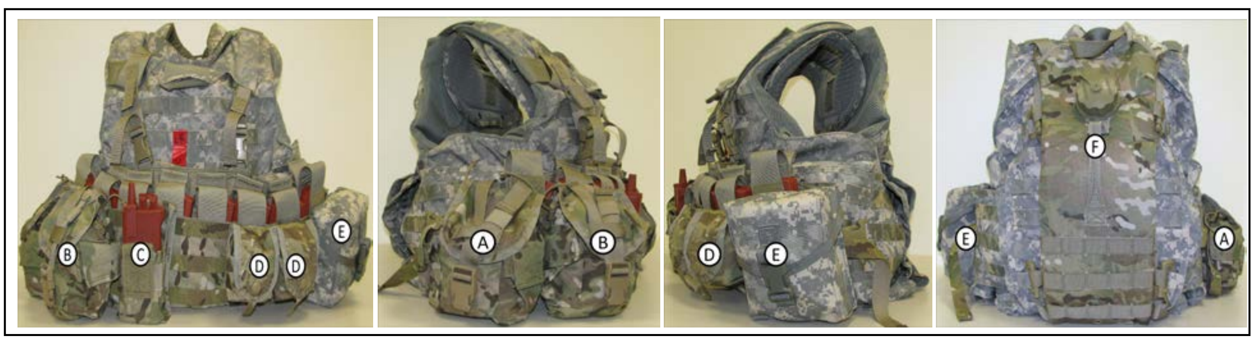


Figure 5: Riflemen configuration for obtaining encumbered anthropometric dimensions

Driver configuration plus SAW Gunner TAP:

- Canteen pouch with cup worn on right side used as an NVD pouch (A)
- Two 200-round SAW Gunner magazines and pouches (B)
- Two 100-round SAW Gunner Magazines and Pouches (C)
- Fragmentation grenade worn on chest (D)
- IFAK worn on left side (E)
- Camelbak hydration bladder and pouch filled (F)

Figure 6: SAW Gunner configuration for obtaining encumbered anthropometric data

Driver configuration plus Combat Medic TAP.

- Canteen pouch with cup worn on right side used as an NVD pouch (A)
- Two tactical tailor medic pouches (left and right side) (B)
- Three double M4 magazine pouches with six 30-round M4 magazines (C)
- Safety scissors (D)
- IFAK worn on the left side (E)
- Camelbak hydration bladder and pouch (F)

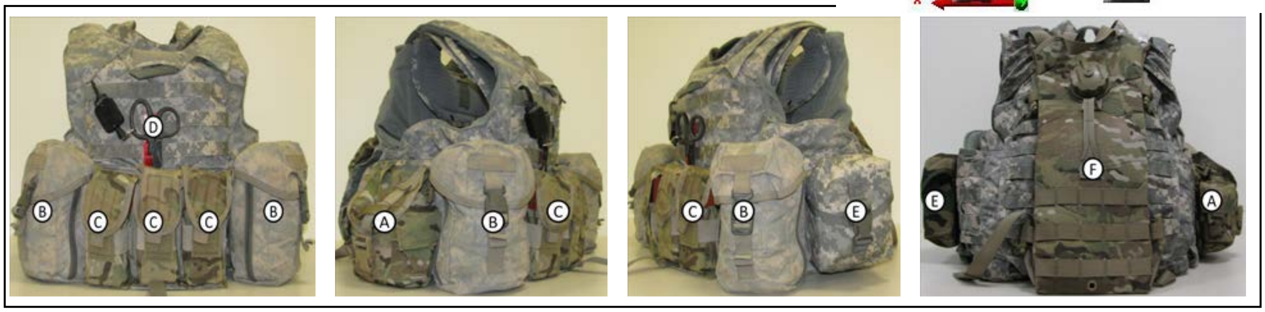


Figure 7: Combat Medic configuration for obtaining encumbered anthropometric dimensions

2.2 Test Instruments

Several standard anthropometric measurement instruments were used to collect Semi-Nude and encumbered body dimensions in this study. Additionally, some of the standard anthropometric equipment was modified for this study in order to collect body dimensions from Soldiers wearing their CIE. Figure 8 illustrates the equipment used in this study to manually obtain anthropometric body dimensions.

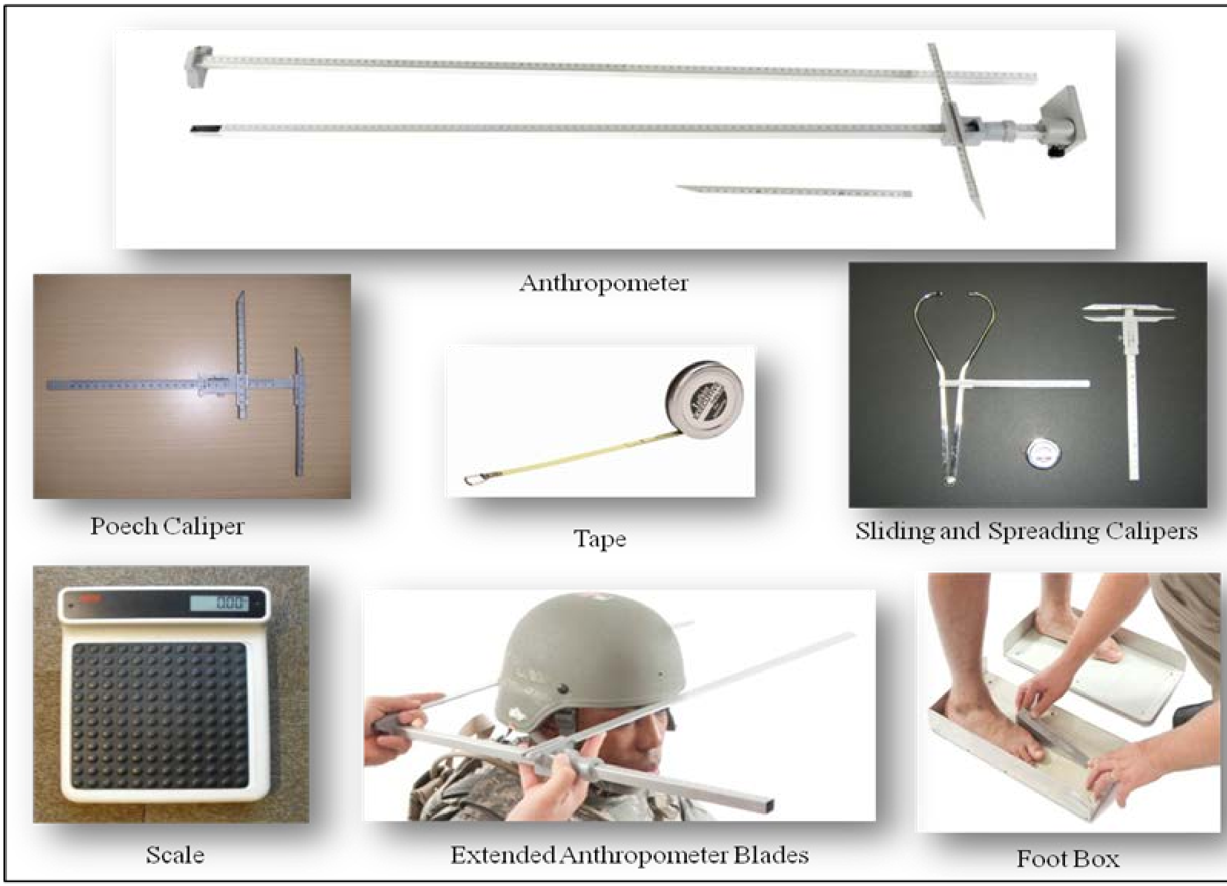


Figure 8: Anthropometric equipment used

A Swiss-made GPM anthropometer was used to collect standing and seated linear body measurements. For encumbered linear measurements extended anthropometric blades were designed and used to obtain measurements because standard anthropometric blades were too short to provide an accurate measurement. In addition, an anthropometer modified with a laser level was developed and used to assist with transferring measurement location landmarks to the various CIE layers (see Figure 9). A Lufkin 2 m steel tape (modified with a tension spring to a constant tension of 80 g) was used to collect specific body circumference measurements. Head length and breadth were measured using a spreading caliper. Foot length and foot breadth were measured using an anthropometric foot box. All measurements were recorded to the nearest mm. Weight was measured to the nearest 10^{th} of kg using a SECA digital scale. A Cyberware WB4 whole body scanner and head scanner were used to collect three-dimensional (3D) digital images for use in future modeling and simulation efforts of the encumbered Soldier (see Figure 10).

Figure 9: Modified anthropometer used for landmark transfer

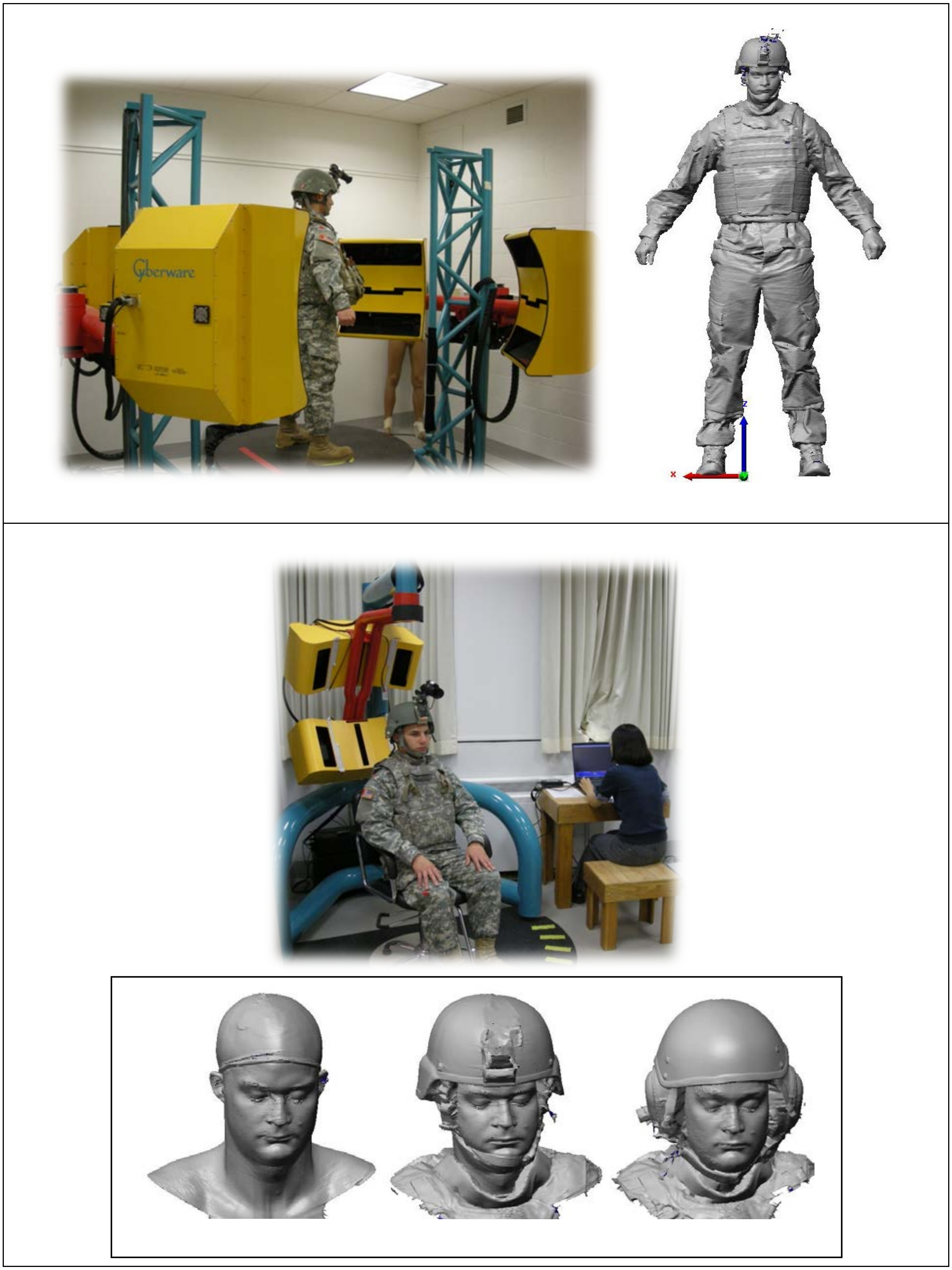


Figure 10: Images of 3D whole body scanner and head scanner with processed models

2.3 Test Participants (TPs)

The TPs for this study were 30 active duty Army personnel (25 males and 5 females), and each one completed a background and demographic questionnaire. Personal information on the TPs has been held in the strictest confidence. To assure the TPs' anonymity and privacy, personal identifiers (e.g., name, social security number, etc.) were not included with any data form, database or printed results. Any photographs used in this study were approved prior to their use.

Due to limitations in the subject pool available, only human research volunteers (HRVs) and local active duty Soldiers were used. HRVs are active duty US Army military personnel who are recruited to come to NSRDEC specifically to serve as TPs for a wide variety of evaluations conducted in support of the development of Soldier-oriented products. They typically come to NSRDEC between their Advanced Individual Training (AIT) and their first duty station, so they have limited military experience and are typically between the ages of 18 and 22. Additional Soldiers were recruited from the local Active Duty forces stationed at the US Army Research Institute of Environmental Medicine (USARIEM), Natick, MA.

Due to the subject pool availability, only five women were available to be tested. The TPs were screened based on their predicted IOTV size and distributed in the study based on their best fitting IOTV size. For center sizes (Small, Medium and Large), TPs were randomly sampled based on given availability. TPs were then sought out in order to populate the X-small and X-large sizes. No long length IOTVs were included in this evaluation. The eventual TP size distribution is shown in Table 1. The females were all fit into size XS IOTVs (currently the smallest available size issued). Males were evenly distributed in each of the most common IOTV sizes (XS, S, M, L, XL). Six TPs were placed in the size Medium IOTV cell and 4 TPs were placed in the size X-large IOTV cell. This sampling method provided the opportunity to distribute the sample size through a range of body sizes that closely matched the overall distribution of the new Army Anthropometric Survey (ANSUR II) database using stature, weight, and chest circumference as matching variables (Gordon et al., 2014), as discussed at the beginning of Chapter 3.

Table 1: TP Sample distribution by IOTV size

IOTV Size	Males	Females	Total
XS	5	5	10
S	5	0	5
M	6	0	6
L	5	0	5
XL	4	0	4
Total	25	5	30

Ages of the TPs ranged between 18 and 26 (*M* =21.32, *SD* =3.18) for the males and between 19 and 34 (*M* =25.80, *SD* =6.06) for the females. Eleven of the TPs classified their race as White, Not Hispanic. Eleven classified themselves as Black, and the rest classified themselves as either Hispanic (n=2), Asian/Pacific Islander (n=4), or Mixed Race (n=2). All but three of the TPs were right handed (27 or 90%), two were left handed, and one was ambidextrous. Seven (23.3%) of the TPs wore glasses. No eyewear was worn during the 3D scanning sessions as light reflection can affect the image quality of the scan.

2.4 Test Procedures

Testing was divided into five stations: 1) briefing, 2) landmarking, 3) standing anthropometric measurements, 4) sitting anthropometric measurements, and 5) 3D whole body and head digital scanning. Each TP completed all stations during a 3-hour testing period. At the first station visited upon arrival at the testing area (the briefing station), the TPs were briefed on the purpose of the study, what they were going to be doing during the 3-hour session, and their ability to withdraw from the study at any time during the measurement session without recourse. The TPs were then given a demographic questionnaire to fill in to gather some background information.

Once the TPs completed the demographic questionnaire, they were provided with foundation garments to change into for measurement (i.e., spandex shorts for the males, and spandex shorts and sports tops for the females). They were advised to change into the measurement garments, but leave their personal undergarments on under the shorts for hygienic reasons.

All anthropometric dimensions were measured based on ANSUR and/or ANSUR II procedures, Clauser et al. (1988), Hotzman et al. (2011) or the Paquette et al. (1999) evaluation of multilayered military clothing, unless otherwise stated. A total of eight body landmarks (Acromion, Buttock, Chest, Deltoid, Waist at Omphalion, Suprapatella, and First and Fifth Metatarsophalangeal protrusions) were palpated and/or located and marked with a hypoallergenic eyebrow pencil on the right side of the body. The marks were then transferred to the front, back, and left sides of the body, where applicable. Table 2 lists the 42 anthropometric dimensions that were measured and the configurations for which they were measured. Descriptions of the measurement methods are briefly outlined in Chapter 3 for each dimension.

Table 2: Anthropometric dimensions measured in each configuration

Anthropometric Dimension	Semi-Nude	Baseline	Driver	Rifleman	SAW Gunner	Combat Medic
			Standing			
Acromial Height	√	√				
Buttock Circumference	√	√				
Buttock Height	√	√				
Chest Breadth	√	√	√	√	√	√
Chest Circumference	√	√	√	√	√	√
Chest Depth	√	√	√	√	√	√
Chest Height	√	√				
Deltoid Height	√	√				
Foot Breadth	√	√				
Foot Length	√	√				
Knee Height, Suprapatella	√	√				

Table 2: Anthropometric dimensions measured in each configuration (continued)

Anthropometric Dimension	Semi-Nude	Baseline	Driver	Rifleman	SAW Gunner	Combat Medic
Maximum Chest Circumference					√	
Maximum Waist Breadth			√	√	√	√
Maximum Waist Circumference			√	√	√	√
Maximum Waist Depth			√	√	√	√
Maximum Waist Height			√	√	√	√
Mid-Shoulder Height	√	√	√	√	√	√
Shoulder Circumference	√	√	√	√	√	√
Stature	√	√	√	√	√	√
Vertical Trunk (USA) Circumference	√	√	√	√	√	√
Waist (Omphalion) Circumference	√	√	√	√	√	√
Waist Breadth	√	√	√	√	√	√
Waist Depth	√	√	√	√	√	√
Waist Height	√	√				
Weight (lb)	√	√	√	√	√	√
Head						
Head Breadth	√		√			
Head Circumference	√		√			
Head Length	√		√			
Sitting						
Biacromial Breadth	√	√	√	√	√	√
Bideltoid Breadth	√	√	√	√	√	√
Buttock-Knee Length	√	√	√	√	√	√
Buttock-Popliteal Length	√	√	√	√	√	√
Elbow-Elbow Circumference	√	√	√	√	√	√
Forearm-Forearm Breadth	√	√	√	√	√	√
Hip Breadth	√	√	√	√	√	√
Knee Height, Suprapatella	√	√				
Maximum Waist Breadth			√	√	√	√
Maximum Waist Circumference			√	√	√	√
Maximum Waist Depth			√	√	√	√
Maximum Waist Height			√	√	√	√
Sitting Height	√	√	√	√	√	√
Waist Height	√	√	√	√	√	√

"√" indicates measurements taken.

Shaded cells indicate no measurements taken.

All TPs were landmarked and measured in the Semi-Nude configuration first. When all of those measurements were completed, the TPs donned their ACUs and socks. All the anthropometric landmarks were then transferred to the ACU using a laser modified anthropometer and adhesive markers. The TPs then donned their duty boots, and all Baseline measurements were completed. Each successive clothing configuration was then built up in increments on the Baseline configuration. All necessary landmarks were either transferred and/or rechecked for each of the different clothing configurations. All TPs were sized for their best fit IOTV and ACH/CVC helmet. Best fit size was determined by a trained anthropometrist, who assessed the fit based on specific fit criteria including head measurements for the helmets and chest circumference, plate location, length, adjustability, and overlap criteria for the IOTV. In addition, TPs were asked to perform some basic movements in the helmet and armor, including neck movements, standing, turning, and sitting, to ensure the fit was acceptable.

Each of the three measurement stations had one measurer and one trained data recorder. Each data recorder completed a data sheet with all TP measurements and any TP or measurer comments for each test configuration (see Appendix A). The data recorder's job also included observing the measurement being taken and ensuring quality assurance. In essence, the data recorder served as a second set of eyes for the measurer.

As shown in Table 2, 20 anthropometric dimensions (e.g., Waist Circumference at Omphalion) were measured in all six configurations, as the increment due to CIE was expected to change depending on the equipment configuration. A total of 13 dimensions were measured in only two configurations (10 of them, e.g., Knee Height and Buttock Circumference, i.e., Semi-Nude and the Baseline configurations and the three Head dimensions, Semi-Nude and Driver) because no CIE was added to these locations in any of the other configurations studied, and therefore the measurements will not differ. Eight dimensions were measured in only the four IOTV encumbered configurations (Driver, Rifleman, SAW Gunner, and Combat Medic) because the reference landmarks for these dimensions were located at specific maximum protrusions on the IOTV and had no related Semi-Nude or Baseline landmarks. The other dimension, Maximum Chest Circumference, was measured only in the SAW Gunner configuration due to additional grenade located on the chest in the Saw Gunner configuration.

After each set of TP dimensions was measured, the TPs were directed to move to the Cyberware WB4 3D whole body scanner where they were scanned in two standing postures and one seated posture to obtain 3D whole body digital images for use in potential future modeling and simulation efforts (not discussed in this study). In addition, TPs were scanned in the Driver configuration using the Cyberware 3D head scanner to capture a digital image of their head without any covering and while wearing the ACH and then the CVC helmet (see Figure 10). In total, 21 digital images are associated with each TP across all of the five encumbered configurations.

After the TPs were measured in all configurations listed in Table 2, a subset of 17 TPs (16 males and 1 female) was re-measured for one of the six configurations during the 3-hour session. These re-measured dimensions were later used to calculate inter-observer error and to assist in the development of reference values for allowable error ranges for encumbered anthropometric dimensions.

2.5 Analysis

The measurements and comments were entered into computers and tabulated using Microsoft Excel 2007. Predictive Analytics Software (PASW) Statistics 18 for Windows (Statistical Product and Service Solutions (SPSS)) and Microsoft Excel were both used to perform data reduction and analyses on the anthropometric data. Microsoft Excel was used to create table and chart summaries of the results. STASISTICA V10 was used to generate scatter plots with a 95% ellipse of the target population (ANSUR II) (see Gordon et al., 2014).

Before the data from the anthropometric dimension measurements were analyzed, analyses of observer error and gender differences were conducted. The observer error analysis was conducted to develop initial reference values of allowable error ranges for encumbered anthropometric data for use in the analysis of the data from this study and, if successful, for use in future studies. The analysis for gender differences was conducted to investigate the dimensional differences of encumbered anthropometric torso data between male and female Soldiers to determine whether male and female encumbered torso data should be separated or combined within the same IOTV size categories.

2.5.1 Observer Error

The collection of a reliable dataset is the most critical goal in any anthropometric study, and there are a number of quality control procedures required for such a study to be successful. One of the first steps to minimize measurement error was utilizing the same measurement team comprised of two trained anthropometrists at each station throughout to collect and record measurement values, as mentioned in Section 2.4. Another critical method for assuring quality data is to re-measure a randomized subset of TPs and to compare the absolute differences between the repeated measurements and the reference allowable error range for each measurement. In the current study, both Semi-Nude and encumbered anthropometric data were collected. For the Semi-Nude body dimensions, the allowable error range developed for ANSUR and ANSUR II (Gordon et al., 1989; Gordon et al., 2014) was adopted as a reference guide for allowable error ranges in this study. However, due to the large independent variability inherent in encumbered anthropometry configurations used in this study, there were no known allowable error ranges available for encumbered data. Thus, as mentioned in Section 2.4, a subset of the TPs were re-measured in order to assess and to develop reference values of allowable error ranges for the encumbered anthropometric data collected.

