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ANTHROPOMETRY AND RANGE OF MOTION OF THE ENCUMBERED SOLDIER

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14. ABSTRACT

While much work has been done to detail the physical anthropometry and range of motion ranges of the semi-nude or lightly clothed individual, limited information and data currently exists characterizing the space and movement claims of the encumbered dismounted Soldier. Soldiers are required to wear multiple layers of clothing and protective equipment in addition to mission essential gear. In order to document and measure impacts on space claims/bulk and mobility, 32 active duty, male Soldiers were measured in four loaded configurations; two duty positions (rifleman and grenadier) were represented in two different body armor systems (plate carrier and vest, where the vest had a larger area of coverage).

Across the four loaded conditions, increases in size (59-101%) were evident in addition to increases in weight (13-23 kg). These corresponded to decreases in mobility, measured via range of motion. Soldiers typically saw their range of motion degrade between 6-27° for the goniometer measurements and 25-159 mm for the majority of the reach measurements. Larger increases in bulk and decreases in mobility were seen in the body armor system with the increased area of coverage. Additionally, larger increases in bulk and decreases in mobility were seen for the grenadier than for the rifleman duty position. Because much of the bulk was added around the waist, movements that involved bending at the waist (e.g., Trunk Flexion Standing and Sitting) had the largest degradations from the Baseline (duty uniform only).

15. SUBJECT TERMS

MOTION FLEXIBILITY ARMY PERSONNEL MEASURING INSTRUMENTS BODY MOVEMENTS
FLEXION SPACE(ROOM) ANTHROPOMETRY RESTRICTION MOBILITY PHYSICAL WORKSPACE
UNIFORMS LUMBAR SPINE DATA COLLECTION PROTECTIVE EQUIPMENT PERFORMANCE(HUMAN)
BODY SIZE MEASUREMENT POSTURE(GENERAL) HUMAN FACTORS ENGINEERING
COMFORT CONFIGURATIONS RANGE OF MOTION CIE(CLOTHING AND INDIVIDUAL EQUIPMENT)

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PREFACE

This report documents the methods used in and the results from anthropometric and range of motion testing of human research volunteers wearing four different configurations, with relevant gear, that combined two body armor protection levels (plate carrier and full vest) and two duty positions (Rifleman and Grenadier). The purposes were to provide knowledge on (1) how much space is filled by a Soldier when wearing multilayered Clothing and Individual Equipment (CIE) and (2) the movement and performance impact on the individual Soldier when outfitted in that equipment. This work was performed from April to December of 2012 by the Natick Soldier Research, Development and Engineering Center (NSRDEC) under: Lighten the Load Program (Program Element No. 32, Project No. J50).

The authors would like to thank the test team members (Megan Coyne, Linda DeSimone, Jay McNamara, Christopher Simone, and Christine Sniezek) and the Soldiers who volunteered to be test participants for this study.

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EXECUTIVE SUMMARY

Introduction:
From April to December of 2012, the Natick Soldier Research, Development and Engineering Center (NSRDEC) conducted a study to better understand the extremely limited information pertaining to how much space a fully encumbered Soldier occupies and to begin to compile information on the unknown movement and performance impact on individual Soldiers when outfitted in the multilayered Clothing and Individual Equipment (CIE) designed to protect them. There is a critical need to recognize that, while CIE provides the essential protection and gear needed to perform a mission and protect the Soldier, it can ultimately interfere with the Soldier's ability to maneuver in order to accomplish mission critical tasks and activities. It is therefore necessary to evaluate protective systems to ensure that mobility is not compromised to the point where mission performance is degraded to an unacceptable level, thereby increasing Soldier vulnerabilities. Numerous studies have investigated the range of motion of minimally clad individuals (Boone and Azen, 1979; Gaidosik and Bohannon, 1987), and two preliminary studies were conducted in 2010 (Mitchell, 2013) assessing the impact of body armor alone on Soldier range of motion; however, only very minimal work has been completed on individuals in full military CIE.

Methods:
Soldiers' anthropometry and range of motion was measured while wearing the CIE systems available at the time of data collection (in 2012). Configurations were based on the Army's five Body Armor Protection Levels (BAPLs 1-5), and guidance was provided by the Maneuver Center of Excellence (MCoE) with respect to the ancillary gear and equipment that was worn with the armor (MCoE, ATZB-CIS, 13 Oct 10, subject: Body Armor Protection Levels).

Due to limitations in resources (time and funding), all BAPL and potential duty position configurations could not be assessed; therefore, in cooperation with the Project Manager (PM) of the Lighten the Load Program, four armor configurations combining BAPLs 2 and 5 and the Rifleman and Grenadier duty positions were chosen for study, along with two minimally clad configurations as baselines. BAPL 2 includes the Soldier Plate Carrier System (SPCS) with front and back plates. BAPL 5 includes the Improved Outer Tactical Vest (IOTV) with front, back, and side plates. Two types of measurements were taken on 32 male test participants (TPs): anthropometric and range of motion. The six tested configurations were: Semi-Nude (anthropometric measurements only), Baseline Army Combat Uniform (ACU), BAPL 2 Rifleman (2R), BAPL 2 Grenadier (2G), BAPL 5 Rifleman (5R), and BAPL 5 Grenadier (5G).

Anthropometric measurements, including the 3D scanning of test participants and range of motion testing, was conducted in separate locations on the same day. The order of test presentation for each test configuration was quasi-randomized so that the TPs would wear the same body armor configurations back-to-back and ease the amount of time it took to dress each TP in a configuration (e.g., 2R and then 2G or vice versa).

Anthropometric Measurements: For all TPs, the Semi-Nude anthropometric measurements were completed first, and the Baseline (ACU only) measurements were completed second. The TPs were properly fit with the correct size in each new clothing item (with the exception of the ACU

trouser, which was the TP's personal garment), as it was added to their configuration. Each station had one measurer (either a trained anthropologist or human factors personnel, depending on the station) and a trained data recorder.

All anthropometric dimensions were measured by one of the two measurers based on ANSUR II procedures (Gordon et al., 2014; Hotzman et al., 2011) or the Paquette et al. (1999) evaluation of multilayered military clothing, unless otherwise stated. A total of 11 body landmarks (Acromion, Buttock, Chest, Deltoid, Metacarpale II and V, Waist at Omphalion, Stylion, Suprapatella, First and Fifth Metatalsophalangeal Protrusions) were palpated and marked with an eyebrow pencil on the right side of the body and transferred to the front, back, and left sides, where applicable.

Anthropometric dimensions measured were:

- Acromion Height
- Biacromial Breadth, Sitting
- Bideltoid Breadth, Sitting
- Buttock Circumference
- Buttock Height
- Buttock-Knee Length
- Buttock-Popliteal Length
- Chest Breadth
- Chest Circumference
- Chest Depth
- Chest Height
- Deltoid Height
- Elbow Circumference, Sitting
- Foot Breadth
- Foot Length
- Forearm-Forearm Breadth, Sitting
- Hand Breadth
- Hand Circumference
- Hand Length
- Head Breadth
- Head Circumference
- Head Length
- Hip Breadth, Sitting
- Knee Height, Suprapatella
- Knee Height, Suprapatella, Sitting
- MAX Backpack Height
- MAX Backpack Depth
- MAX Chest Circumference
- MAX Waist Breadth
- MAX Waist Breadth, Sitting
- MAX Waist Circumference
- MAX Waist Circumference, Sitting
- MAX Waist Depth
- MAX Waist Depth, Sitting
- MAX Waist Height
- MAX Waist Height, Sitting
- Mid-Shoulder Height
- Shoulder Circumference
- Sitting Height
- Stature
- Vertical Trunk (USA) Circumference
- Waist (Omphalion) Circumference
- Waist (Omphalion) Breadth
- Waist (Omphalion) Depth
- Waist Height
- Waist Height, Sitting
- Weight With Backpack (lb)
- Weight (lb)
- Wrist Circumference

After one set of dimensions was measured per each configuration, TPs were scanned in three postures, two standing and one seated, to obtain 3D whole body digital images for use in future modeling and simulation efforts. These are not discussed in this report.

Range of Motion Measurements: No Semi-Nude range of motion measurements were taken in this study. All range of motion measurements were conducted by one of the two measurers. Measurements were taken at least three times. If one of the measurements was drastically

different from the others or if it appeared that a TP's muscles were still tight during a measurement, additional measurements were taken, and the closest three measurements were used to obtain a mean measurement of the movement. After each movement was performed in each of the configurations (other than Semi-Nude), TPs were asked to subjectively rate the extent to which the movement was restricted by the equipment and to provide comments regarding the related causes. The movements performed and evaluated in this study were:

- Cervical Rotation
- Cross Body Reach
- Forward Extended Reach
- Overhead Fingertip Reach
- Thoracic/Lumbar Spine Lateral Flexion
- Thoracic/Lumbar Spine Rotation
- Trunk Flexion – Seated Trunk Flexion – Standing
- Upper Arm/Shoulder Abduction
- Upper Arm/Shoulder Backward Extension
- Upper Arm/Shoulder Forward Extension
- Upper Leg/Hip Flexion
- Ventral-Dorsal Cervical Flexion

Results and Discussion:
The results across all configurations (i.e., 2R, 2G, 5R, and 5G) indicate there were general increases in key circumference, breadth, and depth (i.e., bulk) measurements related to Soldier CIE that had a significant decrement on the Soldiers' range of motion for many body movements relative to the Baseline. Table ES-1 shows significant differences (or no difference) and the direction of difference for each dimension with armor system measurements between the Semi-Nude configuration, between the two BAPLs, and between the two duty positions. Table ES-2 shows significant difference (or no difference) and the direction of difference for each range of motion measurement between each loaded configuration and the baseline, between the two BAPLs, and between the two duty positions.

When the TPs were encumbered with CIE outlined in this study, their body weights increased by 30-50 lb beyond the Baseline measurements depending on BAPLs and duty positions. In addition to CIE weight, the equipment is concentrated around the torso, especially on the front and the sides of the abdominal area. Furthermore, Soldiers typically carry backpacks in addition to their poorly distributed CIE. In this study Modular Lightweight Load Carrying Equipment (MOLLE) mediums with a 72 h mission load, weighing 27-31 lb, were placed on the back of the torso of the TPs when outfitted in each of the four loaded configurations. This total weight of 57-81 lb beyond the Baseline configuration had a significant impact on various body dimensions.

Table ES-1: Significant differences for anthropometric measurements in loaded configurations relative to the Semi-Nude configuration.

Dimension	Semi-Nude measurements relative to:				BAPL 2 vs. BAPL 5	Rifleman vs. Grenadier
	2R	2G	5R	5G		
Chest Breadth	No Difference	Increased	Increased	Increased	Increased in BAPL 5	No Difference
Chest Circumference	Increased	Increased	Increased	Increased	Increased in BAPL 5	No Difference
Chest Depth	Increased	Increased	Increased	Increased	Decreased in BAPL 5	No Difference
Mid-Shoulder Height	Decreased	Decreased	No Difference	No Difference	Increased in BAPL 5	Decreased in Grenadier
Shoulder Circumference	Increased	Increased	Increased	Increased	Increased in BAPL 5	No Difference
Stature	Increased	Increased	Increased	Increased	No Difference	No Difference
Vertical Trunk (USA) Circumference	Increased	Increased	Increased	Increased	Increased in BAPL 5	Increased in Grenadier
Waist Breadth	Increased	Increased	Increased	Increased	Increased in BAPL 5	Increased in Grenadier
Waist (Omphalion) Circumference	Increased	Increased	Increased	Increased	Increased in BAPL 5	Increased in Grenadier
Waist Depth	Increased	Increased	Increased	Increased	Increased in BAPL 5	Increased in Grenadier
Weight(lb)	Increased	Increased	Increased	Increased	Increased in BAPL 5	Increased in Grenadier
Biacromial Breadth, Sitting	No Difference	No Difference	No Difference	No Difference	No Difference	No Difference
Bideltoid Breadth, Sitting	Increased	Increased	Increased	Increased	Increased in BAPL 5	Increased in Grenadier
Buttock-Knee Length	Increased	Increased	Increased	Increased	Increased in BAPL 5	Increased in Grenadier
Buttock-Popliteal Length	Increased	Increased	Increased	Increased	Increased in BAPL 5	Increased in Grenadier
Elbow Circumference, Sitting	Increased	Increased	Increased	Increased	Increased in BAPL 5	Increased in Grenadier
Forearm-Forearm Breadth, Sitting	Increased	Increased	Increased	Increased	Increased in BAPL 5	Increased in Grenadier
Hip Breadth, Sitting	Increased	Increased	Increased	Increased	Increased in BAPL 5	Increased in Grenadier
Sitting Height	Increased	Increased	Increased	Increased	No Difference	No Difference
MAX Waist Breadth	Increased	Increased	Increased	Increased	Increased in BAPL 5	Increased in Grenadier
MAX Backpack Chest Circumference	Increased	Increased	Increased	Increased	Increased in BAPL 5	Increased in Grenadier
MAX Backpack Depth	Increased	Increased	Increased	Increased	Increased in BAPL 5	Increased in Grenadier
MAX Waist Circumference	Increased	Increased	Increased	Increased	Increased in BAPL 5	Increased in Grenadier
MAX Waist Depth	Increased	Increased	Increased	Increased	Increased in BAPL 5	Increased in Grenadier
Weight with Backpack	Increased	Increased	Increased	Increased	Increased in BAPL 5	Increased in Grenadier

Table ES-2: Significant difference for range of motion measurements in loaded configurations relative to the Baseline configuration.

Movement	Baseline measurements relative to:				BAPL 2 vs. BAPL 5	Rifleman vs. Grenadier
	2R	2G	5R	5G		
Cervical Rotation	Degraded	Degraded	Degraded	Degraded	No Difference	No Difference
Ventral-Dorsal Cervical Flexion	No Difference	No Difference	No Difference	No Difference	No Difference	No Difference
Thoracic/ Lumbar Spine Rotation	Degraded	Degraded	Degraded	Degraded	Degraded in BAPL5	Degraded in Grenadier
Thoracic/ Lumbar Spine Lateral Flexion	No Difference	No Difference	Degraded	Degraded	Degraded in BAPL5	Degraded in Grenadier
Upper Arm/ Shoulder Abduction	Degraded	Degraded	Degraded	Degraded	Degraded in BAPL5	Degraded in Grenadier
Upper Arm/ Shoulder Overhead Reach, Extension	Degraded	Degraded	Degraded	Degraded	Degraded in BAPL5	Degraded in Grenadier
Upper Arm/ Shoulder Forward Flexion Extension	Degraded	Degraded	Degraded	Degraded	Degraded in BAPL5	Degraded in Grenadier
Upper Arm/ Shoulder Forward Extended Reach	No Difference	Degraded	Degraded	Degraded	Degraded in BAPL5	Degraded in Grenadier
Upper Arm/ Shoulder Backward Extension	No Difference	No Difference	No Difference	No Difference	No Difference	No Difference
Upper Arm/Shoulder Cross Body Reach	Degraded	Degraded	Degraded	Degraded	No Difference	Degraded in Grenadier
Trunk Flexion - Standing	No Difference	No Difference	Degraded	Degraded	Degraded in BAPL5	Degraded in Grenadier
Trunk Flexion – Seated	Degraded	Degraded	Degraded	Degraded	Degraded in BAPL5	Degraded in Grenadier
High Knee/ Knee Lift	No Difference	Degraded	Degraded	Degraded	Degraded in BAPL5	Degraded in Grenadier

Conclusions:

In simplified terms, the more CIE that is put on Soldiers, the larger they will be and the less range of motion they will have. Across both the anthropometric and the range of motion data, there were increases in bulk, thereby leading to increased size dimensions and decreased range of motion. This was seen both as the BAPL increased (from BAPL 2 to BAPL 5) and as the amount of equipment worn increased (from the Rifleman to Grenadier duty positions). The increase in encumbered measurements can be linked to the degradation in range of motion performance, specifically in how much increase in bulk and degradation in range of motion varies by part of the body, configuration, and movement.

It is well known that the space in vehicles and/or at workstations occupied by the encumbered Soldiers, sitting or standing, is not enough and needs to be increased substantially, especially for breadth and depth (Garlie and Choi 2014; Johnson 1984; Paquette et al., 1999). However, because few studies have ever looked at encumbered anthropometry, these clothed dimensions cannot be estimated from Semi-Nude dimensions. In the current study, encumbered anthropometric data provided unique information on size increments at specific locations (e.g., Waist at Omphalion) relative to Semi-Nude and Baseline configurations, as well as the actual measurements per BAPL and duty position. This information is expected to contribute

significantly to future designs of CIE and to vehicles and workspace platforms to decrease Soldier load, improve performance, and enhance Soldier comfort and survivability.

For future testing, similar measurements outlined in this current study would likely be recommended as important for assessing the amount of occupied space related to CIE and the effects on the Soldiers' range of motion. Specific measurements recommended for future studies will need to be addressed and identified based on the end goals of the program and on the CIE being worn.

Data collected in this study showing the increased body dimensions and decreased range of motion due to Soldier CIE can be utilized by military equipment designers and requirements developers (both of CIE and military platforms). Designers and requirements developers need to remember:

1) Any clothing or equipment that is added needs to be developed not just for the individuals (in their Semi-Nude/Baseline configurations), but for all the equipment that they wear.
2) These increased sizes need to be accounted for when developing next generation equipment and platforms.
3) The gear that Soldiers are wearing impedes their ability to move and perform physical tasks.
    a. Care should be taken with CIE design to minimize these performance decreases.
    b. Care should be taken with platform and workspace designers to create spaces where tasks, job duties, and missions can be easily carried out even with this decreased range of motion.
    c. Creating CIE that is too bulky can lead to safety hazards (e.g., snags, increased fatigue, and increased thermal burden).

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ANTHROPOMETRY AND RANGE OF MOTION OF THE ENCUMBERED SOLDIER

1. INTRODUCTION

From April to December of 2012, the Natick Soldier Research, Development and Engineering Center (NSRDEC) conducted a study to better understand the extremely limited knowledge of how much space a fully encumbered Soldier occupies and to begin to compile information on the unknown movement and performance impact on individual Soldiers when outfitted in the multilayered Clothing and Individual Equipment (CIE) designed to protect them. There is a critical need to recognize that, while CIE provides the essential protection and gear needed to perform a mission and protect the Soldier, it can ultimately interfere with the Soldier's ability to maneuver in order to accomplish mission critical tasks and activities. It is therefore necessary to evaluate protective systems to ensure that mobility is not compromised to the point where mission performance is degraded to an unacceptable level, thereby increasing Soldier vulnerabilities. Numerous studies have investigated the range of motion of minimally clad individuals (Boone and Azen, 1979; Gaidosik and Bohannon, 1987), and a preliminary study was conducted in 2010 (Mitchell, 2013) assessing the impact of body armor alone on Soldier range of motion; however, only very minimal work has been completed on individuals in full military CIE.

The nature and length of missions and Military Occupational Specialties (MOSs) introduce a myriad of clothing and equipment combinations. Each of these combinations has a unique influence on Soldier space claims and limitations to their range of motion. This can have a critical impact on mission success and Soldier survivability (via performance and effectiveness). There is a need to recognize that while CIE provides the essential protection and gear needed to perform a mission, it can also interfere with the individual's ability to maneuver in order to accomplish mission critical tasks and activities. It is important to evaluate systems to ensure that mobility is not compromised to the point where mission performance is degraded to an unacceptable level. This work is just a start to investigate the role that CIE has on Soldier space claims and range of motion. This work will continue to improve the designs of vehicle platforms/workstations, CIE, and human performance models.