Due to time constraints on measurement sessions, only 17 (approximately 57%) of the 30 TPs were re-measured, and each TP was re-measured in only one of the six configurations. However, all the anthropometric dimensions in each configuration listed in Table 2 were fully measured a second time. Five TPs were re-measured in the Semi-Nude configuration, and either two or three TPs were re-measured in each of all the other configurations.

Once all the dimensions were re-measured, a subset of them (17 critical dimensions, 10 standing and 7 sitting postures) was selected for the error analysis. Measurement inclusion qualified based on two conditions: 1) as a group, they were measured in all six configurations so that they could be compared across all configurations, and 2) they were measured in ANSUR so that the allowable error range for the Semi-Nude configuration was available as a reference guide.

The mean absolute differences (MADs) for the Semi-Nude configuration were first compared to the ANSUR allowable error range for each qualified dimension. All MADs were smaller than the current allowable error except for four dimensions, which exceeded the range: Stature, Forearm-Forearm Breadth, Hip Breadth, and Buttock-Knee Length (see Table 3). Because the re-measure session was performed after 3-hour of encumbered anthropometric data collection where the TPs wore loads up to 33 kg (72.6 lb), it might be expected that the dimensions that are highly related to the TPs' posture could show relatively greater MADs. These posture inconsistencies were likely not solely due to study fatigue and exhaustion, from the length of the measurement session, but were likely also related to the temporary shrinkage of some of the vertical lengths at the shoulder and torso due to the heavy loads that the TPs wore during the session. For example, Stature decreased by 4 mm in the last configuration (Combat Medic) relative to the first IOTV configuration (Driver) worn, which resulted in a greater MAD than allowable by 3 mm.

Table 3: ANSUR Allowable error range and MAD for Semi-Nude configuration (n=5)

Posture	Dimension	Allowable Error (mm)	Semi-Nude MAD (mm)
Standing	**Stature**	6	*9**
	Shoulder Circumference	12	6
	Chest Circumference	14	10
	Waist Circumference	12	5
	Vertical Trunk Circumference	24	16
	Chest Depth	4	2
	Waist Depth	6	6
	Chest Breadth	7	3
	Waist Breadth	6	2
	Weight (Kg)	0.3	0.1
Sitting	**Sitting Height**	6	7
	Biacromial Breadth	8	5
	Bideltoid Breadth	8	8
	Forearm-Forearm Breadth	17	*21**
	Hip Breadth	6	*11**
	Buttock-Knee Length	6	*8**
	Buttock Popliteal Length	7	6

*These four MADs exceeded the ANSUR and ANSUR II allowable errors by 2 mm to 5 mm.

The four dimensions that showed greater MADs relative to the allowable error by only approximately 2 mm to 5 mm are not likely to produce meaningful functional or operational differences. Because the TPs were extremely fatigued, leading to some difficulties in controlling posture during the re-measurement sessions, the collected data by the two trained anthropometrists is considered to be reliable and repeatable. For comparison, ANSUR and ANSUR II TPs were measured in only a Semi-Nude condition for a much shorter amount of time.

Unfortunately, there currently are no allowable error ranges to determine how reliable and repeatable encumbered measurements are. If the recorded measurements in this study are similar to those of the Semi-Nude error ranges found in ANSUR or ANSUR II then there is confidence that those encumbered dimensions should not cause considerable issues with regard to reliability and repeatability (Paquette et al., 1999). However, if the encumbered measurements are different from the ANSUR and ANSUR II Semi-Nude allowable errors, they should not necessarily be disregarded as these types of measurements are inherently much more variable and difficult to measure than the Semi-Nude dimensions. In order to try and provide some sort of encumbered error ranges that may be useful when analyzing encumbered data, some preliminary allowable error ranges were developed based on the current encumbered anthropometric data collected. For this analysis the MADs of the five encumbered configurations were compared with each other in order to determine whether the MADs were correlated to the delta increments (i.e., bigger MADs in each IOTV configuration compared to the Baseline) and whether individual reference error ranges per configuration are needed. The results showed there was no trend between the MADs and the delta values (i.e., no increase or decrease in MADs between configurations). Even though the encumbered delta values in the Baseline were smaller than those in the IOTV configurations, there were no distinctive differences in the MADs between the Baseline and any of the IOTV configurations. Therefore, all the MADs from the five encumbered configurations were combined and averaged ("Averaged MAD encumbered," n=12, see Table 4).

Next, ANSUR and ANSUR II allowable error ranges were adjusted to compare the averaged MADs. The assumption behind this is that the reference allowable error can be calculated proportionally as the dimensions get increased or decreased. MCANSUR (Anthropometric survey for Marine Corps, Gordon et al., 2013) used a similar methodology to develop the allowable error range for the derived dimensions in that survey. This method was adapted to the current study. In the MCANSUR, "Clavicle Link, which was created by dividing Biacromial Breadth by two, the observer error is estimated by dividing the observer error of Biacromial Breadth by two". For this current study, delta values were converted to delta percentages, then the average along with 25th and 75th percentiles of the delta percentages were computed. These statistics of delta percentages were then applied to ANSUR and ANSUR II allowable error ranges to calculate a proportional allowable error range for each dimension. This proportional error range provides a rough guideline. However, because the proportional range does not take into account the instability of multiple layers when measuring the encumbered anthropometric dimensions, it remains a rather conservative guideline for determining allowable error ranges for each dimension.

In Table 4, proportionally calculated ANSUR and ANSUR II allowable error ranges (25th, 50th and 75th percentile) along with averaged MADs for encumbered measurements of specific dimensions are listed and compared. Based on this comparison, it seems that dimensions that were measured over the IOTV (i.e., circumference, breadth, and depth on torso) are less than the mean or 75th percentile of proportioned ANSUR allowable error, whereas dimensions measured over the ACU showed relatively greater variability. To take into account the mechanism between multiple layers along with the proportional expectation due to increments in delta values, the final allowable error for encumbered anthropometric data was determined so that the values, whichever greater, could be selected between the mean value of proportionally calculated ANSUR and ANSUR II allowable error and averaged MADs for encumbered measurements. The final set of allowable errors for encumbered measurements based on this data are suggested and outlined in Table 4. Based on this analysis it was concluded that the MADs for the encumbered data generated by the same two anthropometrists can be considered as a new reference values of allowable error ranges when measuring encumbered anthropometric data.

Table 4: Allowable error ranges for encumbered anthropometric data (n=12) compared to ANSUR and ANSUR II allowable error ranges

Dimension	ANSUR Allowable Error (mm)	Delta Values			Proportioned Allowable Error (mm)			Averaged MAD Encumbered (mm)	Encumbered Allowable Error (mm)
		25th	Mean	75th	25th	Mean	75th		
Standing									
Stature	6	3%	3%	4%	6	6	6	4	6
Shoulder Circumference	12	12%	16%	21%	13	14	15	13	14
Chest Circumference	14	23%	27%	37%	17	18	19	11	18
Waist Circumference	12	29%	67%	105%	15	20	25	22	22
Vertical Trunk Circumference	24	8%	12%	17%	26	27	28	17	27
Chest Depth	4	32%	53%	77%	5	6	7	9	9
Waist Depth	6	46%	91%	137%	9	11	14	10	11
Chest Breadth	7	8%	13%	18%	8	8	8	4	8
Waist Breadth	6	17%	60%	97%	7	10	12	7	10
Weight (Kg)	0.3	20%	26%	36%	0.4	0.4	0.4	0.2	0.4
Sitting									
Sitting Height	6	1%	3%	4%	6	6	6	6	6
Biacromial Breadth	8	1%	3%	4%	8	8	8	7	8
Bideltoid Breadth	8	6%	8%	11%	9	9	9	*11**	11
Forearm-Forearm Breadth	17	12%	20%	29%	19	20	22	*26**	26
Hip Breadth	6	5%	24%	47%	6	7	9	*12**	12
Buttock-Knee Length	6	7%	16%	23%	6	7	7	*12**	12
Buttock Popliteal Length	7	9%	18%	28%	8	8	9	*15**	15

***** These five MADs exceeded the ANSUR and ANSUR II proportioned allowable errors by 2 mm to 6 mm.

2.5.2 Gender Differences

Having an equal number of male and female TPs in all size categories would be ideal for studies on anthropometry and human performance. However, since recruiting female TPs for all size categories is not statistically feasible based on female body size proportions in the current US Army population, it is very common that US Army CIE, specifically combat related equipment, is not designed with female body proportions in mind. This is not because there are no known body proportion differences between males and females, but because there are currently no encumbered reference data to clarify what the differences are. Therefore, it was necessary to develop references on gender differences in order to show whether male and female encumbered data can be combined or if they should be separated in the analysis.

The measurements for six torso dimensions in the Semi-Nude and Driver configurations collected from the five male and five female TPs who had an acceptable fit in size X-small IOTVs were used to investigate gender differences within the same IOTV size. The torso dimensions selected for this comparison were in locations where donning the IOTV was thought to influence size differences: Chest Circumference, Waist Circumference, Chest Depth, Waist Depth, Chest Breadth, and Waist Breadth.

The Semi-Nude male and female measurements were compared to determine whether any body size differences within the X-small IOTV size category existed between males and females prior to donning the IOTV. The measurements in the Diver configuration were compared to determine whether any body size differences existed after donning the unloaded IOTV. The results are presented in Table 5. No significant differences were found between Semi-Nude males and females except for Chest Circumference, where male TPs (M= 927.20 mm) were larger than female TPs (M=858.80 mm), $p<.05$. When all the body dimensions for the Driver configuration were compared, no statistical differences were seen between males and females (see Table 5) for any of the dimensions. This suggests that once the IOTV is donned, gender has little or no effect on the torso dimensions within the same IOTV size category.

Table 5: Comparison of X-small male and female measurements for six torso dimensions in Semi-Nude and Driver configurations

Dimension	Gender	Semi-Nude (mm)				Driver (mm)			
		Mean	SD	*t*	p	Mean	SD	*t*	p
Chest Circumference	Male Female	927 859	39 23	3.35	***.01****	1163 1158	24 16	.37	.72
Waist (Omphalion) Circumference	Male Female	804 785	43 19	.92	.38	1168 1191	54 16	-.90	.39
Chest Depth	Male Female	221 228	9 13	-.89	.40	316 318	11 7	-.49	.64
Waist Depth	Male Female	211 204	17 19	.54	.61	335 350	21 16	-1.25	.25
Chest Breadth	Male Female	290 278	13 9	1.71	.13	319 314	12 16	.60	.56
Waist Breadth	Male Female	285 283	9 10	.36	.72	367 362	13 7	.76	.47

*Statistical significance at $p <.05$

The delta values between the two configurations for the males and females were also compared. They were computed by subtracting the measurements of the Semi-Nude configuration from the corresponding measurements in the Driver configuration so that only the increments due to the IOTV were compared. There were no statistically significant differences between genders for any torso delta values except for Chest Circumference (see Table 6). Since as previously mentioned there was a size difference for Chest Circumference between males and females that disappeared once the IOTV was donned, different delta values at Chest Circumference were expected.

Table 6: Comparison of X-small male and female delta values between Driver and Semi-Nude configurations for six torso dimensions

Dimension	Gender	Delta, Driver - Semi-Nude (mm)			
		Mean	**SD**	***t***	**p**
Chest Circumference	Male Female	236 316	19 34	-4.57	***.00****
Waist (Omphalion) Circumference	Male Female	364 406	40 27	-1.95	.09
Chest Depth	Male Female	94 91	4 10	.69	.51
Waist Depth	Male Female	124 146	14 22	-1.84	.10
Chest Breadth	Male Female	29 36	16 10	-.81	.44
Waist Breadth	Male Female	82 79	12 9	.43	.68

* Statistical significance at $p < .05$

These findings indicate that combining male and female encumbered anthropometric data for the torso area within the same IOTV size category would not be influenced by gender differences in the overall results. In other words, results suggest that the male torso data collected in this study can act as surrogate data for both genders except for Chest Circumference deltas. It is strongly recommended, however, that this gender difference be investigated more closely by including additional TPs and IOTV sizes.

2.5.3 Anthropometric Data

Once the observer error and gender difference analyses were completed, descriptive statistics including the mean, median, minimum, maximum, range (as well as 25th percentile and 75th percentile), and standard deviation were calculated for the 25 male TPs for 36 of the 42 measured anthropometric dimensions. In addition, the mean value for each configuration with the percent increment due to CIE relative to the Semi-Nude configuration was calculated for those TPs for the 23 of those 36 dimensions that were measured in all four IOTV configurations. (No calculations were done for the four sitting maximum dimensions nor for the standing maximum height or chest circumference dimensions.) Additional data analyses were done for two of the three groups of anthropometric dimensions mentioned in Section 2.4. The anthropometric data analysis was limited to male data in order to balance the total TPs' number per each size cell to 4 to 6 people (n=25) given the findings of the gender analysis.

For the 20 dimensions that were measured in all six configurations, a mixed design analysis of variance (ANOVA) was used to test for differences among the five IOTV sizes (XS, S, M, L, and XL) while subjecting the TPs to repeated measures. A mixed design ANOVA included a repeated measures ANOVA for within-subject variability and a one way ANOVA for betweensubjects variability. A repeated measures ANOVA was performed to investigate if the increments due to CIE relative to the Semi-Nude configuration (delta values) were statistically different among five configurations: Baseline, Driver, Rifleman, SAW Gunner, and Combat Medic. A one way ANOVA was performed along with a repeated measures ANOVA to test the differences on the overall delta among the five IOTV sizes. For all repeated measures ANOVAs, the concept of sphericity (i.e., that the variance of differences between the levels of the repeated measures design is equal) was examined using Mauchly's test (Mauchly, 1940). If the concept of sphericity was violated, one of the alternatives (i.e., the Greenhouse-Geisser, the Huynh-Feldt, or the Lower-bound corrections) was selected to report the statistics. The selection was dependent on the epsilon value. If the epsilon was greater than 0.75, the Huynh-Feldt correction was used. If the epsilon was smaller than 0.75, the Greenhouse-Geisser correction was used (Girden, 1992). To determine further differences among the means for both tests, a series of pairwise comparisons with Bonferroni corrections were performed to control for type I error for all pairwise comparisons ($\alpha_{\text{pairwise comparison}} = \alpha_{\text{family}} / N_{\text{pairwise comparisons}}$). Reported probabilities with Bonferroni correction were computed internally by SPSS.

For three of the eight maximum dimensions that were measured for only the four IOTV configurations, a mixed design ANOVA was performed on the delta values. Follow-up *post hoc* (Bonferroni) tests were completed on all pairwise comparisons. Since there were no Baseline or Semi-Nude locations to match to these dimensions in order to calculate the deltas, the closest Semi-Nude location was used (i.e., Waist Circumference at Omphalion for Maximum Waist Circumference). No deltas were calculated for the four sitting positions because no specific Semi-Nude landmark in the seated position was measured. No deltas were calculated for the height measurements because they were used only for calculation of maximum breath, circumference, and depth.

3. ANTHROPOMETRIC MEASUREMENT DESCRIPTIONS AND RESULTS

A total of 30 TPs (25 males and 5 females) were measured, and all body dimensions were input and analyzed. Given the results of the gender analysis (described in Section 2.5.2) showing no differences between males and females while wearing the size XS IOTV, the data for the female TPs were dropped from the rest of the analysis to provide an even distribution of TPs among all IOTV sizes. The distribution of Stature by Weight and Stature by Chest Circumference for all TPs was compared with current ANSUR II data (see Figure 11 and Figure 12). The ellipsoid represents the 95% range of the Army population. The TPs in the current study were well distributed from the X-small to X-large sizes.

This chapter provides a detailed description of the measurement of each anthropometric dimension and a summary of the results for the 25 male TPs, including a table of summary statistics for each dimension measured. The dimensions are grouped in five sections: 3.1) anthropometric reference heights, 3.2) standing anthropometry, 3.3) sitting anthropometry, 3.4) head and foot anthropometry, and 3.5) anthropometric maximum measurements. A graph of the mean values and percent increments relative to the Semi-Nude configuration by body location is also provided for each dimension (Sections 3.2, 3.3, and 3.4) that was measured for all four IOTV configurations.

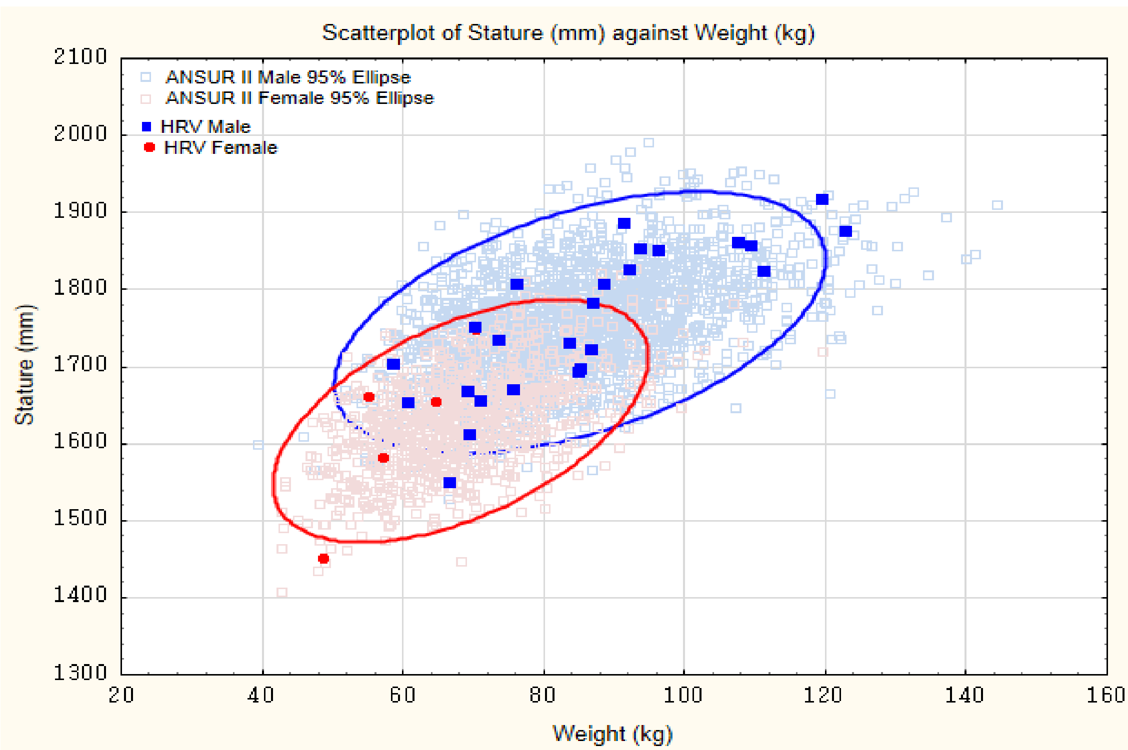


Figure 11: Stature by Weight distribution of TPs with ANSUR II data as background

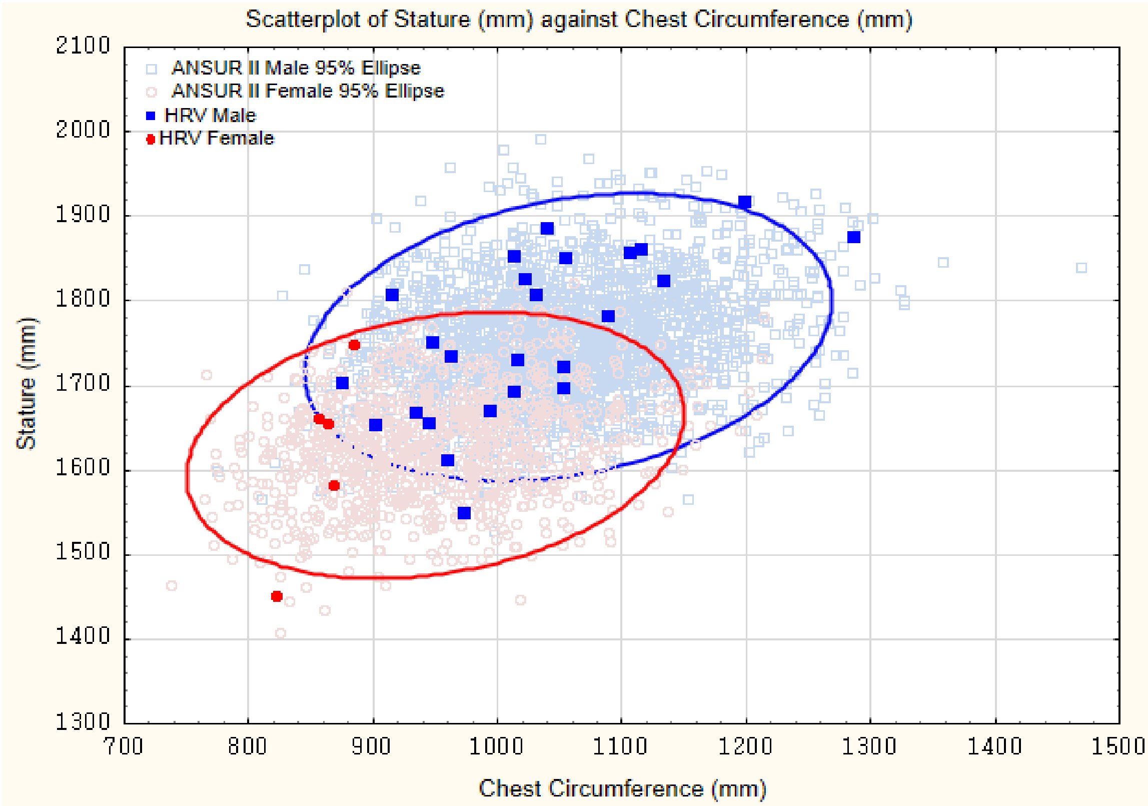


Figure 12: Stature by Chest circumference distribution of TPs with ANSUR II data as background

3.1 Anthropometric Reference Height Measurements

The height measurements in this section were used as landmarks to define where related breadth, depth and circumference measurements were taken. The height measurements are listed in the order in which they were taken. As shown in Table 2, these dimensions were measured only for the Semi-Nude and Baseline configurations because additional CIE would not add to those locations and thus no further changes were expected in the IOTV configurations. The differences between the Semi-Nude measurements and the Baseline measurements for these heights were relative only to the footwear worn (i.e. Army combat boots). The only non-height measurement included here is Buttock Circumference, which is included because it was also only measured in the Baseline and Semi-Nude configurations as no additional CIE was worn around the buttock region in this study.

Table 7 provides the summary results and delta calculations for these height and circumference measurements. In general, the heights differed by about 40 mm, the average amount added by the TP's combat boot heel.

Table 7: Distribution of mean deltas between Baseline and Semi-Nude measurements for single dimensions used as reference points for related depths, breadths, and circumferences (n=25)

Dimension	Configuration	Mean (mm)	SD (mm)	Min (mm)	25th (mm)	50th (mm)	75th (mm)	Max (mm)	Range (mm)	Absolute Mean Delta (mm)
Acromial Height	Semi-Nude	1441	93	1227	1374	1456	1517	1581	354	45.84
	Baseline	1487	93	1285	1420	1497	1555	1631	346	
Deltoid Height	Semi-Nude	1356	89	1150	1290	1367	1433	1493	343	45.04
	Baseline	1401	89	1191	1340	1418	1460	1549	358	
Chest Height	Semi-Nude	1293	81	1123	1224	1294	1369	1429	306	42.12
	Baseline	1335	80	1161	1277	1344	1405	1471	310	
Waist Height (Omphalion)	Semi-Nude	1070	72	908	1026	1068	1120	1213	305	43.92
	Baseline	1114	71	950	1076	1115	1174	1235	285	
Buttock Height	Semi-Nude	915.1	63	797	877	915	966	1024	227	39.76
	Baseline	954.9	65	842	920	948	1009	1064	222	
Knee Height, Suprapatella	Semi-Nude	528.5	41	454	504	521	544	625	171	37.56
	Baseline	566.1	39	500	543	564	588	662	162	
Knee Height Sitting, Suprapatella	Semi-Nude	566.6	41	480	537	580	592	653	173	39.64
	Baseline	606.2	39	529	584	600	630	701	172	
***Buttock Circumference**	Semi-Nude	1031	80	887	973	1035	1078	1160	273	66.88
	Baseline	1098	76	971	1043	1100	1140	1251	280	

*Buttock Circumference is included here, as it was measured only in the Semi-Nude and Baseline configurations

Acromial Height

Acromial Height is the vertical distance taken from a standing surface to the right Acromial landmark (see Figure 13). The TP is in the anthropometric standing position. The measurer stands to the right of the TP and uses an anthropometer to measure the vertical distance between the standing surface and the drawn Acromial landmark on the tip of the right shoulder. For the encumbered measurement, the method above is followed. If the CIE is a lightweight garment, the measurer palpates the Acromial landmarks and relocates the adhesive marker each time. The measurement is made at the maximum point of quiet respiration. The measurer is careful not to compress the CIE.