Soldiers' anthropometry and range of motion were measured while wearing the CIE systems available at the time of data collection (2011). Configurations were based on the Army's establishment of Body Armor Protection Levels (BAPLs) and guidance provided by the Maneuver Center of Excellence (MCoE) with respect to the ancillary gear and equipment that was worn with the armor (MCoE, ATZB-CIS, 13 Oct 10, subject: Body Armor Protection Levels). The BAPLs are:

BAPL 0: No body armor worn
BAPL 1: Vest or Plate Carrier with soft armor only
BAPL 2: Soldier Plate Carrier System (SPCS) with front and back plates
BAPL 3: Plate Carrier with front, back, and side plates
BAPL 4: Improved Outer Tactical Vest (IOTV) with front and back plates
BAPL 5: IOTV with front, back, and side plates

2. METHODS

2.1 Test Items

Test items were composed of currently fielded US Army CIE. This evaluation was not intended to be an evaluation of the body armor systems chosen or the individual components of Soldier gear, but instead these items were chosen as representative of "typical" equipment currently worn by Soldiers.

Configurations were chosen based on the BAPLs and duty position. No extremity armor pieces were added to the armor (e.g., groin protector). Due to limitations in resources (time and funding), all BAPLs and potential duty position configurations could not be assessed; therefore, in cooperation with the Project Manager (PM) for the Lighten the Load program, a total of six configurations were chosen: a Semi-Nude (anthropometry only) configuration, a Baseline configuration (Army Combat Uniform), a BAPL 2 Rifleman (2R) configuration, a BAPL 2 Grenadier (2G) configuration, a BAPL 5 Rifleman (5R) configuration, and a BAPL 5 Grenadier (5G) configuration:

Semi-Nude:
- Spandex shorts

Baseline:
- No body armor or equipment
- Duty uniform (Army Combat Uniform (ACU) trousers with Army Combat Shirt (ACS))
- Duty boots
- Personal undergarment
- Riggers belt

BAPL 2:
- Soldier Plate Carrier System (SPCS) with Enhanced Small Arms Protective Insert (ESAPI) plates in front and back
- Advanced Combat Helmet (ACH)
- Approved eye protection spectacles (Oakley M-frames) or personal eyewear (not worn during body scans)
- AN/PVS 14 with helmet mount and arm (worn only for anthropometric weights)
- Summer Flyers Gloves (SFG)
- Tactical Assault Panel (TAP)
- Plus all components of the Baseline

Rifleman (2R)

Worn with:
- Six 30-round magazines for M4
- One M67 (baseball grenade)
- One Improved First Aid Kit (IFAK)

or

Grenadier (2G)

- Six 30-round magazines for M4
- One M67 (baseball grenade)
- One IFAK
- Eighteen 40 mm grenades in the shape of High Explosive, Dual Purpose (HE/DP) grenades (M433) to represent
    - 14 HE/DPs and 4 STAR (M661)
- One magazine bag

BAPL 5:

- IOTV with ESAPI plates in front and back and Enhanced Side Ballistic Inserts (ESBI) side plates
- ACH
- Approved eye protection spectacles (Oakley M-frames) or personal eyewear
- AN/PVS 14 with helmet mount and arm (worn only for anthropometric weights)
- SFG
- TAP
- Plus all components of the Baseline

Worn with:

Rifleman (5R)

- Six 30-round magazines for M4
- One M67 (baseball grenade)
- One IFAK

Or

Grenadier (5G)

- Six 30-round magazines for M4
- One M67 (baseball grenade)
- One IFAK
- Eighteen 40mm grenades in the shape of HE/DP (M433) to represent
    - 14 HE/DPs and 4 STAR (M661)
- One magazine bag

The various CIE items and their weights by body size for each of the four encumbered configurations tested (2R, 2G, 5R, and 5G) are listed in Appendix A. In addition, for some anthropometric measurements, an assault pack was included. Inside the assault pack for the Rifleman configurations (2R and 5R) were:

- 3 L of water in a hydration bladder
- Three Meals, Ready to Eat (MREs)
- One pair of socks
- One additional ACS
- One poncho with poncho liners
- One wet weather bag (a surrogate of similar weight, bulk, and rigidity was used)

- One hygiene kit (a surrogate of similar weight, bulk, and rigidity was used)
- One weapon cleaning kit
- One pair of M24 binoculars
- One carrying case for the AN/PVS 14s
- One carrying case for the eye protection

Inside the assault pack for the Grenadier configurations (2G and 5G) were all the items listed for the Rifleman configurations, plus ten additional mock HE/DP grenades, representing six smoke (M714) grenades and four Parachute (M583) grenades. The Rifleman assault pack weighed 26.53 lb and the Grenadier assault pack weighed 31.38 lb.

Images of the IOTV and SPCS can be seen in Figure 1. Images of the ESAPI plates can be seen in Figure 2 and of the ESBI in Figure 3.

IOTV SPCS

Figure 1: Body Armor Systems: IOTV (left) used in BAPL 5; SPCS (right) used in BAPL 2

Figure 2: ESAPI used in BAPLs 2 and 5

Figure 3: ESBI (side plates) used in BAPL 5

Images of the on-body load configurations for each duty position can be seen in Figure 4, Figure 5, and Figure 6. Additional photos of a test participant (TP) outfitted in configuration 2R (left) and 2G (right) can be seen in Figure 7.

Figure 4: TAP loaded for Rifleman configurations (2R and 5R), including magazines, grenade, and IFAK

Figure 5: TAP loaded for Grenadier configurations (2G and 5G), including magazines, grenade, and IFAK, and 12 HE/DP grenades (eight grenades carried in add-on pouches and four grenades carried in magazine pockets integrated into TAP)

Figure 6: Magazine bag used to hold six additional HE/DP grenades for Grenadier configurations (2G and 5G)

Figure 7: Image of TP outfitted in 2R (left) and 2G (right) (Glasses/spectacles were not worn for anthropometric measures.)

2.2 Test Instruments

Several standard instruments were used in addition to a few unique tools that were created for this data collection effort. Some instruments were used for both the range of motion and the anthropometric measurements, while others were used for only one or the other.

The Acumar Digital Inclinometer was the primary goniometer used (Figure 8), although the protractor goniometer was used for the spine rotation (Figure 9). A Swiss-made GPM anthropometer (Figure 10) was used to collect standing and seated linear body measurements, in addition to various floor reach measurements highlighted in the range of motion study. A Lufkin 2-m steel tape was used to collect various body circumference measurements. Head length and head breadth were measured using a spreading caliper. Hand length and hand breadth were measured using a Poech sliding caliper while foot length and foot breadth were measured using anthropometric foot boxes. All measurements were recorded in millimeters. Weight was measured using a SECA digital scale that measured to the nearest 10^{th} of a lb (Figure 11). An anthropometer modified with a laser level was used to assist with transferring measurement location landmarks to the various CIE layers (Figure 11). A Cyberware WB4 whole body 3D scanner was used to collect three dimensional images for use in modeling and simulation of the encumbered Soldier (Figure 12).

Figure 8: Acumar Digital Inclinometer ACU 360 with ruler attachment (digital inclinometer)

Figure 9: Lafayette Gollehon Extendable Goniometer (protractor goniometer)

Figure 10: GPM Anthropometer Model 101 (partially assembled) with base plate, 0-2100 mm

Figure 11: Assortment of anthropometric equipment used to measure body dimensions

Figure 12: Image of 3D scanner

A variety of measurement charts were used for the reaches and mission movements. All were designed similar to graph paper, with 1 mm blocks, and thicker outlines at every 5, 10 and 100 mm marks. The charts differed primarily in how they were mounted. The 3 m high vertical wall chart (Figure 13) was mounted against a wall. The wall was stable enough to support a person in body armor leaning against it. A level was used to ensure that the chart was positioned vertical to the standing surface.

The vertical chart was broken into separate pieces, which could be connected. They were 110 cm long (with 10 cm for overlapping with the next piece) and 45 cm wide. All pieces were laminated so they could be written on with washable markers. The "0" mark was placed against the baseboard of a wall.

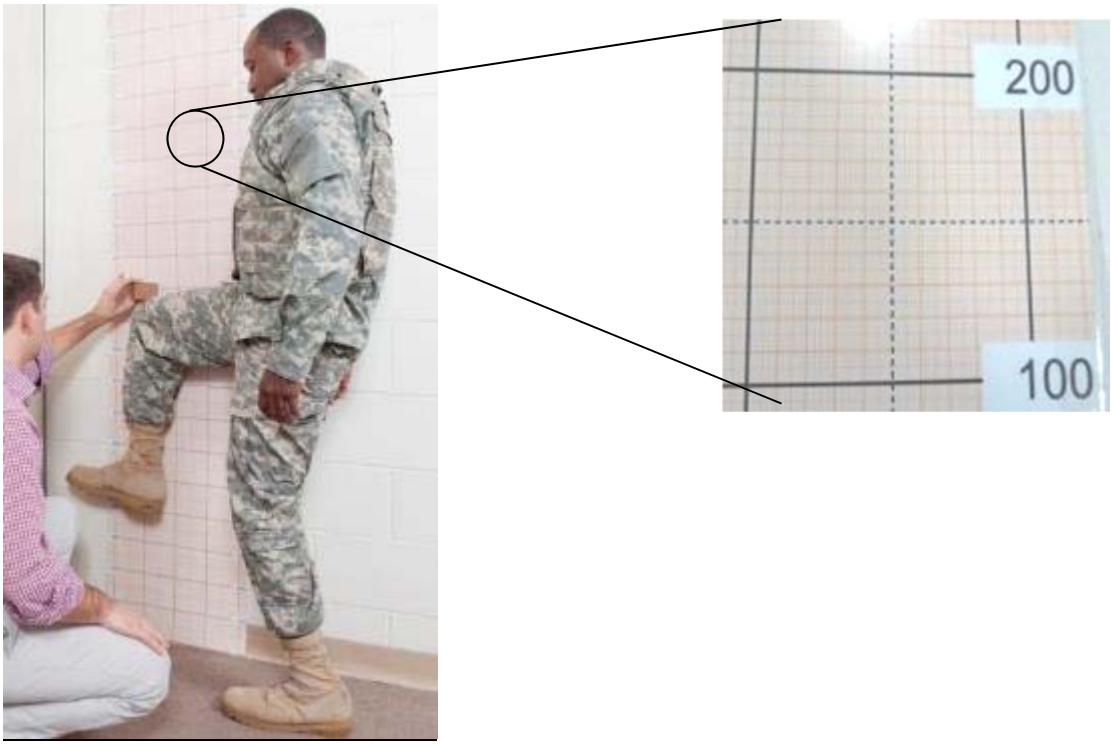


Figure 13: Vertical wall chart (in use and with close up)

The horizontal wall chart (Figure 14) was affixed to a wall that was at least the length and width of the chart. The chart was 110 cm wide and 50 cm tall. This chart started at 30 cm, so it was placed 30 cm away from the corner of two walls. This was done so that when the TP stood against the perpendicular wall, their right arm rested against the wall, as depicted in Figure 14. A level was used to ensure that the chart was positioned parallel to the standing surface.

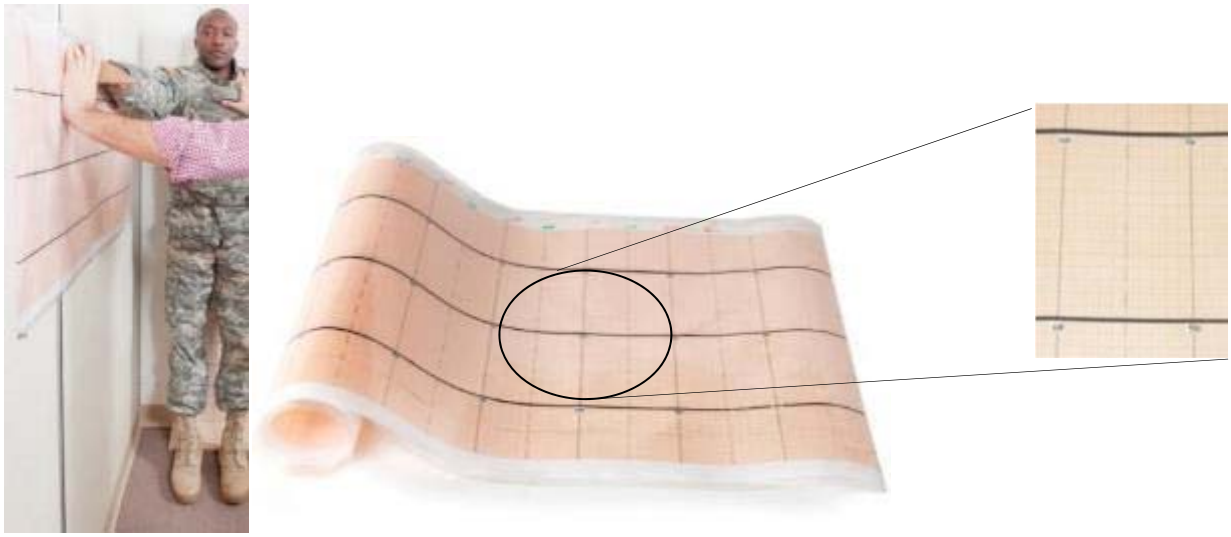


Figure 14: Horizontal wall chart (in use and with close up)

For many of the reach measurements, the TP must stand with heels or toes 20 cm away from the wall. A block of wood (Figure 15) was used to force that 20 cm difference between the TP's heel and the wall. A second block of wood (in the shape of a right angle scalene triangle, Figure 16) was used by the tester to place against the measurement chart. A variety of rulers and meter sticks (Figure 17) were used as well. All rulers and meter sticks had cm and mm marks on them.

Figure 15: 20 cm block

Figure 16: Measuring block

Figure 17: Meter stick (with close up)

Platforms were needed for the trunk flexion measurements, since many of the TPs were able to reach past their feet when performing these tasks. A custom platform was designed that could hold a folding chair and was used for the standing and seated trunk flexion movements (Figure 18). Additionally, a variety of seats were used. Seats without arms were needed for some tasks while others required seats without arms or a back (e.g., a stool). A step ladder was used for testers in the cases where they had to be above the TPs (e.g., overhead reaches, cross body reaches).

Figure 18: Raised platform for Trunk Flexion measurements

2.3 Test Procedures

Anthropometric measurements, including whole body 3D scanning and range of motion measurements, were conducted in two locations on the same day. Prior to any measurements, TPs were briefed on the purpose of the study and what they were going to be doing during the session.

The TPs were given a demographic questionnaire to complete upon arrival for data collection. Once the TPs completed the questionnaire, they were given measurement garments to change into (i.e., spandex shorts) and were asked to remove all clothing except their personal undergarments and to put on the spandex shorts over their undergarments. All Semi-Nude and Baseline anthropometric measurements were completed prior to the TPs beginning the range of motion portion of the study for these measurement locations were required to transition measurement locations to the fully encumbered configurations (i.e., 2R, 2G, 5R, 5G).

The order of test presentation for both types of measurements was quasi-randomized so that TPs would wear the same body armor configurations back-to-back to ease the amount of time it took to dress each TP in a configuration (i.e., 2R and then 2G or vice versa).

TPs were properly fit into their correct size for each new clothing item (with the exception of the ACU trouser, which was the TP's personal garment) as it was added to their configuration. The TP tried on alternate sizes until the best fitting size was identified. Best fitting sizes were determined by a trained anthropometrist, who assessed the fit based on specific fit criteria, including chest circumference, plate location, vest length, adjustability, and overlap criteria (if defined by the armor design criteria). In addition, TPs were asked to perform some basic movements in the armor, including standing, turning, and sitting to ensure the fit was acceptable.

2.3.1 Anthropometric Measurements

For all TPs, testing began with Semi-Nude anthropometric measurements, with the TPs wearing only their measurement garments. Next, Baseline measurements were completed for all TPs as

many of these measurements were needed in order to transition measurement locations to the fully encumbered configurations (i.e., 2R, 2G, 5R, and 5G).

Each station had one measurer (either a trained anthropologist or human factors personnel, depending on the station) and a trained data recorder. The data recorder's job, beyond recording the measurements on the data sheet and the comments and ratings made by the TP, was to observe the measurement being taken and ensure that it was being done properly. In essence, the data recorder acted as a second set of eyes for the measurer.

All anthropometric dimensions were measured based on ANSUR II procedures (Gordon et al., 2014; Hotzman et al., 2011) or Paquette et al. (1999) Evaluation of Multilayered Military Clothing, unless otherwise stated. A total of 11 body landmarks (Acromion, Buttock, Chest, Deltoid, Metacarpale II and V, Waist at Omphalion (navel), Stylion, Suprapatella, and First and Fifth Metatalsophalangeal Protrusions) were palpated and marked with an eyebrow pencil on the right side of the body and transferred to the front, back, and left sides, where applicable.

There were a total of six configurations measured: Semi-Nude (clothed in only a measurement garment), Baseline (ACS top, ACU bottom, and boots), 2R, 2G, 5R, and 5G. TPs were always measured in the Semi-Nude configuration first, followed by the Baseline configuration. The order of the four loaded configurations varied by test participant.

Because the same body dimensions (Waist Circumference, etc) were supposed to be measured at identical locations across all configurations, the height dimensions measured in the Semi-Nude configuration were transferred to the Baseline configuration after having TPs don the ACS top and ACU bottom without boots. Once all the landmarks were transferred to the TPs' ACS and ACU using adhesive landmarks, TPs donned their boots. Body dimensions for the Baseline configuration were then measured. Since height dimensions measured in the Baseline configuration included boot height, those height dimensions were transferred to all the other configurations so that the body dimensions across all configurations were measured at identical locations. Additional maximum circumference, breadth, and depth measurements related to CIE layers were obtained by visually assessing the maximum protrusions of the CIE. These measurements had no Semi-Nude measurements associated with them and therefore any delta calculations required the use of the closest Semi-Nude surrogate measurement value available. When no Semi-nude surrogate measurement values were available, deltas were not calculated.

After one set of dimensions was measured per each configuration, TPs were scanned in three postures, two standing and one seated, using a Cyberware WB4 whole body laser scanner to obtain 3D whole body digital images for use in future modeling and simulation efforts. In addition, the encumbered configurations were scanned in the three postures using an assault pack loaded specifically for either a Rifleman or Grenadier. Table 1 lists the 49 anthropometric dimensions that were measured and the configurations for which they were measured.

Table 1: Anthropometric dimensions measured in each configuration

Anthropometric Dimension	Semi-Nude	Base-line	BAPL2:		BAPL5:	
			Rifleman	Grenadier	Rifleman	Grenadier
Acromion Height	O	O				
Biacromial Breadth, Sitting	O	O	O	O	O	O
Bideltoid Breadth, Sitting	O	O	O	O	O	O
Buttock Circumference	O	O				
Buttock Height	O	O				
Buttock-Knee Length	O	O	O	O	O	O
Buttock-Popliteal Length	O	O	O	O	O	O
Chest Breadth	O	O	O	O	O	O
Chest Circumference	O	O	O	O	O	O
Chest Depth	O	O	O	O	O	O
Chest Height	O	O				
Deltoid Height	O	O				
Elbow Circumference, Sitting	O	O	O	O	O	O
Foot Breadth	O	O				
Foot Length	O	O				
Forearm-Forearm Breadth, Sitting	O	O	O	O	O	O
Hand Breadth	O		O			
Hand Circumference	O		O			
Hand Length	O		O			
Head Breadth	O		O			
Head Circumference	O		O			
Head Length	O		O			
Hip Breadth, Sitting	O	O	O	O	O	O
Knee Height, Suprapatella	O	O				
Knee Height, Suprapatella, Sitting	O	O				
MAX Backpack Height			O	O	O	O
MAX Backpack Depth			O	O	O	O
MAX Chest Circumference			O	O	O	O
MAX Waist Breadth			O	O	O	O
MAX Waist Breadth, Sitting			O	O	O	O
MAX Waist Circumference			O	O	O	O
MAX Waist Circumference, Sitting			O	O	O	O
MAX Waist Depth			O	O	O	O
MAX Waist Depth, Sitting			O	O	O	O
MAX Waist Height			O	O	O	O
MAX Waist Height, Sitting			O	O	O	O
Mid-Shoulder Height	O	O	O	O	O	O
Shoulder Circumference	O	O	O	O	O	O