Figure 13: Acromial Height measurement

Chest Height

Chest Height is the vertical distance between the standing surface and the right Chest Point Anterior landmark (see Figure 14). The TP is in the anthropometric standing position. The measurer stands in front of the TP and uses an anthropometer to measure the vertical distance between the standing surface and the right Chest Point Anterior landmark. For the encumbered measurement, the right Chest Point Anterior landmark is transferred to all the CIE layers and measured as described above. The measurer verifies that this landmark did not shift when the TP donned the CIE. The measurement is taken at the maximum point of quiet respiration.

Figure 14: Chest Height measurement

Deltoid Height

Deltoid Height is the vertical distance between the standing surface and the right Deltoid landmark (see Figure 15). The TP is in the anthropometric standing position. The measurer stands to the right of the TP and uses an anthropometer to measure the vertical distance between the standing surface and the right Deltoid landmark. The measurement is taken at the maximum point of quiet respiration. The height is then transferred to the left Deltoid. For the encumbered measurement, the deltoid landmarks are rechecked for each additional CIE layer to be sure they did not shift while TP changed configurations. The measurement is taken as described above.

Figure 15: Deltoid Height measurement

Waist Height

Waist Height is the vertical distance between the standing surface and the Omphalion (belly button) landmark (see Figure 16). The TP is in the anthropometric standing position. The measurer stands in front of the TP and uses an anthropometer to measure the vertical distance between the standing surface and the center of the Omphalion. The measurement is made at the maximum point of quiet respiration. For the encumbered measurement this measurement is transferred to the other CIE layers to locate the waist landmarks. This landmark is checked each time to be sure it did not shift when TP changed CIE configurations.

Figure 16: Waist Height measurement

Buttock Height

Buttock Height is the vertical distance between the standing surface and the level of the maximum protrusion of the right buttock (see Figure 17). The TP stands in the anthropometric standing position and keeps the right arm out of the measurement area. The measurer stands at the right of the TP and uses an anthropometer to measure the vertical distance between the standing surface and the level of the maximum protrusion of the right buttock. A mark is placed at this location. This measurement is then transferred and drawn on the right and left thigh. For the encumbered measurement, Buttock Height is located on the CIE layers using adhesive markers that are placed at the posterior, left and right buttock locations. These landmarks are checked to be sure they have not moved when TP changed CIE configurations.

Figure 17: Buttock Height measurement

Knee Height, Suprapatella

Knee Height, Suprapatella is the vertical distance between a standing surface and the Suprapatella landmark (see Figure 18). The TP stands in the anthropometric standing position. The measurer stands at the right of the TP and uses an anthropometer to measure the vertical distance between the standing surface and the drawn Suprapatella landmark at the top of the knee. For the encumbered measurement, the above method is followed. However, it is necessary to place a raised adhesive marker at this location during the Semi-Nude configuration in order to relocate the correct location when the TP is wearing CIE. The measurer palpates for the raised landmark to measure height.

Figure 18: Knee Height, Suprapatella measurement

Knee Height Sitting, Suprapatella

Knee Height Sitting, Suprapatella is the vertical distance between a flat surface while the subject is seated and the Suprapatella landmark (see Figure 19). The TP sits on a table in the anthropometric sitting position (thighs level and knees at 90°) with the heels and knees approximately shoulder width apart with feet on a level, flat surface. The measurer stands at the right of the TP and uses an anthropometer to measure the vertical distance between this flat surface and the drawn Suprapatella landmark at the top of the knee. For the encumbered measurement, the measurer locates the raised adhesive landmark that was placed at this location and positions the anthropometer blade just behind the landmark to obtain the vertical measurement. The measurer is careful not to compress the CIE.

Figure 19: Knee Height Sitting, Suprapatella measurement

Buttock Circumference

Buttock Circumference is the horizontal circumference of the trunk at the level of the maximum protrusion of the right buttock (see Figure 20). The TP stands in the anthropometric standing position. The measurer stands at the TP's right, and uses a tape to measure the horizontal circumference of the trunk at the level of the maximum protrusion of the right buttock. The tape should pass over the posterior Buttock Point and the Buttock Point landmarks drawn on the right and left hips. If necessary, male TPs adjust their genitalia so as to interfere as little as possible with the tape. Measurers exert only enough tension on the tape to maintain contact between the tape and the measurement garment. For the encumbered measurement, the Buttock landmarks are transferred to the CIE layer using adhesive markers that are placed at the location of the Buttock landmarks. The measurer is careful not to compress the CIE.

Figure 20: Buttock Circumference measurement

3.2 Anthropometric Standing Measurements

All the measurements that were taken in the standing position are described in this section. Each body dimension was measured in all six configurations. Delta values (i.e., the differences calculated between the encumbered configurations and the Semi-Nude configuration) with standard deviations and additional summary results are presented in tabular and graphical format for each dimension. Extended anthropometric blades were developed and used for all encumbered measurements as the standard anthropometric blades were too short.

Chest Breadth

Chest Breadth is the maximum horizontal breadth of the chest at the level of the Chest Point Anterior landmark (see Figure 21). The TP is in the anthropometric standing position. The measurer stands in front of the TP and lines up the blades of the beam caliper at the level of Chest Point Anterior. The measurement is taken at maximum inspiration of the Chest. Measurers may have to tilt the beam caliber at an angle, as necessary, to get around larger pectoral muscles of male TPs or the breast tissue of female TPs. Lateral muscles are not included in the measurement. The chest tissue is not compressed during this measurement. The measurer uses the same methods for the encumbered measurements and checks to make sure that the Chest Height landmark did not change, and ensures there is no compression of the CIE.

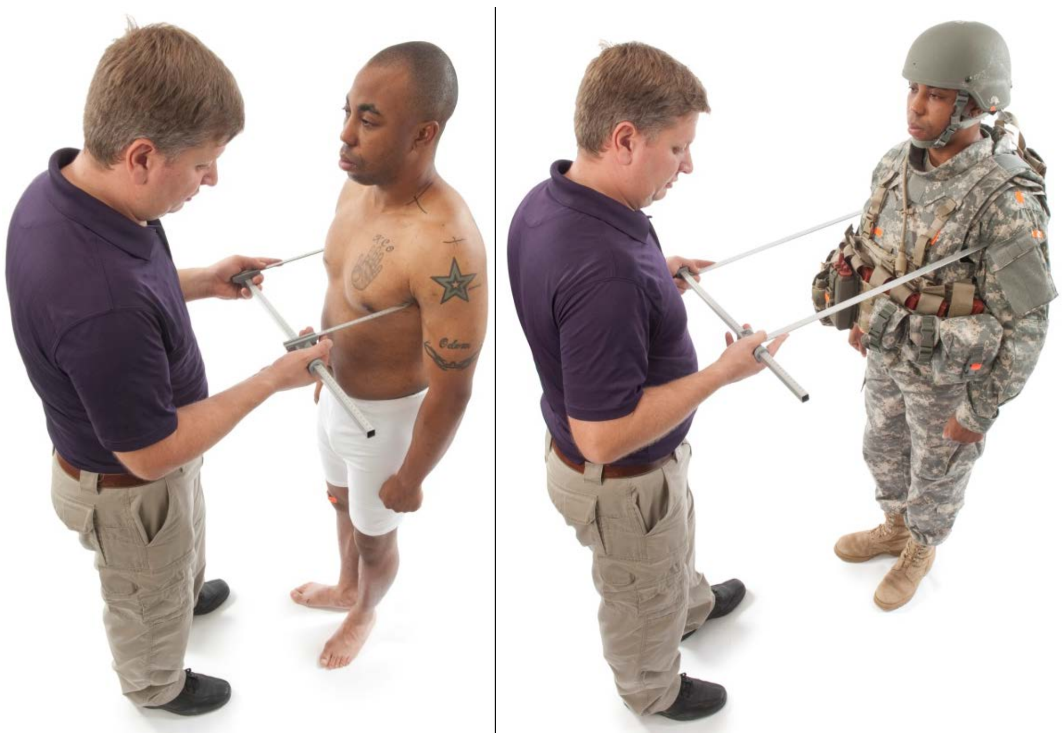


Figure 21: Chest Breadth measurement

A mixed design ANOVA was conducted to investigate whether the various CIE configurations had an effect on the delta values for Chest Breadth and to test for differences among IOTV sizes. The results are shown in Table 8 and are shown graphically with percent increments between configurations in Figure 22. The average delta values among IOTV sizes were statistically different F(4, 20)=3.61, p<.05. However, there were no statistically significant differences in all pairwise comparisons, p>.05. The average delta values among configurations were statistically different, F(4, 80)=123.123, p<.01. There were no statistically significant differences between the three loaded configurations: Rifleman (M=50.09 mm), SAW Gunner (M=46.74 mm), and Combat Medic (M=46.70 mm), p> .05, but they were all significantly larger than the Driver and Baseline configurations, p<.05. The delta for the Baseline configuration (M=10.48 mm) was also significantly smaller than the Driver configuration (M=40.56 mm), p<.05.

Table 8: Summary statistics and mean deltas for Chest Breadth for each configuration

	Semi-Nude (mm)	**Baseline (mm)**	**Driver (mm)**	**Rifleman (mm)**	**SAW Gunner (mm)**	**Combat Medic (mm)**
Δ from Semi-Nude	-	10^{C}	41^{B}	50^{A}	47^{A}	47^{A}
Δ SD	-	12	16	15	16	16
Mean	319	329	360	369	366	366
SD	28	26	27	31	28	25
Min	277	287	309	318	309	312
25th	300	308	345	353	355	356
50th	318	328	365	372	368	369
75th	338	349	378	387	385	382
Max	381	391	402	442	418	410
Range	104	104	93	124	109	98

A>B>C, Superscripts of different letters indicate significant differences at the p<.05 level.

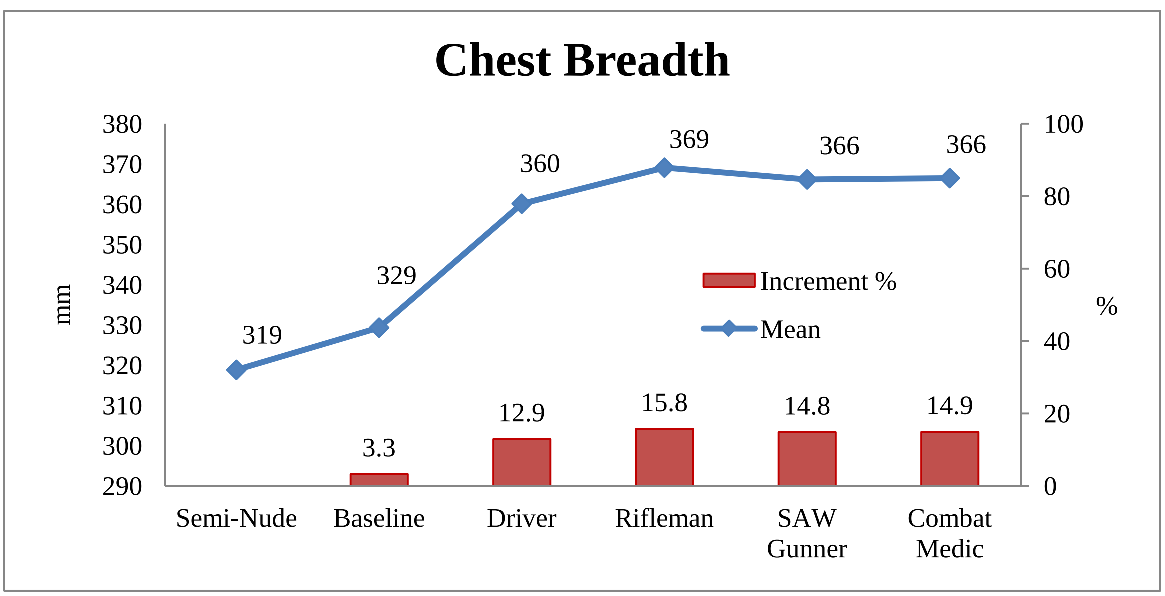


Figure 22: Percent increment relative to Semi-Nude and average Chest Breadth for each configuration

Chest Circumference

Chest Circumference is the maximum circumference of the chest at the fullest part of the breast region (see Figure 23). The TP is in the anthropometric standing position. The measurer stands in front of the TP and uses a tape to measure the horizontal circumference of the chest at the level of the right Chest Point Anterior landmark. The recorder checks the position of the tape as it crosses the TP's back. This dimension crosses very soft tissue at the armpit and bust, and some compression of the tissue will inevitably occur. All efforts are made to keep this compression to a minimum as measurers exert only enough tension on the tape to maintain contact between the tape and the skin. The tape measure spans the hollows between the shoulder blades and chest. The measurement is taken at the maximum point of quiet respiration. For the encumbered measurements, the Chest Point Anterior landmark is transferred to the CIE, rechecked in each configuration, and then measured using the same method as described above. The measurer ensures there is no compression of the CIE.

Figure 23: Chest Circumference measurement

A mixed design ANOVA was conducted to investigate whether the various CIE configurations had an effect on the delta values for Chest Circumference and to test for differences among IOTV sizes. The results are listed in Table 9 and shown graphically with percent increments between configurations in Figure 23. The average delta values among IOTV sizes were not statistically different $F(4, 19)=1.83$, $p=.17$. Since the assumption of sphericity was violated, $\chi^2(9)=32.87$, $p<.01$, $\varepsilon=0.489$, the Greenhouse-Geisser correction was used to report statistics. The average delta values among configurations were statistically different, $F(1.96, 37.16)=1902.24$, $p<.01$. The SAW Gunner configuration (M=374.81 mm) was the largest among all configurations, p<.05. There were no statistical differences between the Rifleman (M=344.50 mm) and the Combat Medic (M=341.35 mm) configurations, p>.05. These three loaded configurations were all larger than the Driver and the Baseline configurations, p<.05. The delta for the Driver configuration (M=260.25 mm) was also larger than the Baseline (M=33.94 mm) configuration, p<.05.

Table 9: Summary statistics and mean deltas for Chest Circumference for each configuration

	Semi-Nude (mm)	Baseline (mm)	Driver (mm)	Rifleman (mm)	SAW Gunner (mm)	Combat Medic (mm)
Δ from Semi-Nude	-	34^{D}	260^{C}	345^{B}	375^{A}	341^{B}
Δ SD	-	14	28	35	42	28
Mean	1024	1058	1283	1364	1401	1366
SD	94	95	92	81	65	87
Min	874	915	1140	1218	1307	1213
25th	959	988	1213	1315	1345	1307
50th	1014	1045	1287	1389	1405	1385
75th	1053	1097	1320	1403	1449	1400
Max	1285	1315	1508	1545	1542	1578
Range	411	400	368	327	235	365

A>B>C>D, Superscripts of different letters indicate significant differences at the p<.05 level.

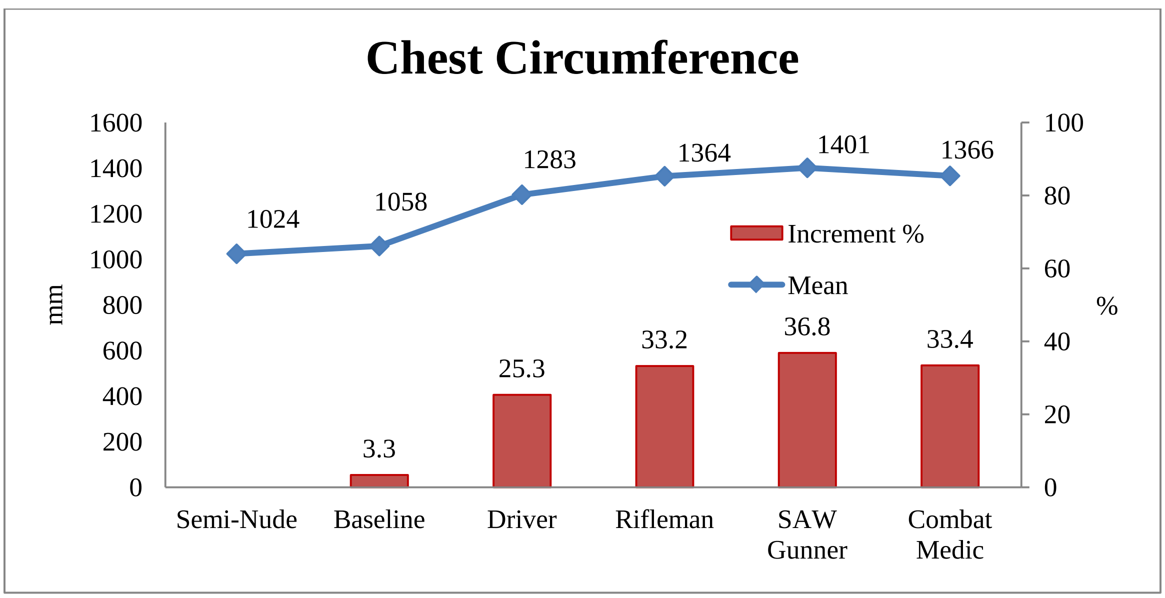


Figure 24: Percent increment relative to Semi-Nude and average Chest Circumference for each configuration

Chest Depth

Chest Depth is the horizontal distance between the right Chest Point Anterior landmark and the back at the same level (see Figure 25). The TP is in the anthropometric standing position. The measurer stands at the right of the TP and uses a beam caliper to measure the horizontal distance between the chest at the level of the right Chest Point Anterior landmark and the back at the same level. The measurer places the fixed blade of the caliper on the back, parallel to the floor. This measurement is taken at the maximum point of quiet respiration. The measurer exerts only enough pressure to maintain contact between the caliper and the skin. For the encumbered measurements, the right Chest Point Anterior landmark is transferred to the CIE layers and rechecked for each configuration. The measurement is then taken as described above. The measurer ensures there is no compression of the CIE.

Figure 25: Chest Depth measurement

A mixed design ANOVA was conducted to investigate whether the various CIE configurations had an effect on the delta values for Chest Depth and to test for differences among IOTV sizes. The results are listed in Table 10 and shown graphically with percent increments between configurations in Figure 26. The average delta values among IOTV sizes were not statistically different, $F(4, 20)=1.42$, $p=.27$. Since the assumption of sphericity was violated, $\chi^2(9)=17.143$, $p<.05$, $\varepsilon=0.699$, the Greenhouse-Geisser correction was used to report statistics. The average delta values among configurations were statistically different, $F(2.79, 55.88)=592.30$, $p<.01$. The SAW Gunner configuration (M=198.99 mm) was the largest and was statistically different than all the configurations, $p<.05$, except for the Rifleman configuration (M=180.73 mm), $p>.05$. There were no statistical differences between the Rifleman and the Combat Medic (M=175.71 mm) configurations, $p> .05$. These three loaded configurations were all statistically larger than the Driver and the Baseline configurations, p<.05. The delta for the Driver configuration (M=92.90 mm) was also statistically larger than the Baseline (M=7.58 mm) configuration, p<.05.

Table 10: Summary statistics and mean deltas for Chest Depth for each configuration

	Semi-Nude (mm)	Baseline (mm)	Driver (mm)	Rifleman (mm)	SAW Gunner (mm)	Combat Medic (mm)
Δ from Semi-Nude	-	8 ^{D}	93 ^{C}	181 ^{AB}	199 ^{A}	176 ^{B}
Δ SD	-	7	11	26	31	20
Mean	252	259	345	432	452	428
SD	32	33	31	43	23	28
Min	198	204	303	374	414	388
25th	224	236	325	401	429	406
50th	251	257	344	430	463	423
75th	265	276	360	441	468	448
Max	335	335	433	574	488	485
Range	137	131	130	200	74	97

A>B>C>D, Superscripts of different letters indicate significant differences at the p<.05 level.

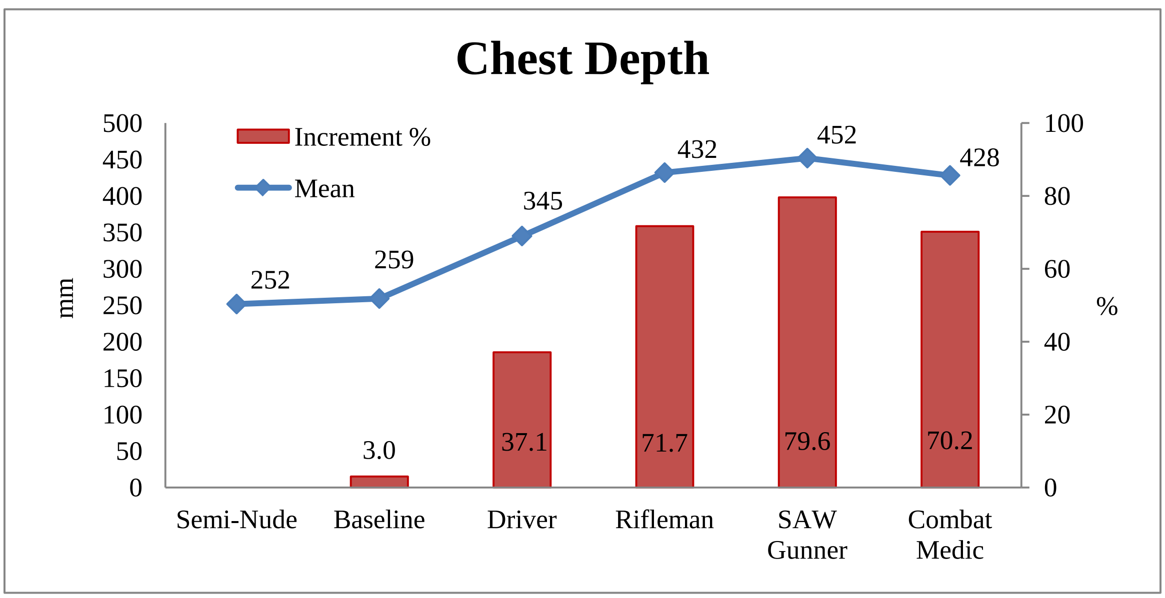


Figure 26: Percent increment relative to Semi-Nude and average Chest Depth for each configuration

Mid-Shoulder Height

Mid-Shoulder Height is the maximum vertical height taken from a standing surface to the Mid-Shoulder landmark (see Figure 27). The TP is in the anthropometric standing position. An anthropometer is used to measure the distance from the standing surface to the midpoint between the Acromial landmark and the Lateral Neck landmark. For the encumbered measurement, the Semi-Nude mid-shoulder landmark is transferred to each successive CIE layer using an adhesive marker. Care is taken not to compress the individual CIE layers.