Table 1: Anthropometric dimensions measured in each configuration (continued)

Anthropometric Dimension	Semi-Nude	Base-line	BAPL2:		BAPL5:	
			Rifleman	Grenadier	Rifleman	Grenadier
Sitting Height	O	O	O	O	O	O
Stature	O	O	O	O	O	O
Vertical Trunk (USA) Circumference	O	O	O	O	O	O
Waist (OMP) Circumference	O	O	O	O	O	O
Waist Breadth	O	O	O	O	O	O
Waist Depth	O	O	O	O	O	O
Waist Height	O	O				
Waist Height, Sitting	O	O	O	O	O	O
Weight with Backpack (lb)			O	O	O	O
Weight(lb)	O	O	O	O	O	O
Wrist Circumference	O		O			

As shown in Table 1, 20 anthropometric dimensions were measured in all six configurations, since the increment due to CIE is expected to change depending on the configurations. A total of 17 dimensions were measured for only two configurations, Semi-Nude and one other configuration. 10 of those 17 dimensions, such as Knee Height or Buttock Circumference, were measured only in Semi-Nude and Baseline configurations because additional CIE was not added to those locations in the loaded configurations. The other seven dimensions, including head and hand dimensions, were measured only in Semi-Nude and 2R to capture the increment due to the helmet and gloves. For those 17 dimensions, no further changes were expected in other loaded configurations. The other 12 dimensions were measured in only the four loaded configurations (i.e., 2R, 2G, 5R, and 5G) because the reference landmarks for these dimensions were located at specific maximum protrusions on IOTV/SPCS with no related Semi-Nude or Baseline landmarks.

"O" indicates measurement taken.

OMP = Omphalion

2.3.2 Range of Motion Measurements

No Semi-Nude range of motion measurements were taken for this study as there was expected to be minimal differences for range of motion between Semi-Nude and Baseline. The order of presentation for the Baseline and four loaded configurations was quasi-randomized. In an effort to reduce the effects of TPs becoming more limber after they had performed the movement repeatedly or tightening up after not moving while waiting for a turn, TPs were asked to stretch out before key movements. Three measurement readings were recorded for each range of motion movement. If one of the measurements was drastically different from the others or if it appeared that a TP's muscles were still tight during a measurement, additional measurements were taken, and the closest three measurements were used to calculate a mean measurement. Because the margin of error for these measurements was not known, measurers and data collectors used their best judgment to determine if another measurement should be taken. For example, if goniometer measurements were greater than 10° different, an additional measurement was taken. If

movements, measured in mm, were highly variable between the same movements (i.e. >50 mm), then measurers obtained additional measurements in order to get a consistent measurement.

After each movement was performed in each of the armor configurations, the TP was asked to rate the extent to which the movement was restricted by the equipment using the scale shown in Figure 19.

No interference or degradation	Slight interference; easily worked around	Moderate interference, difficult, but able to work around	Severe interference, very difficult to work around; unacceptable	Extreme interference, unable to work around; unacceptable
1	2	3	4	5

Figure 19: Interference/restriction ratings

Movements (measured as defined in Mitchell, 2013) performed included:

- Cervical Rotation
- Cross Body Reach
- Forward Extended Reach
- Overhead Fingertip Reach
- Thoracic/Lumbar Spine Lateral Flexion
- Thoracic/Lumbar Spine Rotation
- Trunk Flexion – Seated Trunk Flexion – Standing
- Upper Arm/Shoulder Abduction
- Upper Arm/Shoulder Backward Extension
- Upper Arm/Shoulder Forward Extension
- Upper Leg/Hip Flexion
- Ventral-Dorsal Cervical Flexion

All range of motion measurements were taken by one of two measurers. Comments from TPs regarding what caused any restriction or interference were also collected. For each test configuration worn, a data sheet was completed at each measurement station to record TP measurements, ratings, and comments.

2.4 Data Analysis

The measurements, ratings, and comments were entered into computers and tabulated using Microsoft Excel 2007. Statistical Product and Service Solutions (SPSS) Statistics 18 for Windows, STASISTICA V10 and Microsoft Excel were both used to perform data reduction and analyses on the response data and anthropometric data. SPSS and Excel were used to create table and chart summaries of the results. STASISTICA was used to generate scatter plots with 95% ellipse of the target population (calculated using the ANSUR II Pilot data (Paquette et al., 2009)).

Personal information on the TPs has been held in 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.

2.4.1 Anthropometric Data

For all anthropometric dimensions, descriptive statistics including mean, median, minimum, maximum, range, and standard deviation were calculated along with a graph that shows the average value at each configuration with the increment due to CIE in percent relative to the Semi-Nude configuration. A distribution of delta calculations between the encumbered measurements and the Semi-Nude measurements is also provided. Additional data analyses on deltas were done for two of the three groups of anthropometric dimensions mentioned in Section 2.3.1.

For the 20 anthropometric dimensions that were measured for all six configurations, a repeated measures analysis of variance (ANOVA) was performed to investigate if the deltas due to CIE relative to the Semi-Nude configuration were significantly different (conventional significance level of $\alpha = .05$ was used) among the five CIE configurations: Baseline, 2R, 5R, 2G, and 5G. To determine further differences among the means, a series of pairwise comparisons with Bonferroni corrections was performed to control 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 by SPSS.

For the 12 dimensions that were measured for only the four loaded configurations (2R, 2G, 5R, and 5G), a repeated measures ANOVA was performed on the delta. Since there were no Baseline or Semi-Nude locations to match to these 12 dimensions in order to calculate the deltas, the closest Semi-Nude location (i.e., Waist Circumference at Omphalion for MAX Waist Circumference) was used when applicable. Follow-up *post hoc* (Bonferroni) tests were done on all pairwise comparisons.

Additionally, in order to determine the overall difference in deltas between BAPLs regardless of duty positions and between duty positions regardless of BAPLs, comparisons between BAPL 2 and BAPL 5, and between Rifleman and Grenadier with collapsed delta values for each BAPL and duty position were performed.

2.4.2 Range of Motion Data

For each range of motion variable a repeated measures ANOVA was used to determine if the test configuration worn made a statistically significant impact on the measured scores. Then, if significant difference was found, follow-up *post hoc* (Bonferroni) tests were performed to determine statistical significance between every possible pair of means (i.e., configuration A vs. B, B vs. C, and C vs. A). Additionally, a planned comparison of the four loaded configurations (2R, 2G, 5R, and 5G) was performed, additionally collapsing the scores for each BAPL and for each duty position to determine if there was a main effect for either or if there was an interaction effect between BAPL and duty position.

Statistical significance for this evaluation was defined conventionally as $p < .05$. Therefore, the probability of incorrectly rejecting the null hypothesis, that there was no difference among the

BAPLs, is less than 5%. Only significant differences or differences approaching significance are discussed in the results section.

2.5 TPs

The TPs were 32 male, US Army human research volunteers (HRVs), and each one completed a background and demographic questionnaire. Only HRVs were used due to limitations in the subject pool available, and the only HRVs available were male. HRVs are active duty USA 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 18-22.

The TPs for this study ranged in age between 18 and 25 (M=19.88, SD=1.70). Half (16) of the TPs classified their race as White, Not Hispanic. Eight (25%) classified themselves as Black, and the rest classified themselves as either Hispanic, Asian/Pacific Islander, or Mixed Race. The majority of the TPs were right handed (29 or 91%), and the remaining three were left handed. Ten (32%) wore glasses. For the range of motion movements, they were allowed to wear these in the place of the Oakley M-frames, but they replaced them with the M-frames for any anthropometric weights. TPs were not required to wear the M-frames during the anthropometric portion of the testing. So those who wore glasses wore their personal glasses, and those who did not wear glasses wore no eyewear. No eyewear could be worn for the scanning due to the scanner technology.

The TPs' ranks were E-1 (14 or 44%), E-2 (9 or 28%), and E-3 (9 or 28%). All of the TPs had 1 year or less of time in service. None of them had been deployed. The majority had an MOS of 12B (Combat Engineer). Six of the remaining TPs were aviation mechanics (15 J/T/U). The remaining TPs were 74D, 88H, 91H or 91L (one per MOS).

3. ANTHROPOMETRIC DIMENSIONS AND RESULTS

A total of 31 TPs were randomly sampled for the anthropometric study based on given availability, and all of their body dimensions were input and analyzed. (Only 31 of the 32 TPs mentioned in Section 2.5 participated in the anthropometric evaluation due to time constraints.) The TP distributions for Stature by Weight and Stature by Chest Circumference were compared with current ANSUR II pilot data (Paquette et al., 2009; Figure 20 and Figure 21). The ellipsoid represents the 95% range of the Army male population. TPs were well distributed from x-small to large sizes; however, there were no x-large sizes (Table 2). This chapter provides a detailed description of the measurement of each anthropometric dimension and a summary of the results, including a table of summary statistics for each of the dimensions measured in this study. The dimensions are grouped in five sections: 3.1) anthropometric reference heights, 3.2) standing anthropometry, 3.3) sitting anthropometry, 3.4) head, hand, and foot anthropometry, and 3.5) anthropometric maximum measurements. A graph of the mean values with 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 loaded configurations. A summary table of mean and maximum delta values for all relevant variables is in Appendix B.

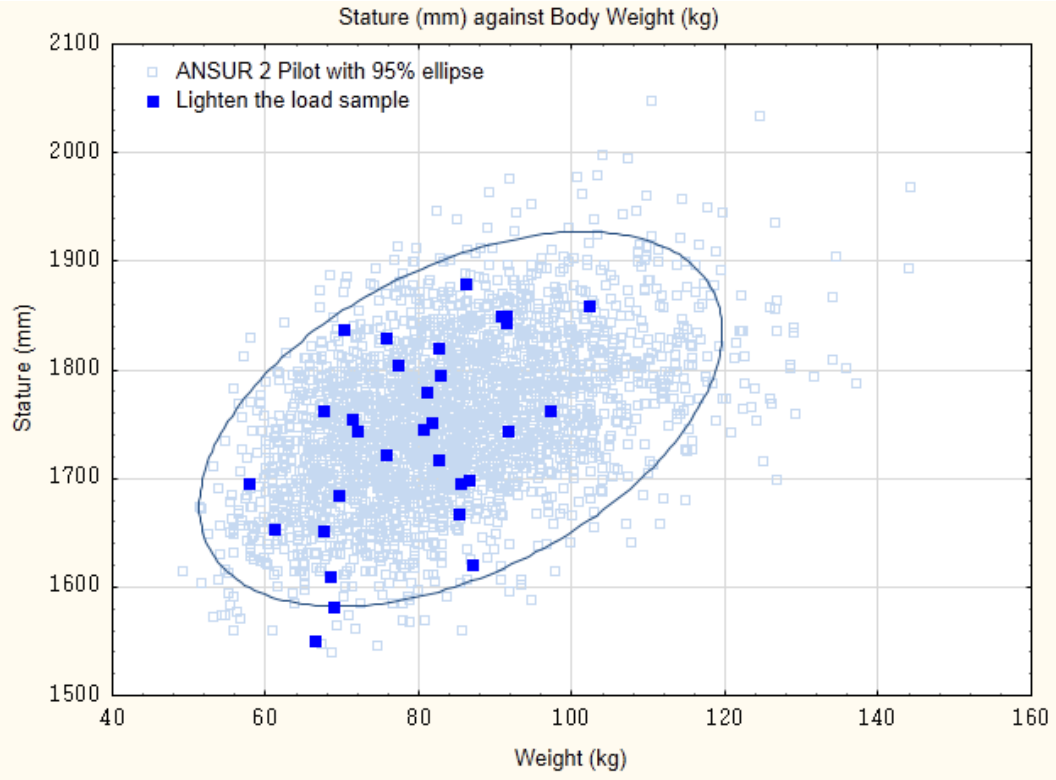


Figure 20: Stature by Weight distribution of TPs with Male ANSUR II Pilot data as background

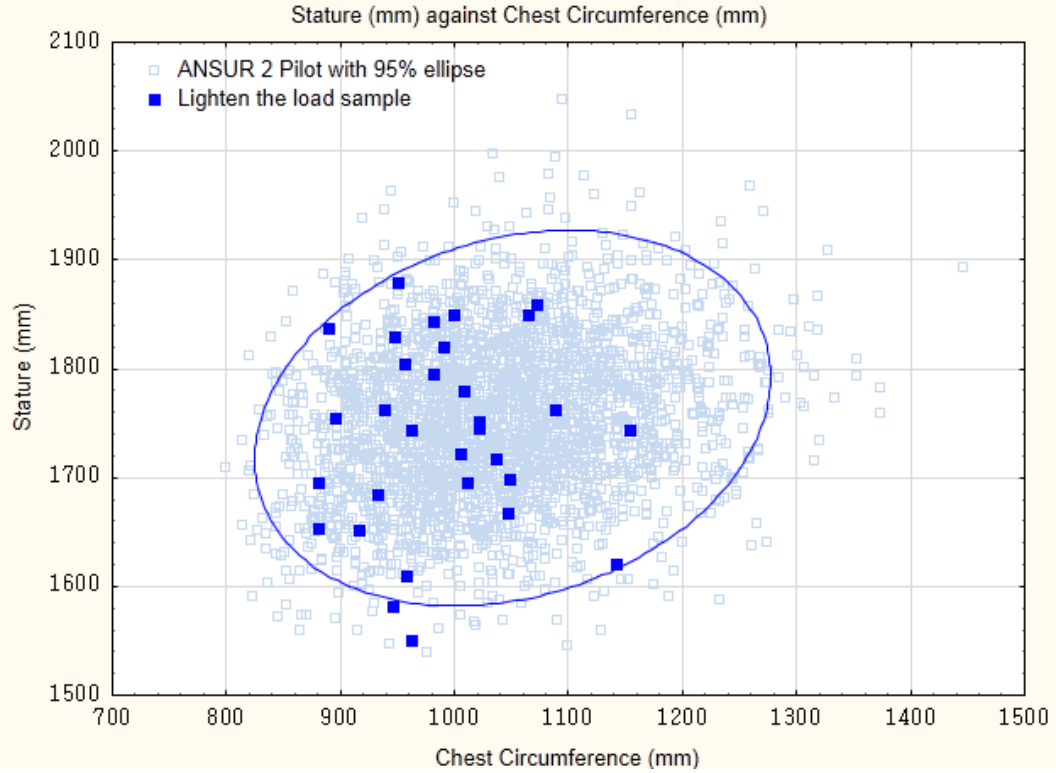


Figure 21: Stature by Chest Circumference distribution of TPs with Male ANSUR II pilot data as background

Table 2: Frequency counts of the CIE by size

Equipment Size	ACS	Carrier (IOTV, Plate Carrier)	ACH
XS	0	8	NA
S	13	15	0
M	8	7	11
L	10	1	19
XL	0	0	1
Total	31	31	31

3.1 Anthropometric Reference Height Measurements

The height measurements described in this section were used as landmarks to define the regions where breadth, depth, and circumference were measured. The height measurements are listed in the order in which they were taken. As mentioned in Section 2.3.1, 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 loaded configurations. The results between the Semi-Nude measurements and the Baseline measurements were related only to the footwear worn. Table 3 provides the summary results and delta calculations for these

measurements. In general, the heights differed by about 40 mm, the amount added by the duty boot.

Table 3: Summary statistics and mean absolute deltas of Baseline and Semi-Nude measurements for single dimensions used as reference points for depths, breadths, and circumferences.

Dimension	Configuration	Mean (mm)	SD (mm)	Min (mm)	25th (mm)	50th (mm)	75th (mm)	Max (mm)	Range (mm)	Absolute Mean Δ (mm)
Acromial Height	Semi-Nude	1425	81	1249	1374	1433	1475	1601	352	40
	Baseline	1465	81	1290	1410	1473	1517	1625	335	
Deltoid Height	Semi-Nude	1347	77	1173	1304	1362	1396	1513	340	39
	Baseline	1386	76	1218	1347	1394	1435	1548	330	
Chest Height	Semi-Nude	1280	72	1121	1227	1286	1330	1412	291	42
	Baseline	1322	73	1178	1273	1320	1369	1460	282	
Waist Height (Omphalion)	Semi-Nude	1057	67	913	1012	1069	1108	1193	280	41
	Baseline	1098	68	963	1054	1109	1146	1236	273	
Buttock Height	Semi-Nude	907	62	792	876	924	950	1030	238	36
	Baseline	943	62	823	907	960	989	1061	238	
Knee Height, Suprapatella	Semi-Nude	520	35	456	503	529	545	580	124	37
	Baseline	557	33	496	538	569	578	622	126	
Knee Height, Sitting	Semi-Nude	553	34	485	532	558	575	614	129	40
	Baseline	593	34	528	572	598	615	656	128	
***Buttock Circumference**	Semi-Nude	991	59	872	948	999	1040	1112	240	61
	Baseline	1052	56	955	1012	1052	1096	1160	205	

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

Acromial Height

Acromial Height is the vertical distance taken from a standing surface to the right Acromion landmark (Figure 22). 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, follow the directions above. If the CIE is a lightweight garment, as was the case in this study for the Baseline configuration, 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 uniform.

Figure 22: Acromial Height measurement (Semi-Nude on left, Baseline on right)

Chest Height

Chest Height is the vertical distance between the standing surface and the right Chest Point Anterior landmark (Figure 23). 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 Anterior Chest landmark is transferred to the various CIE layers and measured as described above. The measurer verifies that this landmark did not shift when the TP donned the different CIE. The measurement is taken at the maximum point of quiet respiration.

Figure 23: Chest Height measurement (Semi-Nude on left, Baseline on right)

Deltoid Height

This is the vertical distance between the standing surface and the right deltoid landmark (Figure 24). 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. For the encumbered measurement, the right deltoid landmark is transferred to the CIE layers on both the right and the left side. The measurement is taken as described above. The landmark should be checked to be sure it did not shift when the TP donned different CIE.

Figure 24: Deltoid Height measurement (Semi-Nude on left, Baseline on right)

Waist Height

Waist Height is the vertical distance between a standing surface and the Omphalion landmark (Figure 25). The TP is in the anthropometric standing position with heels together and weight evenly distributed on both feet. 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. This measurement is transferred to the other CIE layers to locate the waist landmarks for additional measurements during the encumbered measurements.

Figure 25: Waist Height measurement (Semi-Nude on left, Baseline on right)

Buttock Height

Buttock Height is the vertical distance between the standing surface and the level of the maximum protrusion of the right buttock (Figure 26). The TP stands in the anthropometric standing position, but may have the right elbow flexed to keep arms out of the measurement area if needed. 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 buttock. This measurement is then transferred and drawn on the right and left thigh. For the encumbered measurement, Buttock Height is located on the different CIE layers using adhesive markers that are placed at the posterior, left and right buttock locations. The measurer is careful not to compress the CIE.

Figure 26: Buttock Height measurement (Semi-Nude on left, Baseline on right)

Knee Height, Suprapatella

Knee Height, Suprapatella is the vertical distance between a standing surface and the Suprapatella landmark (Figure 27). The TP stands erect with heels together and weight distributed equally on both feet. 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 measurer should follow the above directions; however, it is necessary to place a raised adhesive mark at this location during the Semi-Nude measurements in order to relocate the correct location when the TP is wearing CIE.

Figure 27: Knee Height, Suprapatella measurement (Semi-Nude on left, Baseline on right)

Knee Height, Suprapatella, Sitting

Knee Height, Suprapatella, Sitting is the vertical distance between a flat surface and the Suprapatella landmark (Figure 28). The TP sits on a table in the anthropometric sitting position with the heels and knees approximately shoulder width apart and placed upon 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 28: Knee Height, Suprapatella, Sitting measurement (Semi-Nude on left, Baseline on right)

Buttock Circumference

Buttock Circumference is the horizontal circumference of the trunk at the level of the maximum protrusion of the right buttock (Figure 29). The TP stands erect with heels together. 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, TPs adjust their genitalia so as to interfere as little as possible with the tape measure. 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 any CIE layers using adhesive markers that are placed at the location of the Buttock landmarks. The measurer is careful not to compress the CIE.