Figure 27: Mid-Shoulder Height measurement

A mixed design ANOVA was conducted to investigate whether the various CIE configurations had an effect on the delta values for Mid-Shoulder Height and to test for differences among IOTV sizes. The results are listed in Table 11 and shown graphically with percent increments between configurations in Figure 28. The average delta values among IOTV sizes were not statistically different $F(4, 18)=1.08$, $p=.40$. Since the assumption of sphericity was violated, $\chi^2(9)=31.23$, $p<.01$, $\varepsilon=0.532$, the Greenhouse-Geisser correction was used to report statistics. The average delta values among the configurations were statistically different, $F(2.13, 38.30)=71.33$, $p<.01$. The Baseline configuration (M=45.95 mm) was smaller than all the IOTV configurations, $p<.05$. The Driver configuration (M=71.15 mm) had the largest delta, $p<.05$, of the four IOTV configurations while the SAW Gunner (M=54.35 mm) configuration had the smallest, $p<.05$.

There were no statistical differences between the Rifleman (M=61.08 mm) and the Combat Medic (M=59.82 mm) configurations, p> .05.

Table 11: Summary statistics and mean deltas for Mid-Shoulder Height for each configuration

	Semi-Nude (mm)	Baseline (mm)	Driver (mm)	Rifleman (mm)	SAW Gunner (mm)	Combat Medic (mm)
Δ from Semi-Nude	-	46 [D]	71 [A]	61 [B]	54 [C]	60 [B]
Δ SD	-	7	10	9	11	13
Mean	1479	1524	1549	1540	1525	1530
SD	95	95	96	95	94	95
Min	1274	1324	1347	1350	1340	1343
25th	1411	1449	1478	1464	1456	1457
50th	1478	1520	1532	1530	1515	1520
75th	1555	1600	1617	1606	1603	1602
Max	1625	1673	1705	1694	1685	1697
Range	351	349	358	344	345	354

A>B>C>D, Superscripts of different letters indicate significant differences at the p<.05 level.

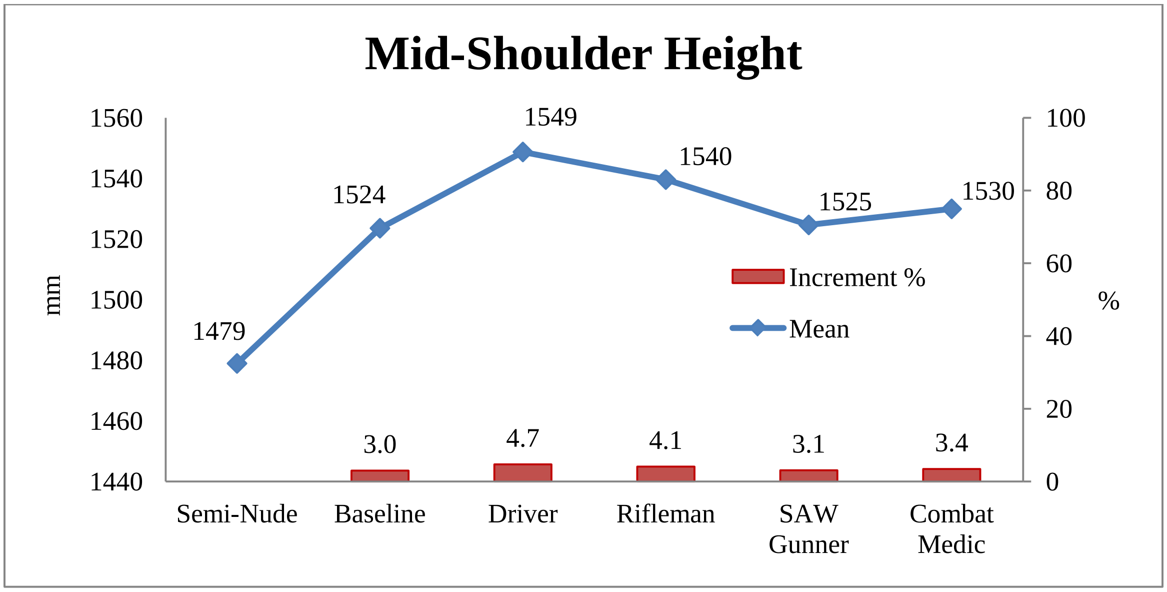


Figure 28: Percent increment relative to Semi-Nude and average Mid-Shoulder Height for each configuration

Shoulder Circumference

Shoulder Circumference is the maximum circumference of the shoulders at the level of the midpoints of the right and left deltoid muscles (see Figure 29). The TP is in the anthropometric standing position. The measurer stands in front of the TP and uses a measuring tape to measure the circumference of the shoulders at the level of the Deltoid landmarks. The tape passes over the drawn right and left Deltoid Point landmarks. The measurer exerts only enough tension on the tape to maintain contact between the tape and the skin. The measurement is taken at the maximum point of quiet respiration. For the encumbered measurement, the Deltoid landmarks are rechecked at each successive layer of the CIE to be sure they did not shift when TP changed configurtions. Care is taken not to compress the CIE.

Figure 29: Shoulder Circumference measurement

A mixed design ANOVA was conducted to investigate whether the various CIE configurations had an effect on the delta values for Shoulder Circumference, and to test for differences among IOTV sizes. The results are listed in Table 12 and shown graphically with percent increments between configurations in Figure 30. The average delta values among IOTV sizes were not statistically different $F(4, 19)=1.20$, $p=.34$, but the average delta values among the configurations were statistically different, $F(4, 76)=579.56$, $p<.01$. The SAW Gunner configuration (M=279.98 mm) was the largest among all configurations, $p<.05$. There were no statistical differences between the Rifleman (M=239.37 mm) and Combat Medic (M=244.14 mm) configurations, $p>.05$. These three loaded configurations were all larger than the Driver and the Baseline configurations, $p<.05$. The delta for the Driver configuration (M=170.55 mm) was also larger than the Baseline (M=65.16 mm) configuration, $p<.05$.

Table 12: Summary statistics and mean deltas for Shoulder Circumference for each configuration

	Semi-Nude (mm)	Baseline (mm)	Driver (mm)	Rifleman (mm)	SAW Gunner (mm)	Combat Medic (mm)
Δ from Semi-Nude	-	65 [D]	171 [C]	239 [B]	280 [A]	244 [B]
Δ SD	-	21	23	25	34	26
Mean	1231	1297	1403	1470	1512	1470
SD	88	85	84	78	84	78
Min	1075	1168	1270	1341	1355	1328
25th	1169	1239	1347	1434	1452	1435
50th	1235	1293	1390	1475	1519	1478
75th	1278	1337	1451	1512	1555	1518
Max	1418	1493	1582	1645	1675	1629
Range	343	325	312	304	320	301

A>B>C>D, Superscripts of different letters indicate significant differences at the p<.05 level.

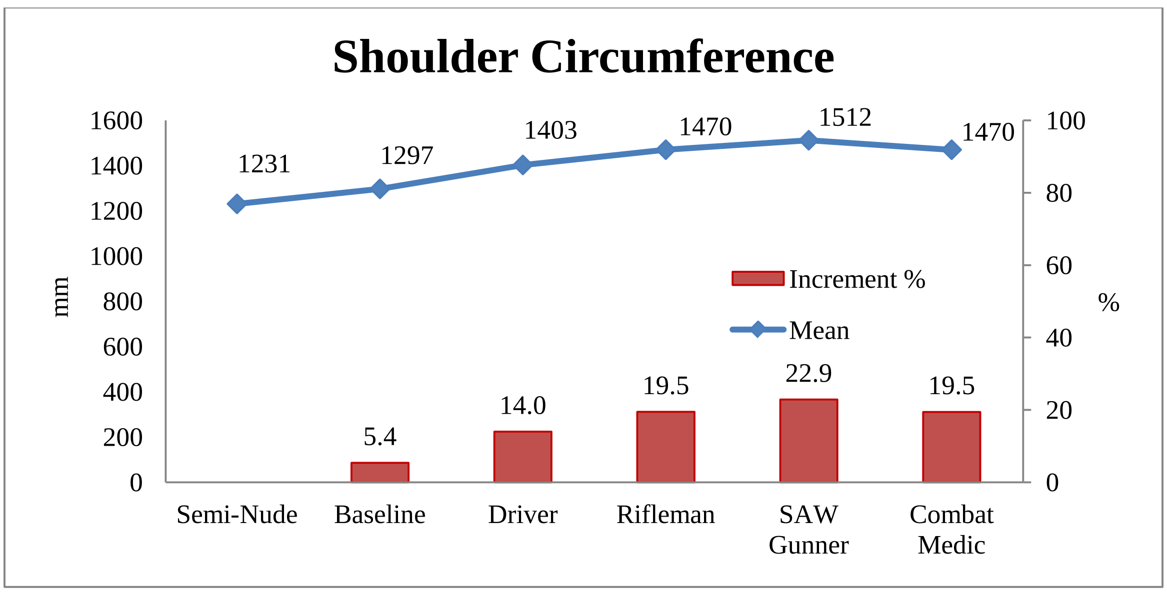


Figure 30: Percent increment relative to Semi-Nude and average Shoulder Circumference for each configuration

Stature

Stature is the vertical distance from a standing surface to the top of the head (see Figure 31). The TP is in the anthropometric standing position with the head in the Frankfort Horizontal plane. The measurer stands at the right side of the TP and uses an anthropometer to measure the vertical distance. The measurer moves the blade of the anthropometer across the top of the TP’s head to ensure measurement of the maximum distance. The measurer uses firm pressure to compress the TP's hair. The measurement is taken at the maximum point of quiet respiration. For the encumbered measurement, the same method described above is followed, but care is taken not to compress the CIE, in this case either the ACH or the CVC. The measurement is taken at the top of the ACH or CVC. Note: the NVDs can add almost 102 mm (4 in) to the overall stature when they are in the up position.

Figure 31: Stature measurement

A mixed design ANOVA was conducted to investigate whether the various CIE configurations had an effect on the delta values for Stature, and to test for differences among IOTV sizes. The results are listed in Table 13 and shown graphically with percent increments between configurations in Figure 32. The average delta values among IOTV sizes were not statistically different F(4, 20)=1.84, p=.16. Since the assumption of sphericity was violated, $\chi^2(9)=27.36$, p<.01, ε=0.561, the Greenhouse-Geisser correction was used to report statistics. The average delta values among configurations were statistically different, F(2.24, 48.87)=64.32, p<.01. The

Baseline configuration delta (M=39.05 mm) was statistically smaller than all the other configurations, $p<.05$. There were no statistical differences among the deltas for the Driver (M=63.39 mm), the Rifleman (M=62.08 mm), the SAW Gunner (M=61.25 mm), and the Combat Medic (M=59.73 mm) configurations, $p>.05$.

Table 13: Summary statistics and mean deltas for Stature for each configuration

	Semi-Nude (mm)	**Baseline (mm)**	**Driver (mm)**	**Rifleman (mm)**	**SAW Gunner (mm)**	**Combat Medic (mm)**
Δ from Semi-Nude	-	39^{B}	63^{A}	62^{A}	61^{A}	60^{A}
Δ SD	-	7	9	12	11	12
Mean	1070	1800	1825	1824	1823	1821
SD	518	97	94	95	96	95
Min	88	1591	1628	1626	1627	1625
25th	894	1723	1747	1747	1747	1745
50th	1233	1790	1822	1816	1807	1820
75th	1433	1894	1908	1907	1913	1900
Max	1625	1958	1980	2000	1987	1988
Range	1537	367	352	374	360	363

A>B>C>D, Superscripts of different letters indicate significant differences at the $p<.05$ level.

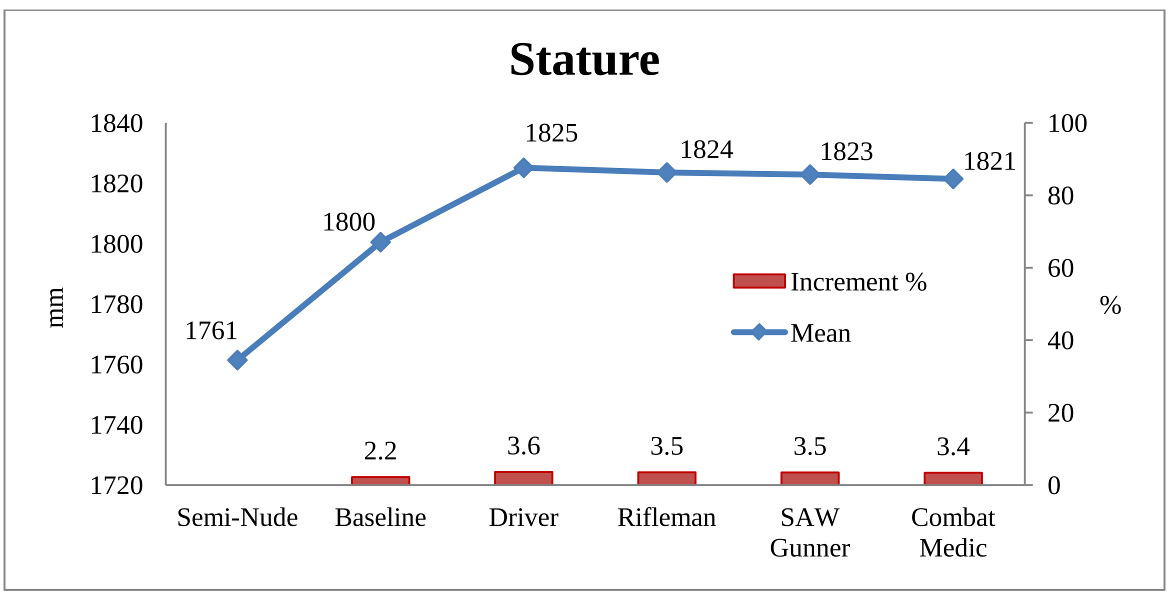


Figure 32: Percent increment relative to Semi-Nude and average Stature for each configuration

Vertical Trunk (USA) Circumference

Vertical Trunk (USA) Circumference is the vertical circumference of the trunk on a line passing through the crotch and over the fullest part of the Chest, Mid-Shoulder, and Buttock Point, posterior (see Figure 33). The TP stands in the anthropometric standing position with the feet about 10 cm apart to allow the placement of a tape in the crotch and then brings the heels together. (On men, the tape passes to the right of the scrotum.). The measurer stands at the right of the TP. The zero end of the tape is brought upward to pass midway between the sternum and the anterior axillary fold and over the Mid-Shoulder landmark. The other side of the tape is brought up the back and to the Mid-Shoulder landmark crossing the maximum protrusion of the right buttock. The measurer holds the case of the tape on the upper chest to help keep the tape in place and asks the TP or the data recorder to hold the tape over the right upper breast with the left hand (if needed). The measurer exerts only enough tension on the tape to maintain contact between the tape and the skin. The tape spans body hollows. The measurement is taken at the maximum point of quiet respiration. For the encumbered measurement, the above method is followed, and care is taken not to compress the CIE. In the encumbered configurations, the measurers make sure to maintain the same plane of measurement as when measuring the Semi-Nude configuration. In some configurations, depending on the CIE, a longer or second tape measure may be needed to capture the full measurement. If a second tape is used, the measurer locates the zero mark at the end of the first tape and continues the measurement procedure.

Figure 33: Vertical Trunk (USA) Circumference measurement

A mixed design ANOVA was conducted to investigate whether the various CIE configurations had an effect on the delta values for Vertical Trunk (USA) Circumference, and to test for differences among IOTV sizes. The results are listed in Table 14 and shown graphically with percent increments between configurations in Figure 34. The average delta values among IOTV sizes were not statistically different $F(4, 18)=0.43$, $p=.78$, but the average delta values among the different configurations were statistically different, $F(4, 72)=232.68$, $p<.01$. Among the three loaded configurations, Combat Medic (M=237.13 mm) was statistically smaller than both the SAW Gunner (M=299.05 mm) and the Rifleman (M=298.00 mm) configurations, $p<.05$. There were no statistical differences between the SAW Gunner and the Rifleman configurations, $p>.05$. The three loaded configurations were all statistically larger than the Driver and the Baseline configurations, $p<.05$. The delta for the Driver configuration (M=167.34 mm) was statistically larger than the Baseline (M=56.04 mm) configuration, $p<.05$.

Table 14: Summary statistics and mean deltas for Vertical Trunk (USA) Circumference for each configuration

	Semi-Nude (mm)	Baseline (mm)	Driver (mm)	Rifleman (mm)	SAW Gunner (mm)	Combat Medic (mm)
Δ from Semi-Nude	-	56 [D]	167 [C]	298 [A]	299 [A]	237 [B]
Δ SD	-	36	34	56	54	45
Mean	1719	1773	1885	2014	2011	1953
SD	115	117	110	111	113	110
Min	1497	1570	1659	1832	1827	1759
25th	1642	1672	1790	1924	1928	1897
50th	1714	1784	1891	2013	2005	1957
75th	1807	1833	1952	2080	2058	2000
Max	1954	2045	2170	2272	2285	2305
Range	457	475	511	440	458	546

A>B>C>D, Superscripts of different letters indicate significant differences at the p<.05 level.

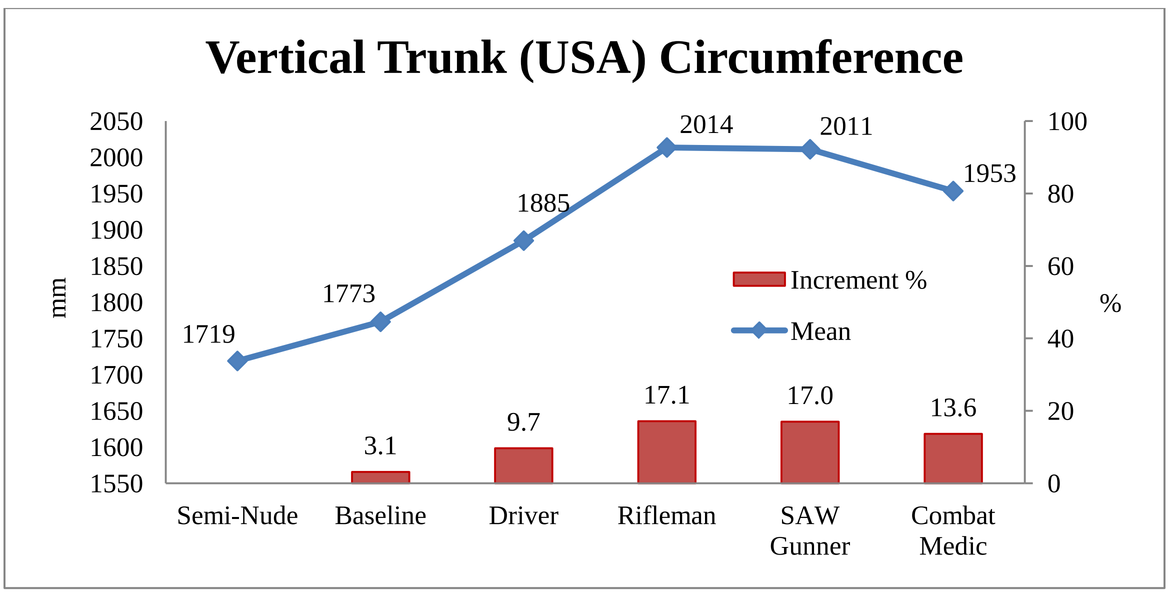


Figure 34: Percent increment relative to Semi-Nude and average Vertical Trunk (USA) Circumference for each configuration

Waist (Omphalion) Breadth

Waist (Omphalion) Breadth is the horizontal breadth of the waist at the level of the Omphalion (see Figure 35). The TP is in the anthropometric standing position. The measurer stands in front of the TP and uses a beam caliper to measure the horizontal breadth of the waist from the drawn landmark at right Waist (Omphalion) to the drawn landmark at left Waist (Omphalion). The measurer exerts only enough pressure to maintain contact between the caliper and the skin. The measurement is taken at the maximum point of quiet respiration. For the encumbered measurement, the method above is followed. The measurer takes care not to compress the CIE. Waist landmarks are transferred from the Semi-Nude configuration using a laser level transfer rod and adhesive markers. Adhesive markers should be rechecked during each configuration change.

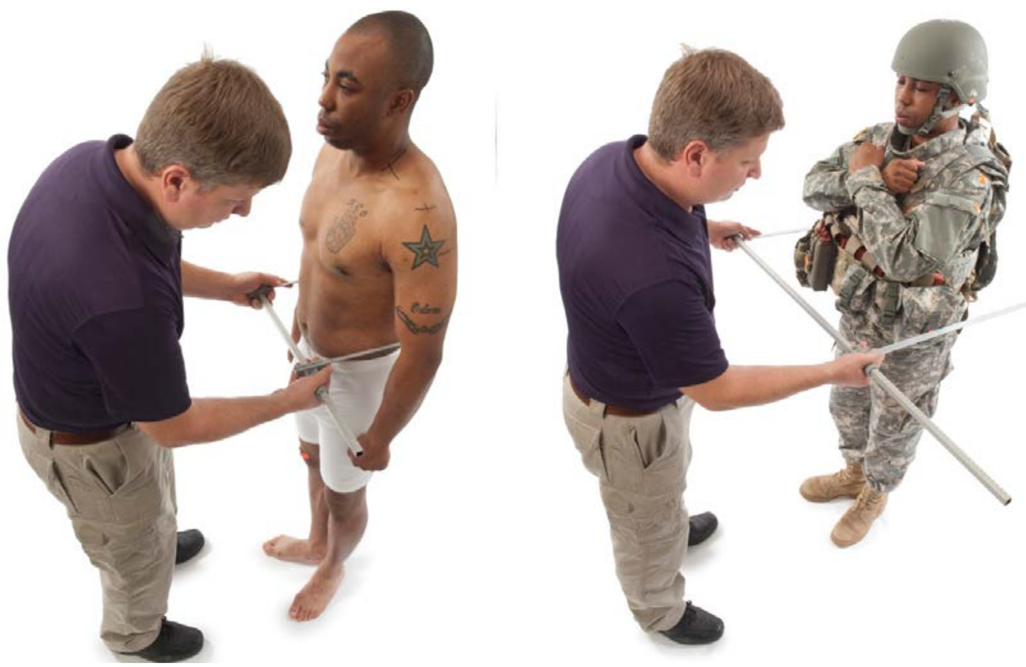


Figure 35: Waist (Omphalion) Breadth measurement

A mixed design ANOVA was conducted to investigate whether the various CIE configurations had an effect on the delta values for Waist (Omphalion) Breadth and to test for differences among IOTV sizes. The results are listed in Table 15 and shown graphically with percent increments between configurations in Figure 36. The average delta values among IOTV sizes were statistically different $F(4, 19)=21.02$, $p<.01$. There were no statistical differences for the delta values between X-small (M=204.96 mm) and Small (M=206.52 mm) size IOTVs, but delta values from these two sizes were statistically larger than sizes Large (M=179.60 mm) and X-large (M=154.00 mm). The size Medium (M=192.00 mm) IOTV deltas were not statistically different from size X-small, Small, and Large. Delta values from size X-large (M=154.00 mm) were statistically smaller than all of the other sizes. One reason for the differences is that the width of the TAP matched the surface area of the larger sized IOTVs better than the smaller sized IOTVs. With the smaller IOTV sizes, there was the possibility of slight gapping between the IOTV surface and the TAP panel, thereby potentially increasing circumference measurements to the individual in these cases.

Since the assumption of sphericity was violated, $\chi^2(9)=28.26$, $p<.01$, $\varepsilon=0.584$ between CIE configurations, the Greenhouse-Geisser correction was used to report statistics. The average delta values among configurations were statistically different, $F(4, 76)=2243.08$, $p<.01$. The SAW Gunner configuration (M=299.83 mm) was the largest of all configurations, $p<.01$. There were no statistical differences between the Rifleman (M=287.33 mm) and the Combat Medic (M=279.96 mm), $p> .05$. All loaded configurations were all larger than the Driver and the Baseline, $p<.05$. The delta for the Driver (M=73.04 mm) was larger than the Baseline (M=3.88 mm), $p<.05$.