Figure 29: Buttock Circumference measurement (Semi-Nude)

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. The summary results and delta values are presented for each dimension.

Chest Breadth

Chest Breadth is the maximum horizontal breadth of the chest at the level of the Chest Point Anterior landmark (Figure 30). The TP stands erect looking straight ahead with heels together and weight distributed evenly on both feet. 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 had to tilt the beam caliber at an angle to get around larger pectoral muscles of male TPs. Lateral muscles were not included in the measurement. The chest tissue was not compressed during measurement. The measurer uses the same method for collecting the encumbered measurements and checks to be sure that Chest Height did not change, and ensures there is no compression of the CIE.

Figure 30: Chest Breadth measurement (Semi-Nude on left, encumbered on right)

A repeated measures ANOVA was conducted to investigate whether the various CIE configurations have an effect on size increments at the Chest Breadth location relative to the Semi-Nude configuration and to each of the other configurations. The results are listed in Table 4 and shown graphically with percent increments between configurations in Figure 31. The averaged delta values among configurations were statistically different, $F(4, 120)=46.69$, $p<.01$. The delta for the Baseline ($M=3.3$ mm) was significantly smaller than all the loaded configurations, $p<.05$ except for 2R ($M=9.4$ mm). As shown in Table 4, both the 5R ($M=34.4$ mm) and 5G ($M=30.8$ mm) configurations were statistically greater than both the 2R and 2G, $p<.05$. There were no statistical differences between the Rifleman and Grenadier configurations

within the same BAPL (i.e., between 2R and 2G and between 5R and 5G) (Table 4). Although the mean deltas were statistically different between configurations, some of the actual differences in delta values did not show drastic changes (i.e., 10.1 mm difference between Baseline and G2). This measurement was taken near the anterior Scye region (armpit), and there was no additional CIE in this area. The slightly larger numbers in the BAPL 5 configurations were related to the puckering of the soft armor in the IOTV at this location.

Table 4: Summary statistics and mean deltas for Chest Breadth for each configuration

	Semi-Nude (mm)	Baseline (mm)	BAPL 2 (mm)		BAPL 5 (mm)	
			Rifleman	Grenadier	Rifleman	Grenadier
Δ from Semi-Nude	-	^{C}3.3	^{BC}9.4	^{B}13.4	^{A}34.4	^{A}30.8
Δ SD	-	5.7	11.7	10.9	14.9	16.0
Mean	306	309	315	319	340	337
SD	21	22	21	24	23	27
Min	269	269	280	287	306	297
25th	292	295	299	301	319	316
50th	303	306	314	314	344	336
75th	324	326	325	329	358	347
Max	345	358	362	375	383	404
Range	76	89	82	88	77	107

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

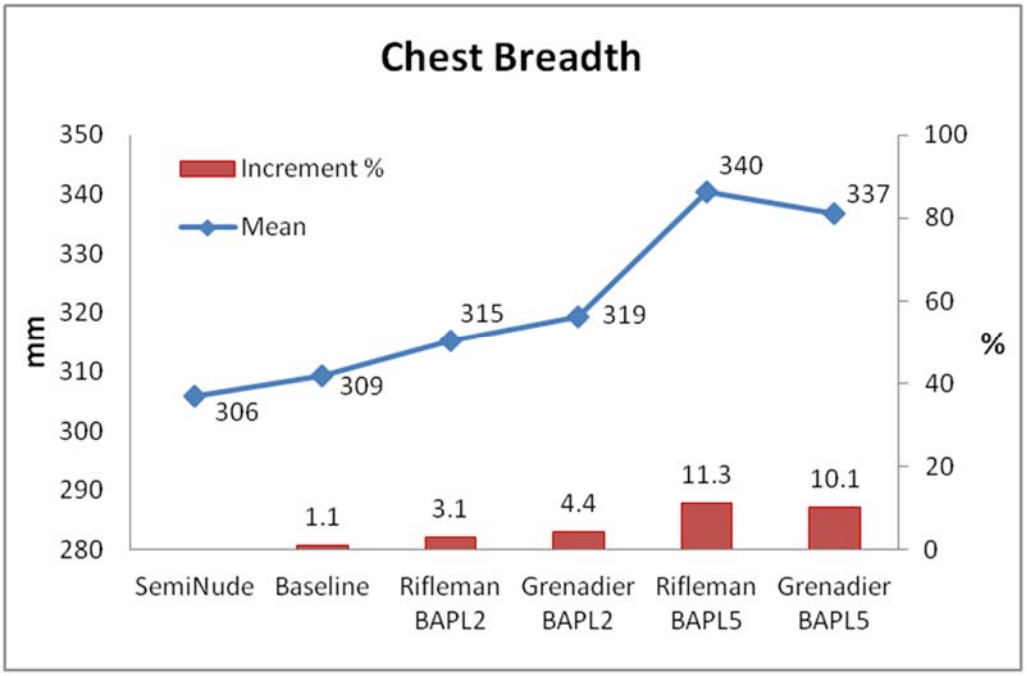


Figure 31: Percent increment relative to Semi-Nude and average Chest Breadth for each configuration.

Chest Circumference

Chest Circumference is the maximum circumference of the chest at the fullest part of the breast region (Figure 32). 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 were made to keep this compression to a minimum, as measurers exerted 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 measurement, the Chest Point Anterior landmark is transferred to the CIE and is re-checked in each loaded configuration and then taken using the same method as described above. The measurer ensures there is no compression of the CIE.

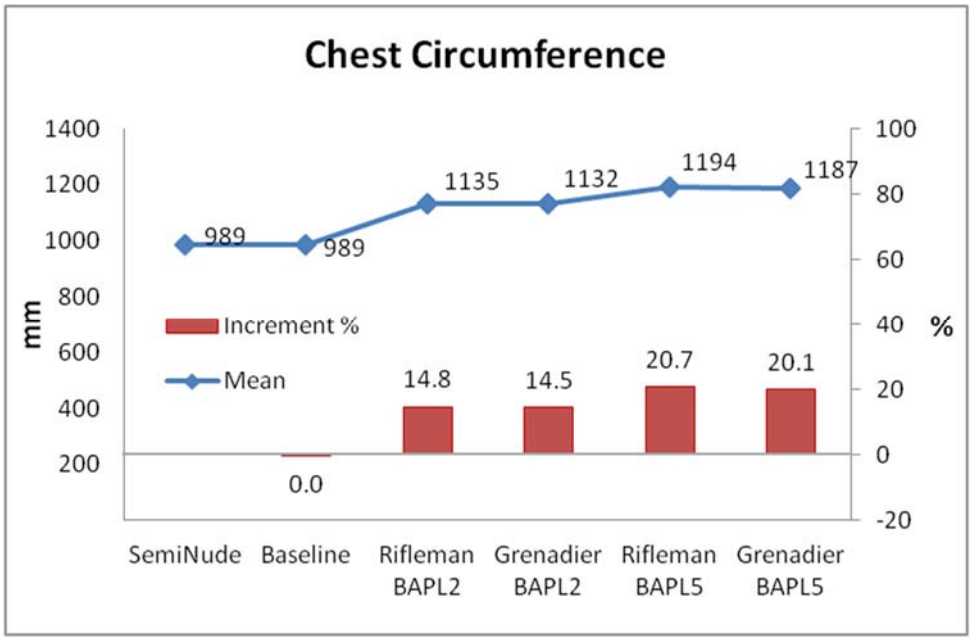
Figure 32: Chest circumference measurement (Semi-Nude on left, encumbered on right)

A repeated measures ANOVA was conducted to investigate whether the various CIE configurations have an effect on size increments at the Chest Circumference location relative to the Semi-Nude configuration and to each of the other configurations. The results are listed in Table 5 and shown graphically with percent increments between configurations in Figure 33. The averaged delta values among configurations were statistically different, $F(4, 120)=1081.12$, $p<.01$. The delta at Baseline (M= -0.3 mm) was significantly smaller than all the loaded configurations, $p<.05$. Both the 5R (M =205.0 mm) and 5G (M=198.5 mm) configurations were statistically greater than both the 2R (M=145.9 mm) and 2G (M=143.4 mm) configurations ($p<.05$). There were no statistical differences between the Rifleman and Grenadier configurations within the same BAPL, i.e., between 2R and 2G and between 5R and 5G (Table 5).

Table 5: Summary statistics and mean deltas for Chest Circumference for each configuration

	Semi-Nude (mm)	Baseline (mm)	BAPL 2 (mm)		BAPL 5 (mm)	
			Rifleman	Grenadier	Rifleman	Grenadier
Δ from Semi-Nude	-	^{C}-0.3	^{B}145.9	^{B}143.4	^{A}205.0	^{A}198.5
Δ SD	-	8.2	22.5	20.6	28.1	25.9
Mean	989	989	1135	1132	1194	1187
SD	70	70	68	68	73	72
Min	879	878	1042	1016	1085	1069
25th	946	951	1094	1090	1142	1142
50th	981	988	1119	1122	1187	1180
75th	1028	1025	1168	1165	1235	1217
Max	1152	1153	1293	1301	1362	1345
Range	273	275	251	285	277	276

A>B>C, 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 33: 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 (Figure 34). 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. 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 measurement the right Anterior Chest landmark is transferred to the CIE layers and rechecked for each loaded configuration. The measurement is taken as described above and the measurer ensures there is no compression of the CIE.