Table 15: Summary statistics and mean deltas for Waist Breadth for each configuration

	Semi-Nude (mm)	Baseline (mm)	Driver (mm)	Rifleman (mm)	SAW Gunner (mm)	Combat Medic (mm)
Δ from Semi-Nude	-	4 ^{D}	73 ^{C}	287 ^{B}	300 ^{A}	280 ^{B}
Δ SD	-	8	19	33	22	37
Mean	321	326	394	609	620	601
SD	36	34	24	15	20	22
Min	278	280	346	583	585	552
25th	293	298	372	602	608	587
50th	317	329	395	607	617	603
75th	343	341	409	620	628	611
Max	417	416	445	638	673	656
Range	139	136	99	55	88	104

A>B>C>D, Superscripts of different letters indicate significant differences at the p<.05 level.

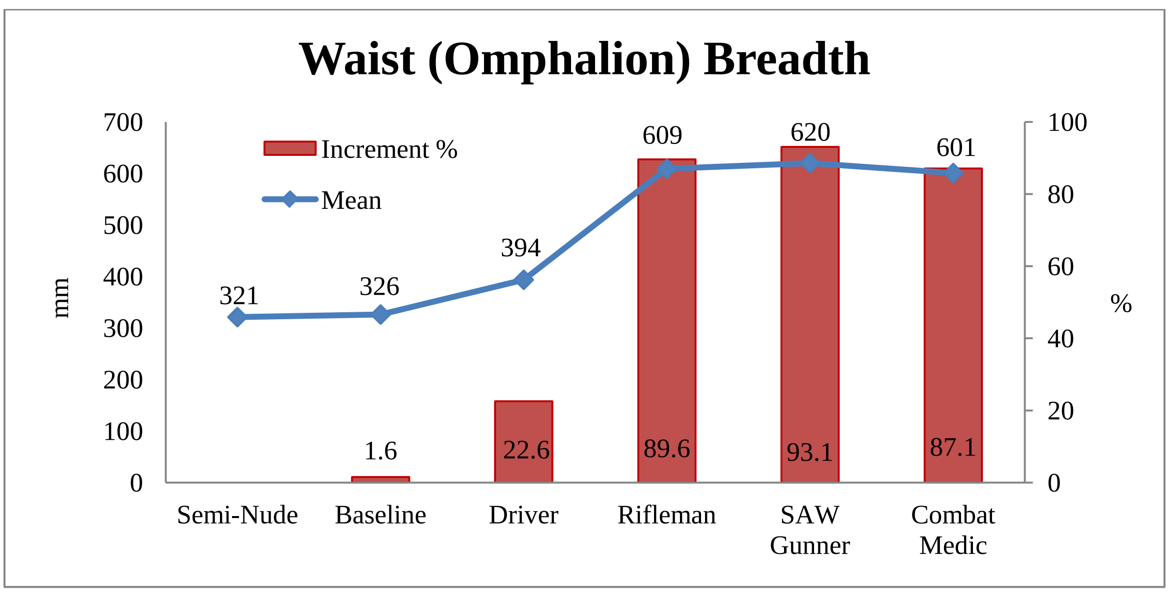


Figure 36: Percent increment relative to Semi-Nude and average Waist Breadth for each configuration

Waist (Omphalion) Circumference

Waist (Omphalion) Circumference is the horizontal circumference of the waist at the level of Omphalion encompassing the Waist (Omphalion) landmarks (see Figure 37). The TP is in the anthropometric standing position. The measurer stands in front of the TP and uses a tape to measure the horizontal distance around the torso at the level of the center of the Omphalion. The tape passes over the drawn Waist (Omphalion) landmarks at the front, back, and sides. The measurer exerts only enough tension on the tape to maintain contact between the tape and the body or CIE, without compressing the CIE, and follows the adhesive Waist landmarks during the encumbered measurements. All measurements are made at the maximum point of quiet respiration. The height of the adhesive landmarks should be rechecked for each configuration.

Figure 37: Waist (Omphalion) Circumference measurement

A mixed design ANOVA was conducted to investigate whether the various CIE configurations had an effect on the delta values for Waist (Omphalion) Circumference and to test for differences among IOTV sizes. The results are listed in Table 16 and shown graphically with percent increments between configurations in Figure 38. The average delta values among IOTV sizes were statistically different $F(4, 19)=9.80$, $p<.01$. There were no statistical differences for delta values between the size X-small (M=648.00 mm) and Small (M=653.32 mm) IOTVs, but the delta values from these two sizes were statistically larger than sizes Large (M=569.20 mm) and X-large (M=522.20 mm) IOTVs, $p<.05$. The size Medium (M=595.32 mm) IOTV was not statistically different from all the other sizes. There were no statistical differences between the delta values for the size Large (M=569.20 mm) and the size X-large IOTV (M=154.00 mm), $p>.05$. One reason for the differences is that the width of the TAP matched the surface area of the larger sized IOTVs better than the smaller sized IOTVs. With the smaller IOTV sizes, there was the possibility of slight gapping between the IOTV surface and the TAP, thereby potentially increasing circumference measurements to the individual in these cases.

Since the assumption of sphericity was violated for CIE configurations, $\chi^2(9)=18.3$, $p<.05$, $\varepsilon=0.658$, the Greenhouse-Geisser correction was used to report statistics. The average delta values among CIE configurations were statistically different, $F(2.63, 49.97)=5014.37$, $p<.01$. The Combat Medic configuration (M=887.03 mm) was the largest among all of the configurations, $p<.01$. There were no statistical differences between the Rifleman (M=865.00 mm) and the SAW Gunner (M=862.90 mm), $p> .05$. The three loaded configurations were all larger than the Driver and the Baseline, $p<.05$. The delta for the Driver (M=336.32 mm) was also significantly larger than the Baseline (M=36.79 mm), $p<.05$.

Table 16: Summary statistics and mean deltas for Waist (Omphalion) Circumference for each configuration

	Semi-Nude (mm)	Baseline (mm)	Driver (mm)	Rifleman (mm)	SAW Gunner (mm)	Combat Medic (mm)
Δ from Semi-Nude	-	37^{D}	336^{C}	865^{B}	863^{B}	887^{A}
Δ SD	-	14	58	82	80	82
Mean	901	938	1237	1771	1768	1792
SD	98	93	68	42	49	43
Min	767	801	1087	1699	1671	1725
25th	820	870	1188	1752	1738	1763
50th	893	920	1237	1766	1775	1792
75th	948	992	1278	1784	1790	1815
Max	1162	1179	1415	1902	1882	1910
Range	395	378	328	203	211	185

A>B>C>D, Superscripts of different letters indicate significant differences at the p<.05 level.

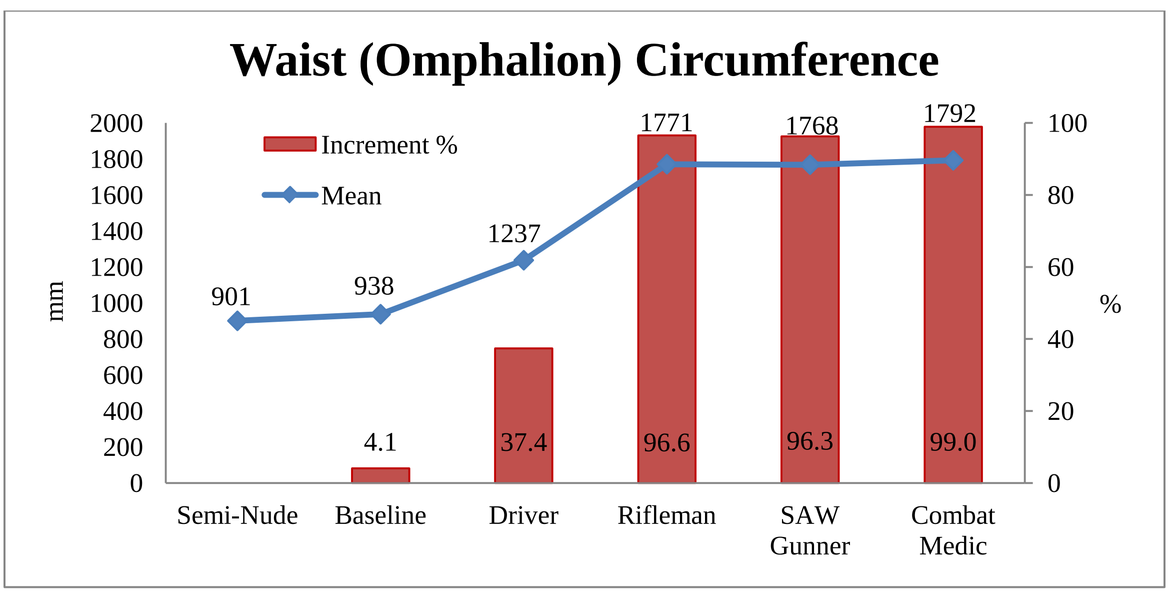


Figure 38: Percent increment relative to Semi-Nude and average Waist (Omphalion) Circumference for each configuration

Waist (Omphalion) Depth

Waist (Omphalion) Depth is the horizontal distance between the front and the back of the waist at the level of the Omphalion (see Figure 39). The TP is in the anthropometric standing position. The measurer stands at the right of the TP and uses a beam caliper to measure the horizontal distance between the drawn landmarks at Waist (Omphalion), Posterior and Waist (Omphalion), Anterior. The fixed blade of the caliper is on the TP's back. The measurer exerts only enough pressure to attain contact between the caliper and the skin, or CIE without compressing the CIE, and transfers the Semi-Nude landmarks to the various CIE layers with adhesive markers for the encumbered measurements. The location of the adhesive landmarks are rechecked for each configuration. The measurements are taken at the maximum point of quiet respiration.

Figure 39: Waist (Omphalion) Depth measurement

A mixed design ANOVA was conducted to investigate whether the various CIE configurations had an effect on the delta values for Waist (Omphalion) Depth and to test for differences among IOTV sizes. The results are listed in Table 17 and shown graphically with percent increments between configurations in Figure 40. The average delta values among IOTV sizes were not statistically different, $F(4, 19)=2.01$, $p=.13$. Since the assumption of sphericity was violated, $\chi^2(9)=36.66$, $p<.01$, $\varepsilon=0.499$, the Greenhouse-Geisser correction was used to report statistics. The average delta values among the configurations were statistically different, $F(4, 76)=816.78$, $p<.01$. There were no statistical differences between the three loaded configurations: Rifleman (M=303.74 mm), SAW Gunner (M=293.84 mm), and Combat Medic (M=308.50 mm), $p> .05$. These three were all larger than the Driver and the Baseline configurations, $p<.05$. The delta for the Baseline configuration (M=10.48 mm) was significantly smaller than the Driver configuration (M=128.57 mm), $p<.05$.

Table 17: Summary statistics and mean deltas for Waist (Omphalion) Depth for each configuration

	Semi-Nude (mm)	Baseline (mm)	Driver (mm)	Rifleman (mm)	SAW Gunner (mm)	Combat Medic (mm)
Δ from Semi-Nude	-	10 C	129 B	304 A	294 A	309 A
Δ SD	-	9	23	28	42	18
Mean	231	241	359	535	527	535
SD	26	28	26	26	33	34
Min	191	204	310	487	401	437
25th	212	217	339	517	512	528
50th	229	240	360	537	536	537
75th	252	261	377	547	544	550
Max	290	304	405	600	572	605
Range	99	100	95	113	171	168

A>B>C>D, Superscripts of different letters indicate significant differences at the p<.05 level.

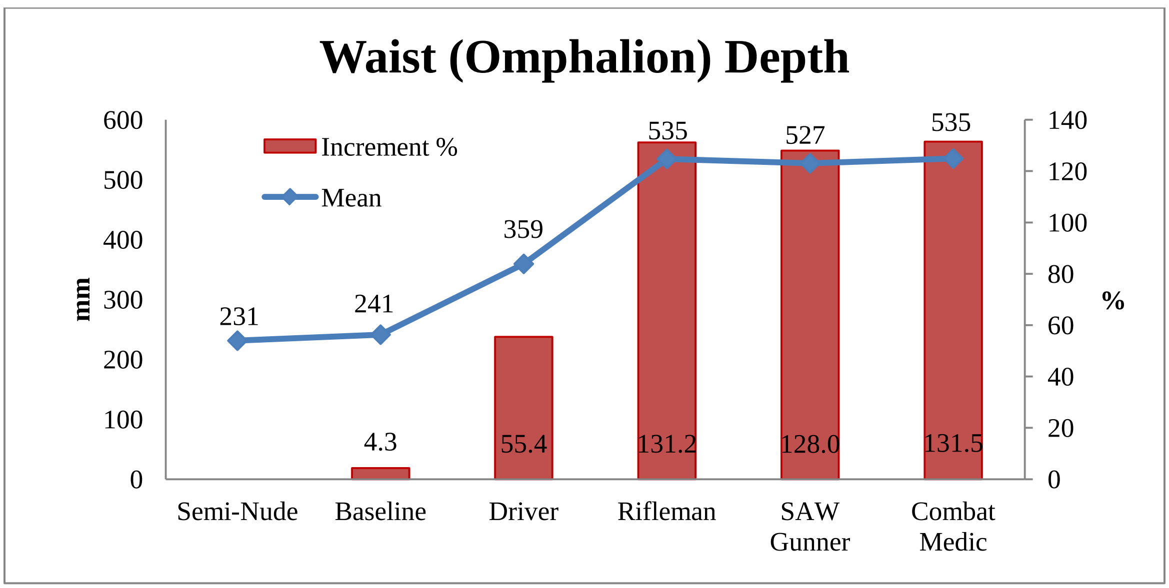


Figure 40: Percent increment relative to Semi-Nude and average Waist Depth for each configuration

Weight (kg)

Weight is the maximum weight of a TP. The TP stands on the platform of the scale with weight distributed evenly on both feet (see Figure 41). The measurer stands to the right or in front of the TP and records the Weight of the TP to the nearest tenth of a kg. The same procedure is followed for each of the encumbered configurations.

Figure 41: Weight (kg) measurement

A mixed design ANOVA was conducted to investigate whether the various CIE configurations had an effect on the delta values for Weight (kg) and to test for differences among IOTV sizes. The results are listed in Table 18 and shown graphically with percent increments between configurations in Figure 42. The average delta values among IOTV sizes were statistically different $F(4, 19)=42.947$, $p<.01$. The size X-large (M=24.25 kg) IOTV was the heaviest, $p<.05$. There were no statistical differences between the size Medium (M=22.24 kg) and the size Large (M=22.62 kg) IOTV, $p>.05$. The size Small (M=21.08 kg) IOTV was statistically lighter than the size Large IOTV, $p<.05$, but did not differ from the size Medium, $p>.05$. The size X-small (M=19.36 kg) IOTV was statistically lighter than all other sizes, $p<.05$. Since the assumption of sphericity was violated, $\chi^2(9)=17.08$, $p<.05$, $\varepsilon=0.678$, the Greenhouse-Geisser correction was used to report statistics. The average delta values among the CIE configurations were statistically different, $F(4, 76)=117438.02$, $p<.01$. All configurations were different from one another. The SAW Gunner configuration (M=32.98 kg) was the heaviest among all of the configurations. This was followed by the Rifleman configuration (M=28.48 kg), the Combat Medic configuration

(M=26.18 kg), then the Driver configuration (M=18.18 kg), and finally the Baseline (M=3.72 kg) configuration, p<.05.

Table 18: Summary statistics and mean deltas for Weight (kg) for each configuration

	Semi-Nude	Baseline	Driver	Rifleman	SAW Gunner	Combat Medic
Δ from Semi-Nude	-	4 [E]	18 [D]	28 [B]	33 [A]	26 [C]
Δ SD	-	1	2	2	2	2
Mean	86	90	104	114	119	112
SD	18	18	20	20	20	20
Min	58	62	73	83	88	81
25th	71	75	86	97	101	95
50th	85	89	104	114	118	112
75th	94	98	112	123	127	120
Max	123	126	143	154	158	151
Range	64	65	70	70	70	70

A>B>C>D>E, Superscripts of different letters indicate significant differences at the p<.05 level.

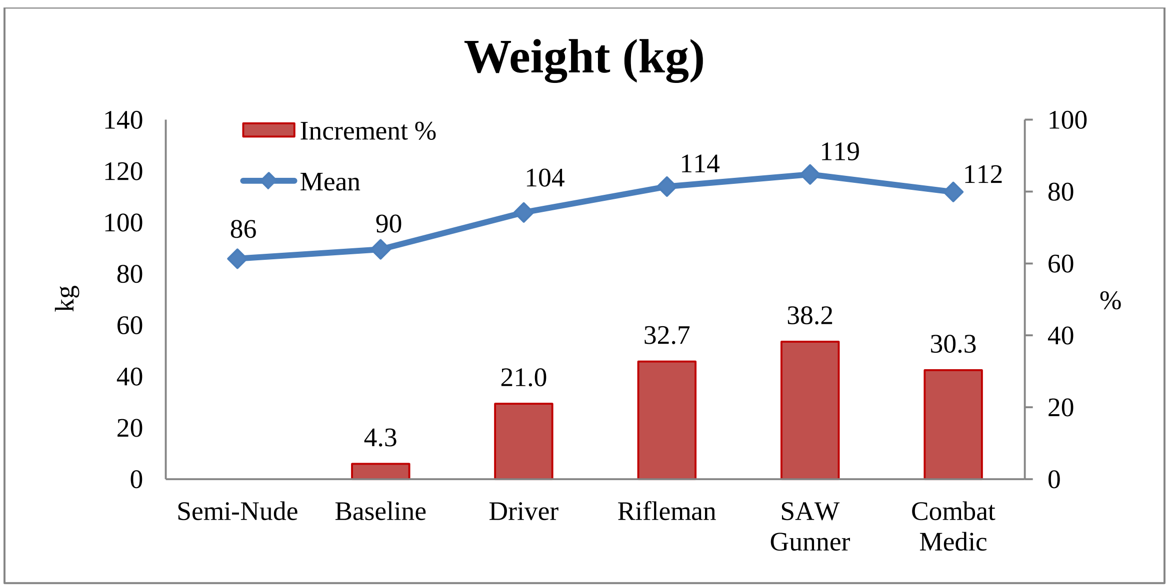


Figure 42: Percent increment relative to Semi-Nude and average Weight (kg) for each configuration

3.3 Anthropometric Seated Measurements

All the measurements that were taken in the sitting position are described in this section. Each body dimension was measured in all six configurations. Delta values (i.e., the differences calculated between the encumbered configuration and the Semi-Nude configurations) with standard deviations and additional summary results are presented in tabular and graphical format for each dimension. The extended anthropometric blades were used for all encumbered measurements. In some cases the TP was not able to sit completely straight due to restrictions of the equipment and/or the weight of the equipment. This may introduce additional variability in the overall measurement results that the researcher should be aware of.

Biacromial Breadth

Biacromial Breadth is the horizontal distance between the right and left Acromial landmarks on the tips of the shoulders (see Figure 43). The TP is in the anthropometric sitting position. The measurer stands behind the TP and uses a beam caliper to measure the distance between the right and left Acromial landmarks at the tips of the shoulders. The beam should be parallel to the coronal plane. If the Acromial landmarks cannot be seen from behind, the measurer stands in front of the TP. The measurement is taken at the maximum point of quiet respiration. The measurer uses sufficient pressure to maintain contact with the skin, or CIE without compressing the CIE. Adhesive markers are placed at the location of the Acromial landmarks and are rechecked for each configuration.

Figure 43: Biacromial Breadth measurement

A mixed design ANOVA was conducted to investigate whether the various CIE configurations had an effect on the delta values for Biacromial Breadth and to test for differences among IOTV sizes. The results are listed in Table 19 and shown graphically with percent increments between configurations in Figure 44. The average delta values among IOTV sizes were not statistically different, $F(4, 20)=1.41$, $p=.27$. Since the assumption of sphericity was violated, $\chi^2(9)=19.19$, $p<.05$, $\varepsilon=0.676$, the Greenhouse-Geisser correction was used to report statistics. The average delta values among configurations were statistically different, $F(2.70, 54.07)=10.49$, $p<.01$. There were no statistical differences between the CIE configurations: Driver (M=8.87 mm), Rifleman (M=13.20 mm), SAW Gunner (M=12.02 mm), and Combat Medic (M=13.18 mm), p>.05. These were, however, all statistically larger than the Baseline configuration (M=4.76 mm), p<.05, except for the Driver configuration. There were no statistical differences between the Baseline and the Driver configurations, p>.05.

Table 19: Summary statistics and mean deltas for Biacromial Breadth for each configuration

	Semi-Nude (mm)	**Baseline (mm)**	**Driver (mm)**	**Rifleman (mm)**	**SAW Gunner (mm)**	**Combat Medic (mm)**
Δ from Semi-Nude	-	5 [B]	9 [AB]	13 [A]	12 [A]	13 [A]
Δ SD	-	10	10	14	14	14
Mean	413	418	422	426	425	426
SD	20	24	23	25	26	25
Min	377	381	382	377	381	382
25th	402	408	406	411	409	410
50th	410	413	415	425	421	423
75th	424	429	434	435	436	435
Max	462	469	478	494	503	502
Range	85	88	96	117	122	120

A>B>C>D, Superscripts of different letters indicate significant differences at the p<.05 level.

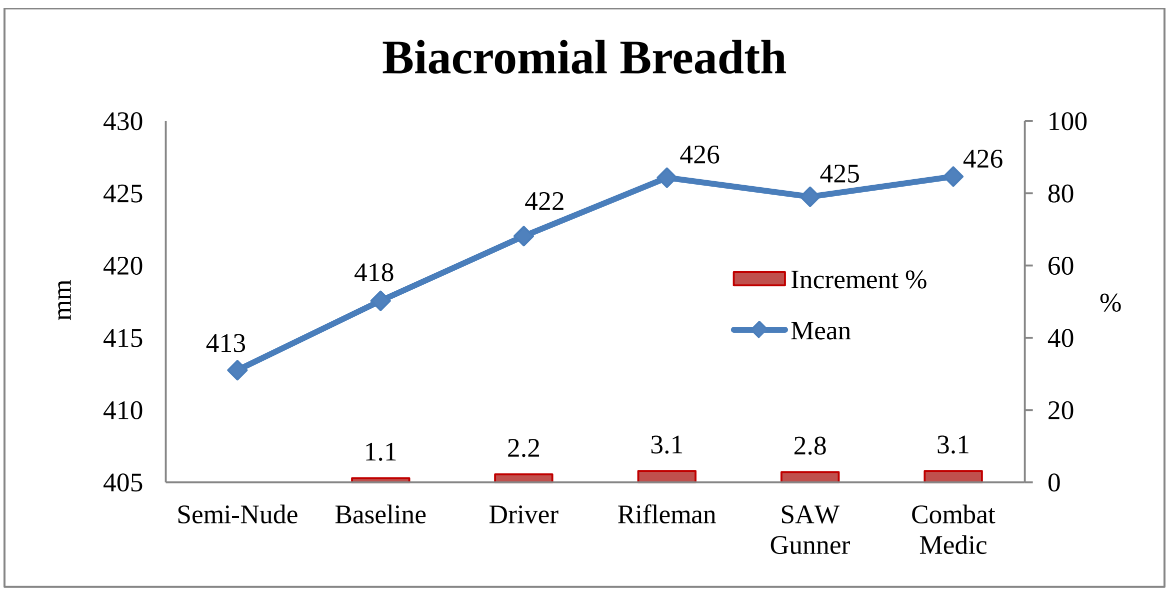


Figure 44: Percent increment relative to Semi-Nude and average Biacromial Breadth for each configuration

Bideltoid Breadth

Bideltoid Breadth is the maximum horizontal distance between the lateral margins of the upper arms on the deltoid muscles (see Figure 45). The TP is in the anthropometric sitting position. The measurer stands behind the TP and uses a beam caliper to locate the greatest horizontal distance between the outside edges of the deltoid muscles on the upper arms. This is done by brushing the caliper blades up and down the TP’s upper arms. When the blades lightly touch the skin on both sides, the measurer withdraws the instrument to read off the measurement. The measurement is made at the maximum point of quiet respiration. For the encumbered measurements the deltoid landmarks are transferred to the CIE and used as a guide to locate the deltoid region. The measurement is taken at these landmarks, and care is taken to ensure there is no compression of the CIE. The location of the adhesive landmarks is rechecked for each configuration

Figure 45: Bideltoid Breadth measurement

A mixed design ANOVA was conducted to investigate whether the various CIE configurations had an effect on the delta values for Bideltoid Breadth, and to test for differences among IOTV sizes. The results are listed in Table 20 and shown graphically with percent increments between configurations in Figure 46. The average delta values among IOTV sizes were not statistically different, $F(4, 20)=0.52$, $p=.73$. Since the assumption for sphericity was violated, $\chi^2(9)=25.32$, $p<.01$, $\varepsilon=0.666$, the Greenhouse-Geisser correction was used to report statistics. The average delta values among the configurations were statistically different, $F(2.67, 53.32)=51.80$, $p<.01$. There were no statistical differences between the three loaded configurations: the Rifleman

(M=49.68 mm), the SAW Gunner (M=50.90 mm), and the Combat Medic (M=49.27 mm), $p > .05$. These were, however, all larger than the Driver (M=35.60 mm) and the Baseline (M=25.38 mm) configurations, $p < .05$. The Driver configuration (M=35.60 mm) was statistically bigger than the Baseline configuration (M=25.38 mm), $p < .05$.

Table 20: Summary statistics and mean deltas for Bideltoid Breadth for each configuration

	Semi-Nude (mm)	Baseline (mm)	Driver (mm)	Rifleman (mm)	SAW Gunner (mm)	Combat Medic (mm)
Δ from Semi-Nude	-	25 [C]	36 [B]	50 [A]	51 [A]	49 [A]
Δ SD	-	14	16	17	17	17
Mean	506	532	542	556	558	556
SD	33	36	39	36	35	36
Min	447	477	465	497	504	495
25th	484	507	523	530	534	530
50th	502	532	546	558	550	554
75th	524	556	569	587	585	578
Max	565	607	618	615	621	614
Range	118	130	153	118	117	119

A>B>C>D, Superscripts of different letters indicate significant differences at the $p < .05$ level.

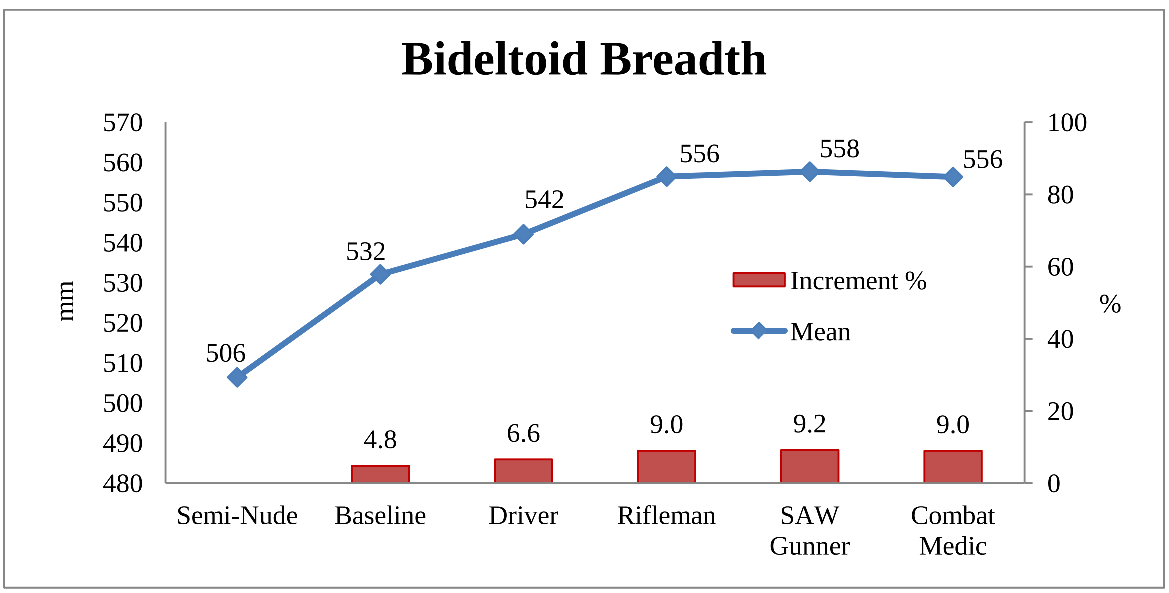


Figure 46: Percent increment relative to Semi-Nude and average Bideltoid Breadth for each configuration

Buttock-Knee Length

Buttock-Knee Length is the horizontal distance between a buttock plate, placed at the most posterior point of either buttock and the anterior point of the right knee (see Figure 47). The TP is in the anthropometric sitting position, but with arms relaxed on the lap. The measurer stands at the right of the TP and slides the buttock plate toward the TP until it makes light contact with the most posterior point on either buttock. When the plate is in position, it is locked in place. The anthropometer is used to measure the horizontal distance between the buttock plate and the front of the knee (Knee Point, Anterior). The base of the anthropometer is anchored on the buttock plate. The measurer exerts only enough pressure on the instrument to maintain contact between the anthropometer blade and the knee. For the encumbered measurement, a vertical board is attached to the buttock plate, and it is slid forward until it makes light contact at the most posterior point on the back of the CIE. The measurer then locks the buttock plate in place and repeats the measurement. This allows for the measurement distance for any CIE located on the TP's back, as well as any equipment that may be worn at the knee.

Figure 47: Buttock-Knee Length measurement

A mixed design ANOVA was conducted to investigate whether the various CIE configurations had an effect on the delta values for Buttock-Knee Length and to test for differences among IOTV sizes. The results are listed in Table 21 and shown graphically with percent increments between configurations in Figure 48. The average delta values among IOTV sizes were not statistically different, $F(4, 19)=1.39$, $p=.28$, but the average delta values among configurations were statistically different, $F(4, 76)=473.80$, $p<.01$. The SAW Gunner configuration (M=147.99

mm) was statistically larger than the Combat Medic configuration (M=136.55 mm), p< .05, and neither of those was statistically different from the other loaded configuration: the Rifleman (M=144.16 mm), p>.05. All three loaded configurations were statistically larger than both the Baseline and the Driver configurations, p<.05. The Driver configuration (M=63.85 mm) was statistically larger than the Baseline configuration (M=7.87 mm), p<.05.

Table 21: Summary statistics and mean deltas for Buttock-Knee Length for each configuration

	Semi-Nude (mm)	Baseline (mm)	Driver (mm)	Rifleman (mm)	SAW Gunner (mm)	Combat Medic (mm)
Δ from Semi-Nude	-	8^{D}	64^{C}	144^{AB}	148^{A}	137^{B}
Δ SD	-	9	20	22	19	21
Mean	626	633	689	767	773	761
SD	47	43	51	50	48	50
Min	544	558	606	702	692	688
25th	585	599	655	728	728	716
50th	612	624	677	758	783	757
75th	660	665	722	785	802	786
Max	727	730	794	880	894	874
Range	183	172	188	178	202	186

A>B>C>D, Superscripts of different letters indicate significant differences at the p<.05 level.

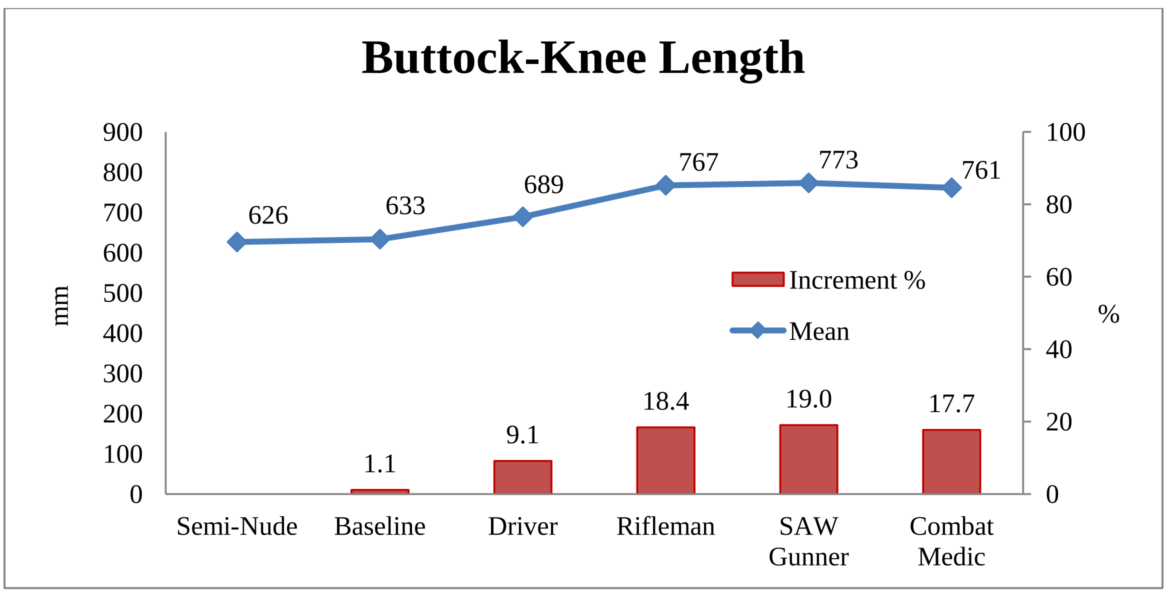


Figure 48: Percent increment relative to Semi-Nude and average Buttock-Knee Length for each configuration

Buttock-Popliteal Length

Buttock-Popliteal Length is the horizontal distance between a buttock plate, placed at the most posterior point of either buttock, and the back of the right knee (the Popliteal Fossa at the dorsal juncture of the calf and thigh) (see Figure 49). The TP is in the anthropometric sitting position with the arms relaxed on the lap. The measurer stands at the right of the TP and slides the buttock plate toward the TP until it makes light contact with the most posterior point on either buttock. When the plate is in position, it is locked in place. An anthropometer is used to measure the horizontal distance from the buttock plate to the back of the knee. This is done in such a way that the blade of the anthropometer is placed as high and as far forward as possible in the Popliteal Fossa behind the knee without compressing tissue. The measurer exerts only enough pressure on the instrument to maintain contact between the anthropometer blade and the skin. For the encumbered measurements, a vertical board is attached to the buttock plate and slid forward until it makes light contact with the most posterior point on the CIE. The buttock plate is then locked in place, and the measurement is taken. This allows for the measurement distance for any CIE located on a TP's back to the back of the knee. There is no compression of the CIE during the measurement. Note that 10 mm is added to the recorded measurement to account for the thickness of the anthropometer blade. If bulk is added to the torso and to the leg, this measurement becomes less clear than other measurements in this study, as delta values would include dimensions from the torso and from behind the knee. One solution would be to evaluate the impact of the delta values independently. In this study only the ACU was present behind the knee, resulting in minimal impact.

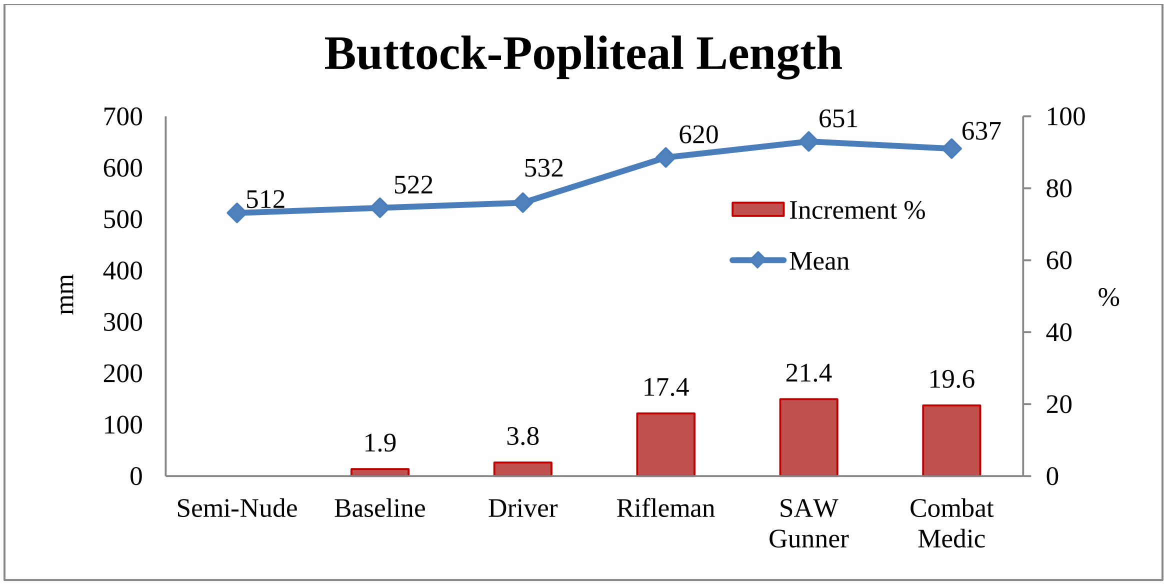
Figure 49: Buttock-Popliteal Length measurement

A mixed design ANOVA was conducted to investigate whether the various CIE configurations had an effect on the delta values for Buttock-Popliteal Length and to test for differences among IOTV sizes. The results are listed in Table 22 and shown graphically with percent increments between configurations in Figure 50. The average delta values among IOTV sizes were not statistically different, $F(4, 19)=2.14$, $p=.12$, but the average delta values among configurations were statistically different, $F(4, 76)=397.80$, $p<.01$. The SAW Gunner configuration (M=139.76 mm) was statistically larger than the Combat Medic configuration (M=126.79 mm), $p< .05$. The Rifleman configuration (M=135.80 mm) was not statistically different from either of the other two loaded configurations: the SAW Gunner or the Combat Medic, $p>.05$. All three loaded configurations were larger than the Baseline and the Driver configurations, $p<.05$. The Driver configuration (M=57.24 mm) was larger than the Baseline configuration (M= -2.01 mm), $p<.05$.

Table 22: Summary statistics and mean deltas for Buttock-Popliteal Length for each configuration

	Semi-Nude (mm)	**Baseline (mm)**	**Driver (mm)**	**Rifleman (mm)**	**SAW Gunner (mm)**	**Combat Medic (mm)**
Δ from Semi-Nude	-	-2 ^{D}	57 ^{C}	136 ^{AB}	140 ^{A}	127 ^{B}
Δ SD	-	14	26	21	20	23
Mean	512	522	532	620	651	637
SD	39	39	39	134	41	43
Min	440	450	460	10	580	585
25th	482	492	502	610	621	599
50th	501	511	521	635	651	635
75th	542	552	562	659	673	654
Max	593	603	613	750	764	749
Range	153	153	153	740	184	164

A>B>C>D, Superscripts of different letters indicate significant differences at the p<.05 level.



Note: The x-axis is below the "0" point on the secondary y-axis because there was a negative mean delta calculated between the Semi-Nude and Baseline configurations. This difference was less than 0.05%

Figure 50: Percent increment relative to Semi-Nude and average Buttock-Popliteal Length for each configuration.

Elbow-Elbow Circumference

Elbow-Elbow Circumference is the maximum circumference of the torso, including the arms, at the level of the inner elbows (see Figure 51). This measurement was developed for this study. The TP is in the anthropometric sitting position. The measurement is taken around the torso and elbows at the widest point. The measurer lets the tape fall along the crease of the inner elbows. The measurement is taken at the maximum point of quiet respiration. For the encumbered measurement, the above method is used, and care is taken not compress the CIE. In some cases a longer or a second measuring tape is required to obtain encumbered measurements.

Figure 51: Elbow-Elbow Circumference measurement

A mixed design ANOVA was conducted to investigate whether the various CIE configurations had an effect on the delta values for Elbow to Elbow Circumference and to test for differences among IOTV sizes. The results are listed in Table 23 and shown graphically with percent increments between configurations in Figure 52. The average delta values among IOTV sizes were not statistically different F(4, 20)=1.68, p=.19. Since the assumption of sphericity was violated, $\chi^2(9)=40.40$, p<.01, ε=0.475, the Greenhouse-Geisser correction was used to report statistics. The average delta values among configurations were statistically different, F(1.90, 38.02)=473.40, p<.01. The Rifleman configuration (M=539.32 mm) was statistically smaller than both of the other two loaded configurations: the SAW Gunner (M=606.84 mm) and the Combat Medic (M=618.66 mm) configurations, p<.05. There was no statistical difference between the SAW Gunner and the Combat Medic configurations, p>.05. All three loaded configurations were larger than the Driver and the Baseline configurations, p<.05, and the delta for the Driver (M=270.28 mm) was larger than the delta for the Baseline (M=116.27 mm), p<.05.

Table 23: Summary statistics and mean deltas for Elbow-Elbow Circumference for each configuration

	Semi-Nude (mm)	**Baseline (mm)**	**Driver (mm)**	**Rifleman (mm)**	**SAW Gunner (mm)**	**Combat Medic (mm)**
Δ from Semi-Nude	-	116 D	270 C	539 B	607 A	619 A
Δ SD	-	59	54	83	93	80
Mean	1311	1429	1582	1852	1921	1932
SD	140	149	127	103	97	96
Min	1106	1201	1390	1648	1737	1776
25th	1189	1331	1482	1795	1846	1858
50th	1295	1400	1563	1841	1928	1944
75th	1425	1569	1692	1880	1980	1968
Max	1594	1681	1814	2095	2079	2148
Range	488	480	424	447	342	372

A>B>C>D, Superscripts of different letters indicate significant differences at the $p<.05$ level.

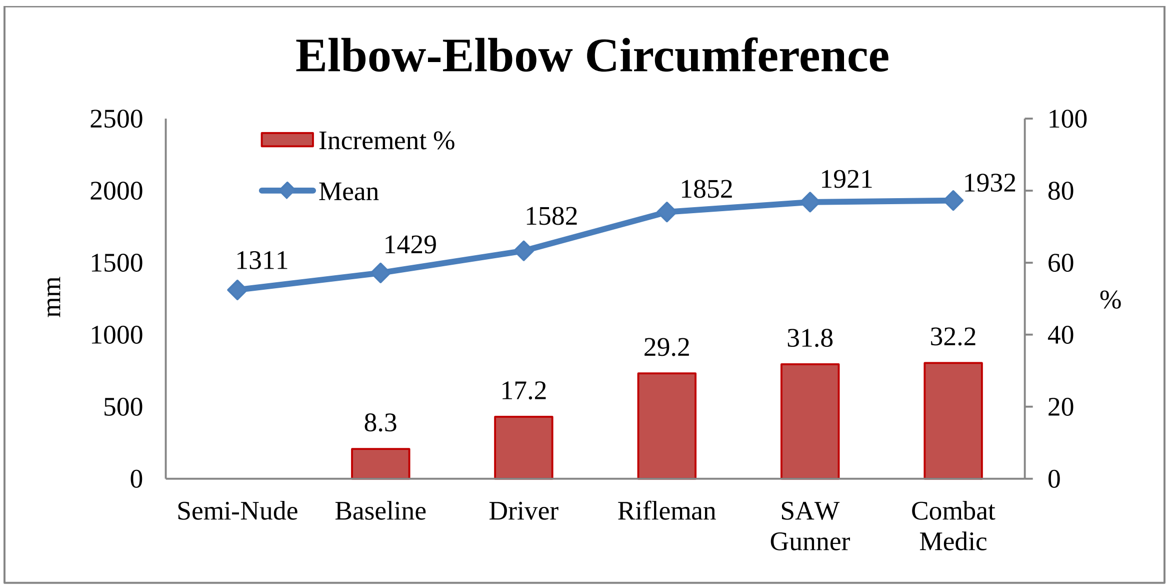


Figure 52: Percent increment relative to Semi-Nude and average Elbow-Elbow Circumference for each configuration

Forearm-Forearm Breadth

Forearm-Forearm Breadth is the maximum horizontal distance between the outer sides of the forearms (see Figure 53). The TP is in the anthropometric sitting position. The measurer stands behind the TP and uses a beam caliper to measure the maximum horizontal distance across the upper body between the outsides of the forearms. The measurer brushes the blades back and forth to ensure that the maximum breadth is attained. The measurer exerts only enough pressure to ensure that the caliper blades are on the lateral points of the forearms and takes care not to compress the CIE. The measurement is taken at the maximum point of quiet respiration.

Figure 53: Forearm-Forearm Breadth measurement

A mixed design ANOVA was conducted to investigate whether the various CIE configurations had an effect on the delta values for Forearm-Forearm Breadth and to test for differences among IOTV sizes. The results are listed in Table 24 and shown graphically with percent increments between configurations in Figure 54. The average delta values among IOTV sizes were not statistically different, $F(4, 20)=1.39$, $p=.27$. Since the assumption of sphericity was violated, $\chi^2(9)=45.25$, $p<.01$, $\varepsilon=0.466$, the Greenhouse-Geisser correction was used to report statistics. The average delta values among configurations were statistically different, $F(1.87, 37.25)=61.52$, $p<.01$. The SAW Gunner configuration (M=159.56 mm) was statistically larger than the Combat Medic configuration (M=140.25 mm), $p< .05$, but the Rifleman configuration (M=151.30 mm) was not statistically different from either of the other two loaded configurations, $p>.05$. All three loaded configurations were larger than the Baseline and the Driver configurations, $p<.05$. The Driver configuration (M=81.65 mm) was statistically larger than the Baseline configuration (M= 51.19 mm), $p<.05$.

Table 24: Summary statistics and mean deltas for Forearm-Forearm Breadth for each configuration

	Semi-Nude (mm)	Baseline (mm)	Driver (mm)	Rifleman (mm)	SAW Gunner (mm)	Combat Medic (mm)
Δ from Semi-Nude	-	51 ^{D}	83 ^{C}	151 ^{AB}	160 ^{A}	140 ^{B}
Δ SD	-	37	42	39	42	45
Mean	595	647	677	748	756	737
SD	58	70	66	40	43	42
Min	496	540	580	682	674	659
25th	558	599	632	721	730	705
50th	587	624	659	742	757	732
75th	648	700	719	779	781	759
Max	680	801	808	843	823	836
Range	184	261	228	161	149	177

A>B>C>D, Superscripts of different letters indicate significant differences at the p<.05 level.

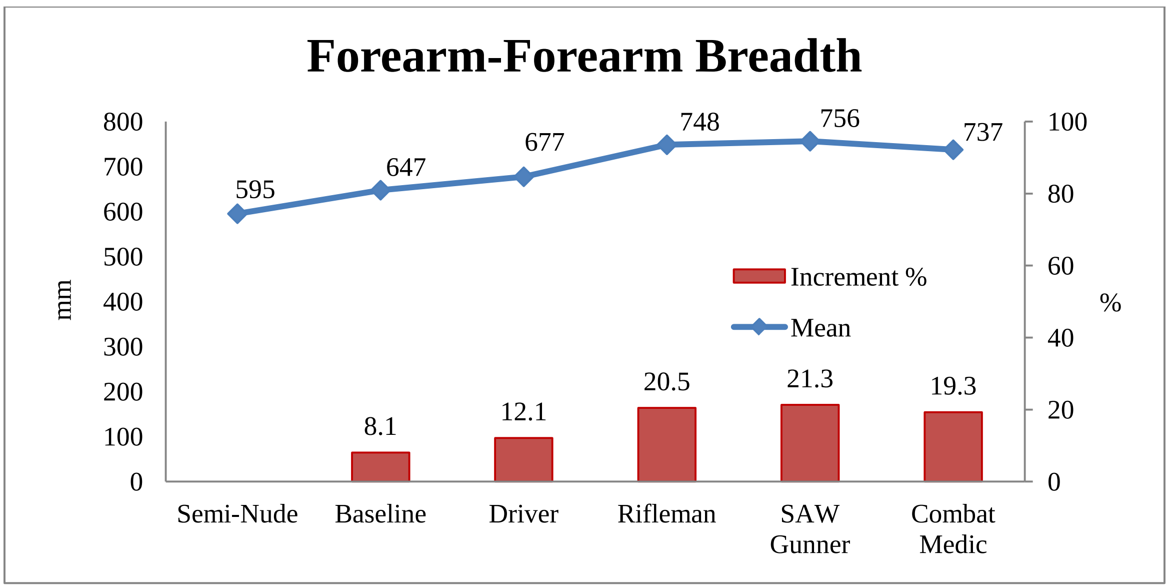


Figure 54: Percent increment relative to Semi-Nude and average Forearm-Forearm Breadth for each configuration

Hip Breadth

Hip Breadth is the horizontal distance between the Lateral Buttock landmarks on the sides of the hips (see Figure 55). The TP is in the anthropometric sitting position. The measurer stands in front of the TP and uses a beam caliper to measure the horizontal distance between the drawn landmarks. The measurer brushes the blades of the beam caliper up and down in the area of the drawn Lateral Buttock landmarks to obtain the broadest hip measurement. Only enough pressure is exerted to ensure that the caliper blades are on the hips, and care is taken not to compress any CIE. Depending on the configuration worn and how the equipment fits the individual TP, the Hip Breadth may (or may not) include various pieces of the CIE, especially low hanging equipment pouches. Therefore, a special note is made signifying if the equipment was included in the measurement for each side of the TP's body.

Figure 55: Hip Breadth measurement

A mixed design ANOVA was conducted to investigate whether the various CIE configurations had an effect on the delta values for Hip Breadth and to test for differences among IOTV sizes. The results are listed in Table 25 and shown graphically with percent increments between configurations in Figure 56. The average delta values among IOTV sizes were not statistically different, $F(4, 20)=0.70$, $p=.60$. Since the assumption of sphericity was violated, $\chi^2(9)=111.86$, $p<.01$, $\varepsilon=0.325$, the Greenhouse-Geisser correction was used to report statistics. The average delta values among configurations were statistically different, $F(1.30, 26.02)=45.81$, $p<.01$. There were no statistically significant differences between the three loaded configurations: Rifleman (M=139.00 mm), SAW Gunner (M=153.48 mm), and Combat Medic (M=131.05 mm), $p> .05$. They were, however, all statistically larger than the Driver (M=21.99 mm) and the Baseline (M=19.22 mm) configurations, $p<.05$. There was no statistically significant difference between Baseline and Driver configuration, $p>.05$.

Table 25: Summary statistics and mean deltas for Hip Breadth for each configuration

	Semi-Nude (mm)	Baseline (mm)	Driver (mm)	Rifleman (mm)	SAW Gunner (mm)	Combat Medic (mm)
Δ from Semi-Nude	-	19 [B]	22 [B]	139 [A]	153 [A]	131 [A]
Δ SD	-	9	13	91	76	85
Mean	382	401	404	519	533	511
SD	36	36	30	93	85	91
Min	321	343	354	374	385	365
25th	357	375	384	419	503	439
50th	373	405	407	544	549	524
75th	400	417	421	600	592	610
Max	457	465	464	643	674	634
Range	136	122	110	269	289	269

A>B>C>D, Superscripts of different letters indicate significant differences at the p<.05 level.

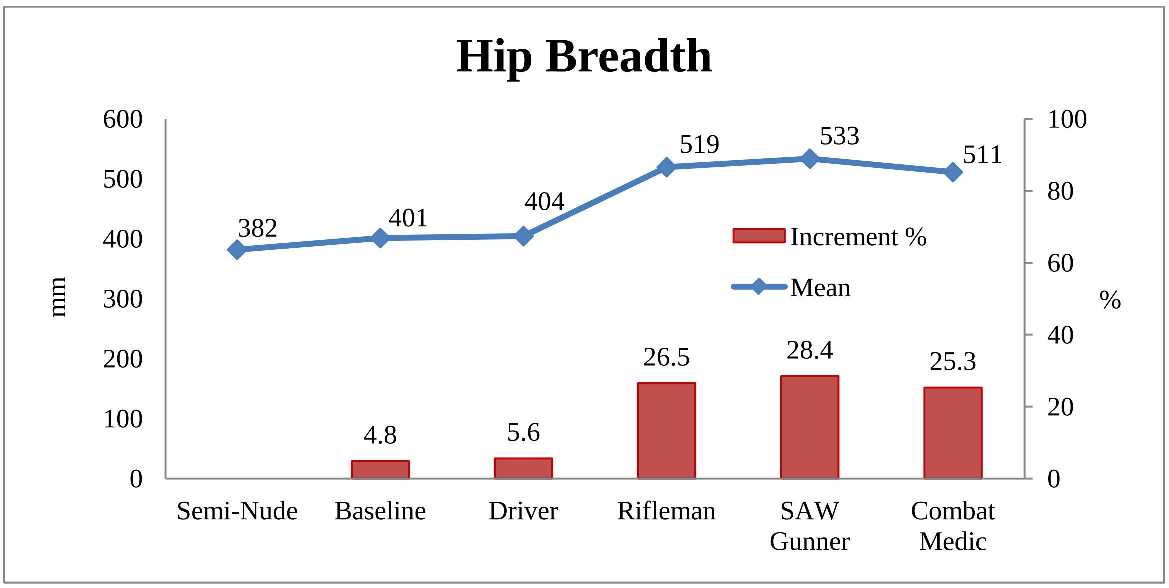


Figure 56: Percent increment relative to Semi-Nude and average Hip Breadth for each configuration

Sitting Height

Sitting Height is the vertical distance between a sitting surface and the top of the head (see Figure 57). The TP is in the anthropometric sitting position with the head in the Frankfort Horizontal plane. The measurer stands at the right rear of the TP and uses an anthropometer to measure the vertical distance between the sitting surface and the top of the head, or the ACH in the encumbered configurations. The measurer uses sufficient pressure to compress the hair. For the encumbered measurement the above method is used, and care is taken not to compress the CIE, in this case the ACH and the CVC helmet. Note that NVDs can add up to 102 mm (4 in) to sitting height when they are in the up position.

Figure 57: Sitting Height measurement

A mixed design ANOVA was conducted to investigate whether the various CIE configurations had an effect on the delta values for Sitting Height and to test for differences among IOTV sizes. The results are listed in Table 26 and shown graphically with percent increments between configurations in Figure 58. The average delta values among IOTV sizes were not statistically different $F(4, 20)=1.93$, $p=1.44$. Since the assumption of sphericity was violated, $\chi^2(9)=19.25$, $p<.01$, $\varepsilon=0.715$, the Greenhouse-Geisser correction was used to report statistics. The average delta values among configurations were statistically different, $F(2.86, 57.18)=61.93$, $p<.01$. The Baseline configuration (M=1.23 mm) was statistically smaller than all the other configurations, $p<.05$. There were no statistical differences among the Driver (M=29.05 mm), the Rifleman (M=30.84 mm), the SAW Gunner (M=27.12 mm), and the Combat Medic (M=27.64 mm) configurations, $p>.05$.

Table 26: Summary statistics and mean deltas for Sitting Height for each configuration

	Semi-Nude (mm)	Baseline (mm)	Driver (mm)	Rifleman (mm)	SAW Gunner (mm)	Combat Medic (mm)
Δ from Semi-Nude	-	1 [B]	29 [A]	31 [A]	27 [A]	28 [A]
Δ SD	-	9	13	14	14	13
Mean	920	921	949	950	947	947
SD	44	43	39	42	43	41
Min	812	826	851	861	848	850
25th	890	895	927	921	921	920
50th	927	932	959	958	952	954
75th	952	947	980	984	983	980
Max	989	995	998	1025	1021	1021
Range	177	169	147	164	173	171

A>B>C>D, Superscripts of different letters indicate significant differences at the p<.05 level.

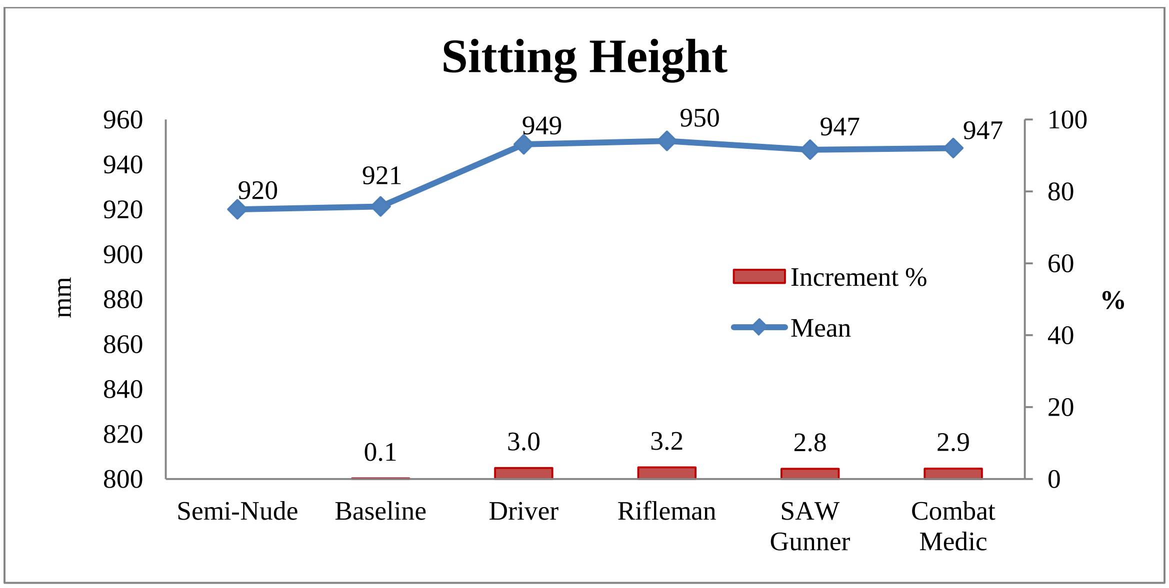


Figure 58: Percent increment relative to Semi-Nude and average Sitting Height for each configuration

3.4 Head and Foot Anthropometry

All the measurements that were taken for the Head and Foot are described are grouped together, as all of them were only measured only in the Semi-Nude and one “encumbered” configuration (i.e., the Driver for the Head dimensions and the Baseline for the Foot dimensions). Only one encumbered configuration was measured because the CIE for the head (helmet) is the same in all four IOTV configurations and the CIE for the foot (boots) is the same in all five encumbered configurations. Table 27 gives the delta values and summary results for these dimensions.

Table 27: Distribution of mean deltas between encumbered and Semi-Nude measurements for single head and foot dimensions

Dimension	Condition	Mean (mm)	SD (mm)	Min (mm)	25th (mm)	50th (mm)	75th (mm)	Max (mm)	Range (mm)	Absolute Mean Δ (mm)	% Increase
Head Breadth	Semi-Nude	154	5	145	150	154	157	165	20	92	60%
	Encumbered	246	8	237	237	247	247	261	24		
Head Circumference	Semi-Nude	575	18	547	565	574	585	621	74	208	36%
	Encumbered	783	23	754	754	785	785	825	71		
Head Length	Semi-Nude	200	8	184	197	200	204	223	39	65	32%
	Encumbered	265	9	255	255	265	265	283	28		
Foot Breadth	Semi-Nude	103	6	95	98	103	106	117	22	9	9%
	Encumbered	113	6	105	108	112	117	127	22		
Foot Length	Semi-Nude	273	18	245	262	271	281	325	80	42	15%
	Encumbered	315	16	294	304	314	322	365	71		

Head Breadth

Head Breadth is the maximum horizontal breadth of the head above the ears (see Figure 59). The TP sits with the head in the Frankfort Horizontal plane. The measurer stands behind the TP and uses a spreading caliper to measure the euryon, right and left. The measurer exerts sufficient pressure to obtain contact between the caliper and the skin. For the encumbered measurement, (the TP wearing the ACH or CVC), the measurer carefully slides the calipers so that they are just touching the left and right edges of the maximum breadth of the helmet, even though this is in a slightly lower position than that for the Semi-Nude Head Breadth location.

Figure 59: Head Breadth measurement

Head Circumference

Head Circumference is the maximum circumference of the head above the supraorbital ridges and ears (see Figure 60). The TP sits with the head in the Frankfort Horizontal plane. The measurer stands to the right of the TP and places the bottom of a tape measure just above the ridges of the eyebrows (supraorbital ridges) and around the back of the head, using enough tension to compress the hair. For the encumbered measurements (the TP wearing an ACH or CVC), the measurer places the tape around the maximum perimeter of the ACH or the CVC without compressing it.

Figure 60: Head Circumference measurement

Head Length

Head Length is the distance from the Glabella landmark between the brow ridges to Opisthocranion (see Figure 61). The TP sits with the head in the Frankfort Horizontal plane. The measurer stands at the right of the TP and uses a spreading caliper to measure, in the Midsagittal plane, the distance between the Glabella landmark and Opisthocranion. One tip of the caliper is placed on the Glabella and the other tip is moved up and down on the back of the head in the Midsagittal plane until the maximum measurement is obtained. The measurer uses light pressure on the Glabella and enough pressure on the Opisthocranion to compress the hair in the Semi-Nude configuration. For the encumbered measurement (the TP wearing an ACH or CVC), the Length of the ACH or CVC is measured from anterior rim to posterior rim.

Figure 61: Head Length Measurement

Foot Breadth

Foot Breadth is the maximum breadth of the right foot (see Figure 62). The TP stands erect with both feet in an anthropometric foot box with weight distributed equally on both feet. Kneeling on the right side of the TP, the measurer makes sure the back of the heel (pternion) is lightly touching the back of the box and the fifth metatarsal is lightly touching the side of the foot box with the foot in the Sagittal plane. The measurer slides the triangular slide to the drawn landmark on the First Metatarsophalangeal Protrusion. When the foot is correctly positioned, the measurer measures the maximum breadth of the foot by moving the "horizontal" slide until it is just touching the side of the foot. The measurement is read at that point from the device scale. For the encumbered measurement (the TP wearing duty boots), the landmarks are palpated, and care is taken not to compress the boot.

Figure 62: Foot Breadth measurement

Foot Length

Foot Length is the maximum length of the right foot (see Figure 63). The TP stands erect with the right and left foot in an anthropometric foot box. The weight is distributed equally on both feet. The measurer kneels to the right side of the TP and ensures the back of the heel (pternion) is lightly touching the back of the box and the Fifth Metatarsal is lightly touching the side of the box with the foot in the Sagittal plane. When the foot is correctly positioned, the measurer measures the maximum length of the foot by moving the triangular slide until it is just touching the tip of the longest phalanx. For the encumbered measurement (the TP wearing duty boots), care is taken not to compress the boot.

Figure 63: Foot Length Measurement

3.5 Anthropometric Maximum Measurements

To assist with the characterization of the dismounted Soldier, several additional dimensions were recorded that highlighted several locations on the body that were determined to be maximal breadths, depths, and circumferences. When these were identified in the Driver configuration, they were landmarked with adhesive markers. The heights of these landmarks were recorded and transferred to the three load configurations and used to capture the breadths, circumferences, and depths at those locations. These dimensions are described in this section. Note that the height measurements are used as reference locations only to locate the breadths, circumferences, and depths. This section provides an analysis of the standing maximum measurements using the Semi-NudeWaist (Omphalion) location as a surrogate for delta calculations. The summary results and delta values are presented for each of the breadth, depth, and circumference dimensions. Sitting maximum dimensions are not discussed here, as no Semi-Nude surrogate measurement (Waist, Hip Breadth, Chest Breadth, etc) could be used to calculate delta values in this study.

Maximum Waist Height

Maximum Waist Height is the height location where the Maximum Waist Breadth, Circumference, and Depth are observed while a TP is wearing CIE. This height measurement is recorded and marked with an adhesive marker as a reference point.

Maximum Waist Breadth

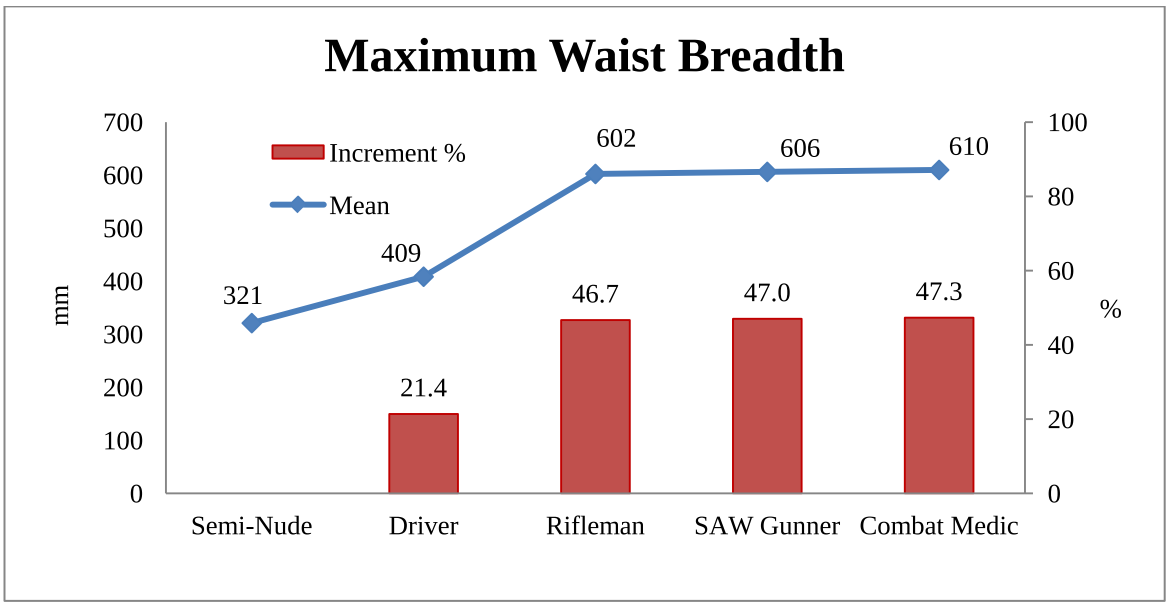
Maximum Waist Breadth is the location of the Maximum Breadth of the Waist while the TP is wearing CIE. This location was earlier identified and marked using Maximum Waist Height. Using a beam caliper this measurement is taken at the maximum horizontal breadth of the TP's CIE. Care is taken to not compress the CIE.

Since there was no Semi-Nude location to match to, Waist Breadth from the Semi-Nude configuration was used as a reference point to calculate the increments caused by CIE. A mixed design ANOVA was conducted to investigate whether the various CIE configurations had an effect on the delta values for Waist Breadth and to test for differences among IOTV sizes. The results are listed in Table 28 and shown graphically with percent increments between configurations in Figure 64. The average delta values among IOTV sizes were statistically different $F(4, 20)=6.48$, $p<.01$. There were no statistically significant differences for the delta values between sizes X-small (M=259.50 mm), Small (M=240.15 mm), and Medium (M=236.83 mm) IOTVs, $p>.05$. The delta values from the size X-small (M=259.50 mm) IOTV, however, were statistically larger than the size Large (M=223.90 mm) and size X-large (M=213.31 mm) IOTVs, $p<.05$. There were no statistical differences between the size Large and X-large IOTVs, $p>.05$. Since the assumption of sphericity was violated, $\chi^2(5)=16.72$, $p<.01$, $\varepsilon=0.681$, the Greenhouse-Geisser correction was used to report statistics. The average delta values among configurations were statistically different, $F(2.04, 40.87)=877.77$, $p<.01$. There were no statistical differences among the three loaded configurations: Rifleman (M=279.49 mm), SAW Gunner (M=284.87 mm), and Combat Medic (M=287.68 mm), $p>.05$. These three loaded configurations, however, were all statistically larger than the Driver configuration (M=86.92 mm), $p<.05$.

Table 28: Summary statistics and mean deltas for Maximum Waist Breadth relative to Semi-Nude Waist Breadth for each configuration

	Semi-Nude (mm)	Driver (mm)	Rifleman (mm)	SAW Gunner (mm)	Combat Medic (mm)
∆ from Semi-Nude	-	87 [B]	279 [A]	285 [A]	288 [A]
∆ SD	-	12	29	35	22
Mean	321	409	602	606	610
SD	-	31	23	37	21
Min	-	361	559	496	577
25th	-	388	585	596	597
50th	-	405	601	608	609
75th	-	425	623	629	626
Max	-	493	637	680	664
Range	-	132	78	184	87

A>B>C>D, Superscripts of different letters indicate significant differences at the p<.05 level



*Deltas were calculated using a surrogate dimension.

Figure 64: Percent increment relative to Semi-Nude Waist Breadth and average Maximum Waist Breadth for each configuration

Maximum Waist Circumference

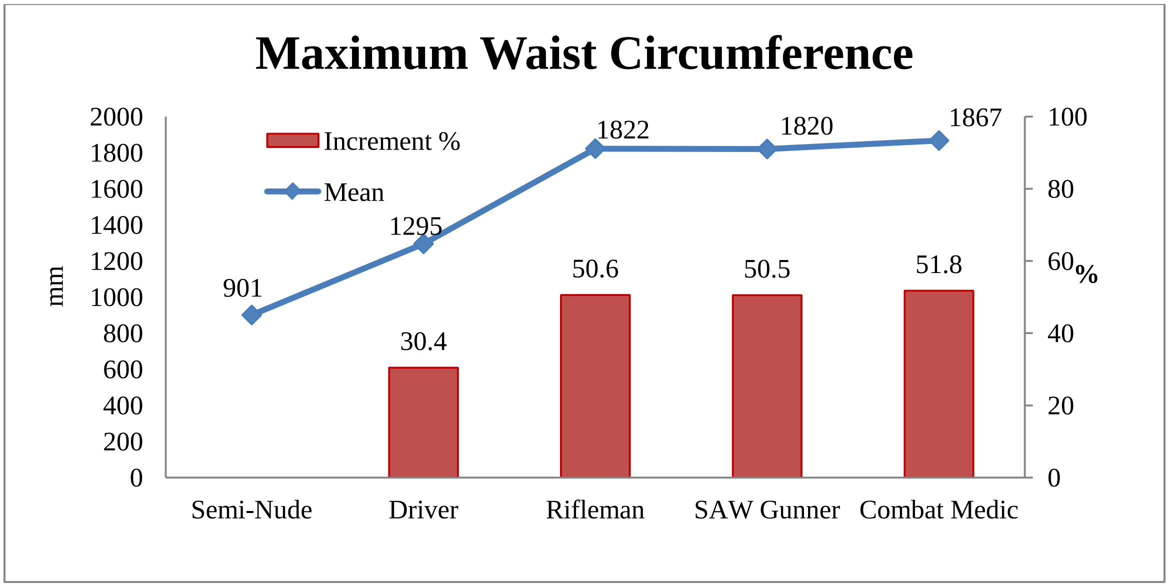
Maximum Waist Circumference is the maximum circumference of the waist taken around the torso while the TP is wearing CIE and is in an anthropometric standing position. The measurement is obtained by taking the greatest horizontal circumference at the waist level region as visually assessed and landmarked at Maximum Waist Height. The measurer takes care not to compress the CIE.

Since there was no Semi-Nude location to match to, Waist (Omphalion) Circumference from the Semi-Nude configuration was used as a reference point to calculate the increments caused by CIE. A mixed design ANOVA was conducted to investigate whether the various CIE configurations had an effect on the delta values for Maximum Waist Circumference and to test for differences among IOTV sizes. The results are listed in Table 29 and shown graphically with percent increments between configurations in Figure 65. The average delta values among IOTV sizes were not statistically different $F(4, 20)=2.31$, $p=.09$. Since the assumption of sphericity was violated, $\chi^2(5)=25.41$, $p<.01$, $\varepsilon=0.627$, the Greenhouse-Geisser correction was used to report statistics. The average delta values among configurations were statistically different, $F(1.88, 37.64)=1787.59$, $p<.01$. The Combat Medic configuration (M=963.40 mm) was statistically larger than the other two loaded configurations: the Rifleman (M=919.24 mm) and the SAW Gunner (M=918.66 mm), $p<.05$. There were no statistically significant differences between the Rifleman and the SAW Gunner configurations, $p>.05$. These three loaded configurations were all statistically larger than the Driver configuration (M=363.21 mm), $p<.05$.

Table 29: Summary statistics and mean deltas for Maximum Waist Circumference relative to Semi-Nude Waist Circumference for each configuration

	Semi-Nude (mm)	Driver (mm)	Rifleman (mm)	SAW Gunner (mm)	Combat Medic (mm)
Δ from Semi-Nude	-	393 ^{C}	919 ^{B}	919 ^{B}	963 ^{A}
Δ SD	-	37	57	71	52
Mean	901	1295	1822	1820	1867
SD	-	86	65	96	62
Min	-	1164	1748	1555	1768
25th	-	1238	1772	1787	1835
50th	-	1289	1790	1809	1865
75th	-	1331	1863	1865	1897
Max	-	1520	1956	2034	2022
Range	-	356	208	479	254

A>B>C>D, Superscripts of different letters indicate significant differences at the p<.05 level.



*Deltas were calculated using a surrogate dimension.

Figure 65: Percent increment relative to Semi-Nude Waist Circumference and average Maximum Waist Circumference for each configuration

Maximum Waist Depth

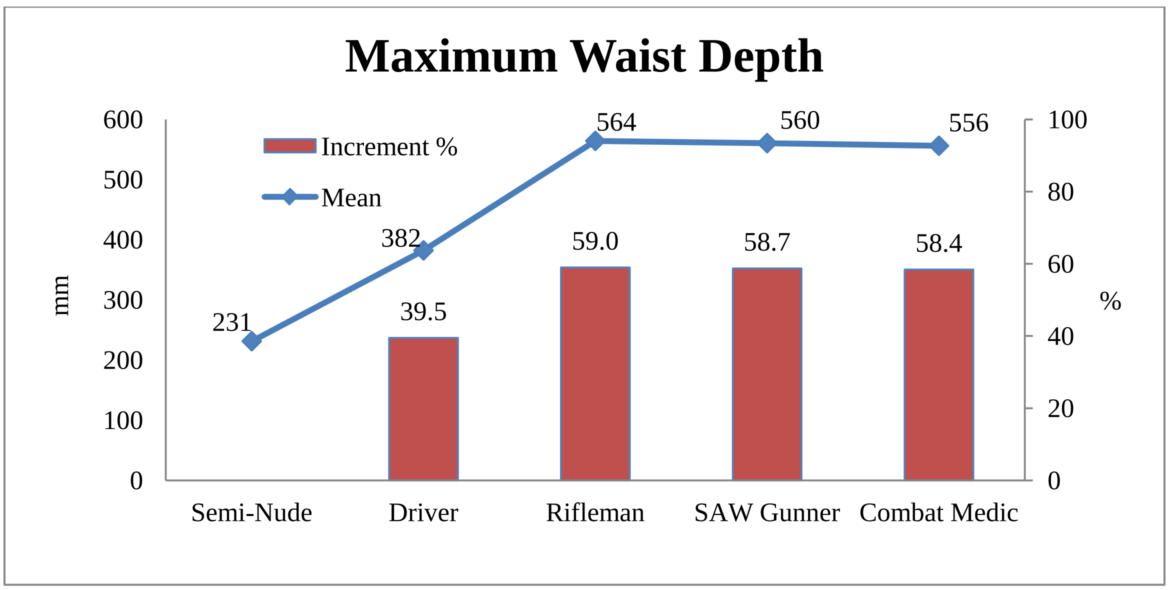
Maximum Waist Depth is the maximum depth of the waist while a TP is wearing CIE in an anthropometric standing position. Using a beam caliper, the measurer takes this measurement at the maximum horizontal depth of the CIE as visually assessed and marked at Maximum Waist Height, taking care not to compress the CIE.

Since there was no Semi-Nude location to match to, Waist Depth from the Semi-Nude configuration was used as a reference point to calculate the increments caused by CIE. A mixed design ANOVA was conducted to investigate whether the various CIE configurations had an effect on the delta values for Maximum Waist Depth and to test for differences among IOTV sizes. The results are listed in Table 30 and shown graphically with percent increments between configurations in Figure 66. The average delta values among IOTV sizes were statistically different $F(4, 20)=5.50$, $p<.01$. The delta values for the size X-small ($M=262.10$ mm) IOTV were statistically smaller than the sizes Small ($M=297.60$ mm), Medium ($M=286.88$ mm), and X-large ($M=292.56$ mm) IOTVs, $p<.05$. There were no further statistically significant differences for pairwise comparisons, $p>.05$. The average delta values among the configurations were statistically different, $F(3, 60)=2649.83$, $p<.01$. There were no statistical differences among the three loaded configurations: Rifleman ($M=333.35$ mm), SAW Gunner ($M=328.83$ mm) and Combat Medic ($M=324.92$ mm), $p> .05$. These three loaded configurations were all larger than the Driver configuration ($M=151.24$ mm), $p<.05$.

Table 30: Summary statistics and mean deltas for Maximum Waist Depth relative to Semi-Nude Waist Depth for each configuration

	Semi-Nude (mm)	Driver (mm)	Rifleman (mm)	SAW Gunner (mm)	Combat Medic (mm)
Δ from Semi-Nude	-	151 [B]	333 [A]	329 [A]	325 [A]
Δ SD	-	18	21	15	21
Mean	231	382	564	560	556
SD	-	32	33	26	35
Min	-	331	497	503	481
25th	-	368	545	548	545
50th	-	385	566	564	556
75th	-	395	582	570	577
Max	-	458	643	623	627
Range	-	127	146	120	146

A>B>C>D, Superscripts of different letters indicate significant differences at the p<0.05 level.



*Deltas were calculated using a surrogate dimension.

Figure 66: Percent increment relative to Semi-Nude Waist Depth and average Maximum Waist Depth for each configuration

4. DISCUSSION AND SUMMARY

This study highlighted and recorded a detailed, but not exhaustive, list of 42 critical anthropometric body dimensions from 30 TPs in 6 different configurations in order to characterize the Soldier in various CIE to better represent the current nine-man dismounted squad, including the driver. These data provide, for the first time, a clear window into the increased size of the Soldier due to the bulk and weight of their current CIE by providing specific delta values that can be added to Semi-Nude anthropometric databases, such as the recently collected Army Anthropometric Survey, ANSUR II (see Gordon et al., 2014). For example, three recent memorandums (Garlie and Choi, 2012a and 2012b; Gordon, 2012) outline some preliminary analyses using specific body dimensions from this study and the Army Anthropometric Survey (ANSUR II) pilot study (Paquette et al., 2009) to investigate Soldier space claims for vehicle seat design.

As described in Section 2.5, it was necessary to conduct an observer error analysis and analysis for gender differences before the data from the anthropometric dimension measurements could be analyzed. The observer error data were needed to develop an initial reference guide on the allowable error ranges for encumbered anthropometric data. The gender data were needed to determine whether male and female encumbered torso data should be separated or combined within the same IOTV size categories. Although both of these analyses were merely methods for use in the analysis of the anthropometric measurements taken and were not data collection objectives in the overall CIE body size/volume characterization effort, their results have useful implications for future similar characterization efforts.

As mentioned in Section 2.5.1, both Semi-Nude and encumbered anthropometric data were compared to allowable error ranges developed for ANSUR and ANSUR II (Gordon et al., 1989; Gordon et al., 2014). However, the TPs in those studies were measured only in a Semi-Nude condition with no additional loads, and their measurement times were significantly shorter than those in the current study. As expected, some of the encumbered measurement differences were larger than the identified allowable Semi-Nude errors from ANSUR and ANSUR II, as encumbered measurements are inherently more variable than Semi-Nude measurements. If these differences were the same, or smaller, than the Semi-Nude measurements then they pose no issues. Also, due to the inherent variability in the encumbered measurements, if they are larger (depending on how large) they should still not necessarily be a cause for concern. To address this issue, ANSUR and ANSUR II data were used for allowable error ranges, and they were adjusted proportionally to better reflect the variability found in encumbered measurements. The results revealed that the adjustments were not greatly different for many of the ANSUR and ANSUR II Semi-Nude allowable errors, but were shifted slightly higher as expected (see Table 3 and Table 4). In general then, for this study, it can be concluded that the data generated by the anthropometrists were repeatable and reliable.

As mentioned in Section 2.5.2, there was an opportunity to test, albeit only in size X-small, the effects of gender while wearing the IOTV. The X-small IOTV is currently the smallest issued personal armor system (although additional smaller sizes are currently in development). The results from the gender evaluation indicate (1) statistical differences between male and female torso dimensions only for Chest Circumference in the Semi-Nude configuration and (2) a strong likelihood that gender differences disappear in the torso region once the IOTV is donned, with the specific CIE (i.e., IOTV) being the strongest factor causing the differences between different encumbered configurations.

4.1 Anthropometric Height Measurements

To obtain the necessary encumbered breadths, circumferences, and depths for an analysis of encumbered anthropometry, it was critical to highlight specific body landmarks on the Semi-Nude body and measure their height locations so that they could be relocated on the various clothing layers throughout the course of the investigation. In this study, seven specific heights were determined to be critical for obtaining the required torso breadths, circumferences, and depths. These were measured and transferred through each configuration. Results generally found that the height deltas were fairly consistent across all configurations and were approximately 40 mm different between the Baseline and the Semi-Nude configurations. These differences were clearly related to the addition of the individual footwear (in this case the height of the Army combat boot) after all initial height landmarks were placed on the ACU using adhesive markers. The other single measurement, Buttock Circumference, had a delta between the Baseline and Semi-Nude configurations that reflected only the ACU trouser, as no other CIE was added to this location during the course of the investigation. The difference was minimal.

4.2 Anthropometric Standing and Sitting Measurements

To characterize the overall shape and size of the encumbered Soldier, it was critical to measure the anthropometric dimensions in the same locations each time so that the addition of the CIE could be subtracted from Semi-Nude configuration to obtain a measurement delta. From the 7 height measurements taken, a total of 19 breadths, circumferences, and depths were measured in the standing and seated positions for each of the encumbered configurations on every TP.

Summary results (Table 31) indicate that, in general, all of the delta calculations from the encumbered configurations were statistically larger than the Baseline configuration deltas (i.e., Baseline minus Semi-Nude). This is not a surprise as the Baseline configuration was quite minimal, consisting only of the TP's ACU and duty boots.

More importantly, the mean deltas generally increased relative to the CIE for the different configurations, although the only clear differences were that the three loaded configurations (the Rifleman, the SAW Gunner and the Combat Medic) were, on the whole, larger than the Driver configuration dimensions. This was expected, as the TPs in the Driver configuration in this study wore only their IOTV and no additional CIE. The only exception was for Mid-Shoulder Height where the Driver had the largest delta. This exception seems to be related to the weight of the other loaded configurations that weighed the shoulders down, resulting in smaller deltas compared to the Driver configuration. Overall, Stature and Sitting Height showed no statistical differences between the four IOTV configurations, as the only encumbrance (for any configuration) affecting measurements of these dimensions was the ACH. Depending on the specific body dimension, the Rifleman, SAW Gunner and Combat Medic configurations were often very similar to each other even though they consisted of different gear components, as defined by McNamara (2012). This trend was found for many body dimensions. While several dimensions revealed significant differences, they were small and are likely not operationally relevant. For example, the SAW Gunner configuration showed significant differences at some of the measurements around the chest region compared to the Rifleman and the Combat Medic configurations, primarily caused by the grenade pouch being near the specific measurement location. Moving the pouch elsewhere would have reduced the differences.

Table 31: Mean and maximum delta values for standing and sitting dimensions for encumbered configurations relative to Semi-Nude configuration

Dimension	Baseline (mm)		Driver (mm)		Rifleman (mm)		SAW Gunner (mm)		Combat Medic (mm)	
	Mean	Max	Mean	Max	Mean	Max	Mean	Max	Mean	Max
Standing										
Weight	4	5	18	22	28	32	33	37	26	30
Stature	39	52	63	78	62	87	61	94	60	92
Mid-Shoulder Height	46	57	71	86	61	77	54	75	60	94
Shoulder Circumference	65	101	171	217	239	286	280	336	244	295
Chest Circumference	34	65	260	318	345	402	375	434	341	398
Waist (Omphalion**) Circumference**	37	74	336	460	865	996	863	989	887	1028
Vertical Trunk (USA) Circumference	56	128	167	230	298	415	299	441	237	351
Chest Depth	8	25	93	117	181	256	199	255	176	221
Waist Depth	10	24	129	180	304	357	294	339	309	339
Chest Breadth	10	43	41	70	50	79	47	81	47	77
Waist Breadth	4	32	73	106	287	328	300	337	280	339
Sitting										
Sitting Height	1	14	29	59	31	57	27	53	28	53
Waist Height	4	72	38	107	45	88	50	116	46	99
Buttock-Knee Length	8	25	64	96	144	176	148	186	137	185
Buttock-Popliteal Length	-2	23	57	96	136	172	140	171	127	158
Biacromial Breadth	5	29	9	38	13	54	12	63	13	62
Bideltoid Breadth	25	57	36	60	50	90	51	85	49	93
Forearm-Forearm Breadth	51	121	83	164	151	252	160	250	140	217
Hip Breadth	19	38	22	55	139	256	153	253	131	253
Elbow Circumference	116	252	270	361	539	686	607	783	619	739

In general, there were no significant differences in deltas between IOTV sizes for the different configurations. Exceptions included Waist (Omphalion) Breadth, Waist (Omphalion) Circumference, Weight, Maximum Waist Breadth, and Maximum Waist Depth. It is believed that this was generally because once a TP is fitted into the smaller size IOTV there is more difficulty in tightening down adjustment straps as the side ballistic plates push up against the edge of the front and back plates, preventing full tightening of the IOTV. Because the TP cannot tighten the adjustment straps, the IOTV cannot be fully tightened down to the torso, creating a kind of “bell effect” potentially leading to larger deltas for these dimensions in the smaller vests than in the larger vests. In addition, the TAP is a one size fits all item that follows more closely the curvature of the IOTV as the IOTV increases in size. On the smaller IOTVs it can be more difficult to completely tighten the TAP, leaving the potential for slight gapping between the surface of the IOTV and the TAP. This could also account for the larger delta values in these variables for smaller size IOTVs when compared to the larger sizes.

4.3 Head and Foot Anthropometry

Additional head and foot anthropometric measurements were measured. For head and foot anthropometry the only differences were related to wearing either the ACH or CVC on the head and the Army combat boots on the feet. Although CVC dimensions were recorded, only ACH dimensions were used in the delta calculations for this report.

4.4 Anthropometric Maximum Measurements

Maximum measurements were related to three specific locations where it appeared that TP CIE was broader and wider at a different waist level than at the standard Omphalion location. In this case the height was recorded and Maximum Waist Breadth, Maximum Waist Circumference, and Maximum Waist Depth were measured, both standing and seated. No Semi-Nude landmarks were available to calculate deltas at these maximum height locations so the Waist (Omphalion) location standing was used as a surrogate for calculating standing delta values. The same seated maximum dimensions (Maximum Waist Breadth, Maximum Waist Circumference, and Maximum Waist Depth) while encumbered were also recorded. However, no specific Semi-Nude landmark in the seated position was measured, and so delta calculations are not reported here for these dimensions. (Mean and maximum measurement values are in Appendix B.) To calculate delta values for these three maximum dimensions a surrogate dimension is required and is dependent on the question that is asked. Again, all three loaded configurations (Rifleman, SAW Gunner, and Combat Medic) were generally similar to each other, but they were all significantly larger than the Driver configuration.

5. CONCLUSIONS

Overall, the results from this study strongly indicate that Soldiers wearing various combat loads are significantly taller, broader front to back, wider, and heavier than when they are in their ACU alone. When Soldiers donned their ACU, an increase in body weight of approximately 4 kg (8.8 lb) was observed. When they donned the IOTV and ACH, an increase in body weight of approximately 18 kg (39.6 lb) was observed. On average, the delta values for body weight in the other three loaded configurations ranged from 26 kg (57.2 lb) to 33 kg (72.6 lb). In addition, except for the Baseline configuration, where TPs wore only the ACU and combat boots, all other configurations are loaded on or around the torso area. This resulted in substantial increases for delta values on the Breadths, Depths and Circumferences around the Chest and Waist regions, as can be seen in Table 31. The results of this work show that the space occupied by a Soldier, wearing an IOTV, sitting or standing, is considerably larger than when wearing only the ACU. Given that the space in many current military vehicle platforms and/or work stations was designed using Baseline or Semi-Nude measurements, it is clearly not satisfactory for Soldiers wearing duty specific equipment. Based on these results, it can be concluded that 1) military vehicle platforms/workstations should be re-designed to sufficiently increase Soldier space and thereby improve Soldier performance, survivability, and comfort while reducing overall risk and/or 2) Soldier CIE should be significantly reduced so that current military platforms/ workstations perform as they were originally designed.

In addition to providing for the first time a clear window into the increased size of the Soldier caused by CIE, this study was the first to employ modern digital 3D whole body and head imaging technology to record individual body scans in all six encumbered configurations, standing and seated resulting in a database of over 600 raw digital images ready for post processing and analysis. Although not directly used in this study, these digital data are available, and with additional financial resources can assist computer modelers and others in generating future simulation and virtual models of the encumbered Soldier. A recent study by Mitchell et. al., (2014) also provides critical linkages between encumbered anthropometric data and range of motion (ROM) data for evaluating how the Soldier functions when loaded down with CIE.

Furthermore, the newly adjusted error ranges developed and used during this study can be used for future encumbered anthropometric studies. Likewise, based on the gender analysis performed during this study, male and female encumbered torso data can be combined in future studies once torso-protective CIE is donned; however, it is recommended that a larger number of TPs in different sized IOTVs be similarly tested.

This document reports research undertaken at the U.S. Army Natick Soldier Research, Development and Engineering Center, Natick, MA, and has been assigned No. NATICK/TR- 14/019 in a series of reports approved for publication.

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APPENDIX A:
DATA COLLECTION FORMS FOR OCP TECD ENCUMBERED ANTHROPOMETRY

(Reprint of Original)

Variable	Configuration 1 Nude	Configuration2 Normal	Configuration3 Driver	Configuration4 Rifleman	Configuration5 Saw Gunner	Configuration6 Combat Medic	Configuration7
Standing (Unit: mm, unless otherwise noted) Mid Shoulder:______________	Scan garment	Scan garment + ACU/Boots	Scan garment + ACU/Boots + IOTV/Helmets	Scan garment + ACU/Boots + IOTV/Helmets + Tap1&Blddr	Scan garment + ACU/Boots + IOTV/Helmets + Tap2&Grnd&Bld dr	Scan garment + ACU/Boots + IOTV/Helmets + Tap3&Blddr	Re-measure Todd(8) Joo(9) Redress(10)
Weight (Kg)			ACH CVC				
Stature			ACH CVC	ACH	ACH	ACH	
Mid Shoulder Height							
Acromion Height (transfer)							
Deltoid Height (transfer)							
Chest HT MAX							
Chest Height (transfer)							
Waist HT MAX (transfer)							
Waist Height (transfer)							
Buttock Height (transfer)							
Suprapatella Height							
Shoulder Circumference							
Chest Circ. Max							
Chest Circumference							
Waist Circ. MAX							
Waist Circumference							
Buttock Circumference							
Vertical Trunk Circumference							
Chest Depth Max							
Chest Depth							
Waist Depth MAX							
Waist Depth							
Chest Breadth							
Waist Breadth MAX							
Waist Breadth							
Foot Length							
Foot Breadth							

Variable	Configuration 1 Nude	Configuration2 Normal	Configuration3 Driver	Configuration4 Rifleman	Configuration5 Saw Gunner	Configuration6 Combat Medic	Configuration7
Sitting (Unit: mm, unless otherwise noted) Troch. HT:_______ Lth:_______	Scan garment	Scan garment + ACU/Boots	Scan garment + ACU/Boots + IOTV/Helmets	Scan garment + ACU/Boots + IOTV/Helmets + Tap1&Blddr	Scan garment + ACU/Boots + IOTV/Helmets + Tap2&Grnd&Blddr	Scan garment + ACU/Boots + IOTV/Helmets + Tap3&Blddr	Re-measure Todd(8) Joo(9) Redress(10)
Head Circumference			CVC				
Head Length			CVC				
Head Breadth			\ \ CVC				
Sitting Height			ACH CVC	ACH	ACH	ACH	
Waist Height MAX							
Waist Height							
Knee Height							
Buttock Knee Length							
Buttock Popliteal Length	+10(mm)	+10(mm)					
Biacromial Breadth							
Bideltoid Breadth							
Forearm-Forearm Breadth							
Waist Depth MAX							
Waist Breadth MAX							
Hip Breadth							
Waist Circumference MAX							
Elbow Circumference							
Buttock Knee Length MAX							
Buttock Popliteal Length MAX			+10(mm)	+10(mm)	+10(mm)	+10(mm)	
Scan Condition	Configuration 1 Nude	Configuration2 Normal	Configuration3 Driver	Configuration4 Rifleman	Configuration5 Saw Gunner	Configuration6 Combat Medic	Configuration7
Head Scan	Head1.iv		Head2_ACH				
			Head3-CVC				
Seated Scan	Seated1.iv	Seated2-ACU	Seated3_IOTV_ACH	Seated5_Rifleman	Seated6_SawGunner	Seated7_CombatMedic	
	Standing1	Standing3-ACU	Seated4_IOTV_CVC				
Standing Scan	Standing2	Standing4_ACU	Standing5_IOTV_ACH	Standing 9_Rifleman	Standing11_SawGunner	Standing13_CombatMedic	
			Standing6_IOTV_ACH	Standing 10_Rifleman	Standing12_SawGunner	Standing14_CombatMedic	
			Standing7_IOTV_CVC				

APPENDIX B:
MEAN AND MAXIMUM MEASUREMENT VALUES FOR MAXIMUM SITTING VARIABLES

Dimension	Baseline Semi-Nude (mm)		Driver Semi-Nude (mm)		Rifleman Semi-Nude (mm)		SAW Gunner Semi-Nude (mm)		Combat Medic Semi-Nude (mm)	
	Mean	Max	Mean	Max	Mean	Max	Mean	Max	Mean	Max
Maximum Waist Breadth	-	-	405	481	603	637	626	663	604	653
Maximum Waist Depth	-	-	383	469	563	652	564	630	555	639
Maximum Waist Circumference	-	-	1293	1535	1834	1980	1858	2043	1865	2049