Figure 34: Chest Depth measurement (Semi-Nude on left, encumbered on right)

A repeated measures ANOVA was conducted to investigate whether the various CIE configurations have an effect on size increments at the Chest Depth location relative to the Semi-Nude configuration and to each of the other configurations. The results are listed in Table 6 and shown graphically with percent increments between configurations in Figure 35. The averaged delta values among configurations were statistically different, $F(4, 120)=563.61$, $p<.01$. The delta at Baseline ($M=0.4$ mm) was significantly smaller than all the loaded configurations, $p<.05$. The delta values at 2R and 2G configurations ($M=81.1$ mm, $M=79.5$ mm, respectively) were slightly but statistically greater than the 5G configuration ($M=72.5$), $p<.05$, but 2R was not greater than the 5R configuration ($M=74.0$). These differences on delta values between loaded configurations are small and close to the allowable observer error for the nude chest depth of 4 mm (Hotzman et al., 2011). There were no statistical differences between the Rifleman and Grenadier configurations within the same BAPL, i.e., between 2R and 2G and between 5R and 5G, but within the same duty position, both BAPL 5 configurations were significantly greater than the BAPL 2 configurations for their respective positions (Table 6).

Table 6: Summary statistics and mean deltas for Chest Depth for each configuration

	Semi-Nude (mm)	Baseline (mm)	BAPL 2 (mm)		BAPL 5 (mm)	
			Rifleman	Grenadier	Rifleman	Grenadier
Δ from Semi-Nude	-	^{D}0.4	^{A}81.1	^{AB}79.5	^{BC}74.0	^{C}72.5
Δ SD	-	5.8	13.6	11.2	12.3	12.4
Mean	246	246	327	326	320	318
SD	22	24	19	19	20	18
Min	214	209	299	295	284	290
25th	232	232	314	313	308	304
50th	243	242	323	323	315	317
75th	256	261	344	338	336	330
Max	298	306	364	364	361	359
Range	84	97	65	69	77	69

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

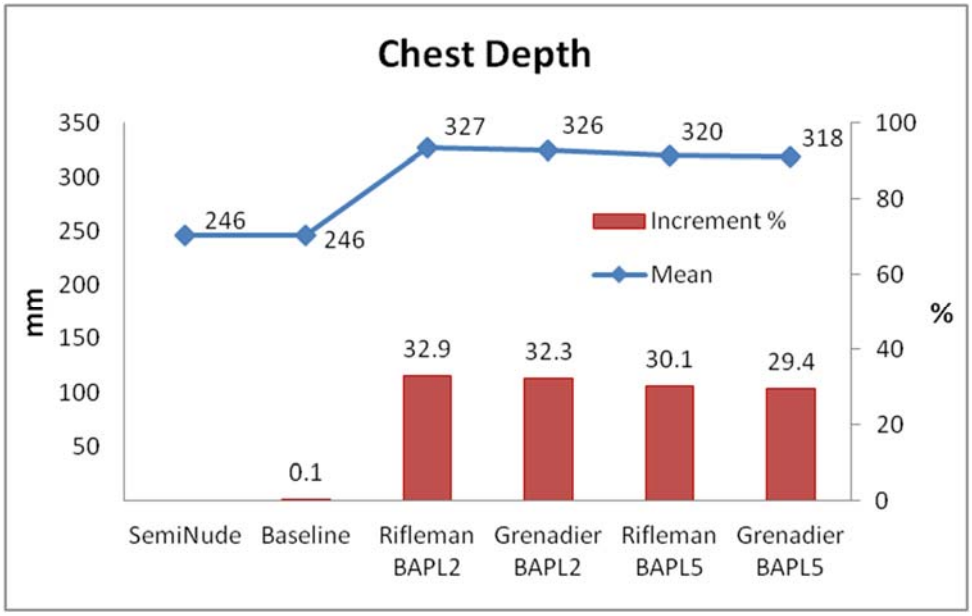


Figure 35: Percent increment relative to Semi-Nude and average Chest Depth for each configuration.

Mid-Shoulder Height

Mid-Shoulder Height is the maximum vertical height taken from a standing surface to the Mid-Shoulder landmark (Figure 36). The TP is in the anthropometric standing position. Using an anthropometer, the measurer measures 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 36: Mid-Shoulder Height measurement (Semi-Nude on left, encumbered on right)

A repeated measures ANOVA was conducted to investigate whether the various CIE configurations have an effect on size increments at the Mid-Shoulder Height location relative to the Semi-Nude configuration and to each of the other configurations. The results are listed in Table 7 and shown graphically with percent increments between configurations in Figure 37. The averaged delta values among configurations were statistically different, $F(4, 120)=15.9$, $p<.01$. The delta for the Baseline ($M=40.6$ mm) was statistically greater than the 2R and 2G configurations ($M=29.1$ mm, and $M=25.1$ mm, respectively), $p<.05$. The larger Baseline measurements relative to the Semi-Nude configuration are a reflection of the addition of combat boots. There were no statistical differences between the Rifleman and Grenadier configurations within the same BAPL (i.e., between 2R and 2G and between 5R and 5G), but for the Grenadier on both BAPLs the delta is smaller than the Rifleman configuration, which reflects the effect of configuration load. Within the same duty position, both BAPL 5 configurations were significantly greater than the BAPL 2 configurations for their respective positions. The increased differences for BAPL 5 relative to BAPL 2 is related to the amount of material in the shoulder region for the two different body armor types (GEN II IOTV and Plate Carrier).

Table 7: Summary statistics and mean deltas for Mid-Shoulder Height for each configuration

	Semi-Nude (mm)	Baseline (mm)	BAPL 2 (mm)		BAPL 5 (mm)	
			Rifleman	Grenadier	Rifleman	Grenadier
Δ from Semi-Nude	-	^{A}40.6	^{BC}29.1	^{C}25.1	^{A}38.5	^{AB}34.9
Δ SD	-	8.8	14.6	12.6	12.9	13.8
Mean	1460	1500	1489	1485	1498	1495
SD	81	80	79	77	78	76
Min	1290	1329	1318	1318	1341	1337
25th	1410	1446	1437	1439	1442	1441
50th	1467	1513	1502	1499	1500	1507
75th	1521	1554	1535	1535	1545	1537
Max	1627	1652	1649	1643	1655	1659
Range	337	323	331	325	314	322

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

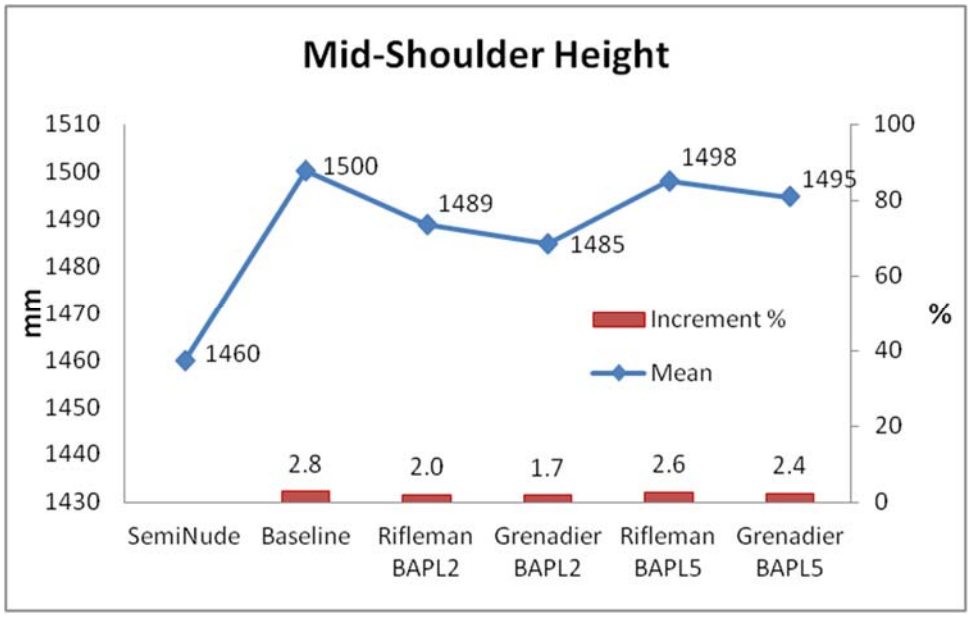


Figure 37: Percent increment relative to Semi-Nude and average Mid-Shoulder Height for each configuration

Shoulder Circumference

Shoulder Circumference is the maximum circumference of the shoulders at the level of the midpoints of the right and left deltoid muscles (Figure 38). The TP is in the anthropometric standing position. The measurer stands in front of the TP and uses a tape to measure the circumference of the shoulders at the level of 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 methods described above are used and care is taken not to compress the CIE.

Figure 38: Shoulder Circumference measurement (Semi-Nude on left, encumbered on right)

A repeated measures ANOVA was conducted to investigate whether the various CIE configurations have an effect on size increments at the Shoulder Circumference location relative to the Semi-Nude configuration and to each of the other configurations. The results are listed in Table 8 and shown graphically with percent increments between configurations in Figure 39. The averaged delta values from the different configurations were statistically different, $F(4, 120)=183.94$, $p<.01$. The delta for the Baseline ($M=32.4$ mm) was statistically smaller than the deltas for the four loaded configurations, $p<.05$. In addition, the 5R and 5G configurations ($M=137.5$ mm, $M=139.9$ mm, respectively) were statistically greater than the 2R and 2G configurations ($M=113.3$ mm, $M=111.6$ mm, respectively), $p<.05$. There were no statistical differences between the Rifleman and Grenadier configurations within the same BAPL (i.e., between 2R and 2G and between 5R and 5G).

Table 8: Summary statistics and mean deltas for Shoulder Circumference for each configuration

	Semi-Nude (mm)	Baseline (mm)	BAPL 2 (mm)		BAPL 5 (mm)	
			Rifleman	Grenadier	Rifleman	Grenadier
Δ from Semi-Nude	-	^{C}32.4	^{B}113.3	^{B}111.6	^{A}137.5	^{A}139.9
Δ SD	-	14.4	33.3	29.8	22.8	25.5
Mean	1175	1209	1289	1287	1313	1315
SD	66	70	70	67	70	75
Min	1048	1094	1181	1186	1190	1191
25th	1126	1153	1228	1231	1267	1266
50th	1175	1215	1293	1285	1303	1313
75th	1220	1248	1327	1317	1366	1354
Max	1286	1335	1432	1437	1446	1452
Range	238	241	251	251	256	261

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

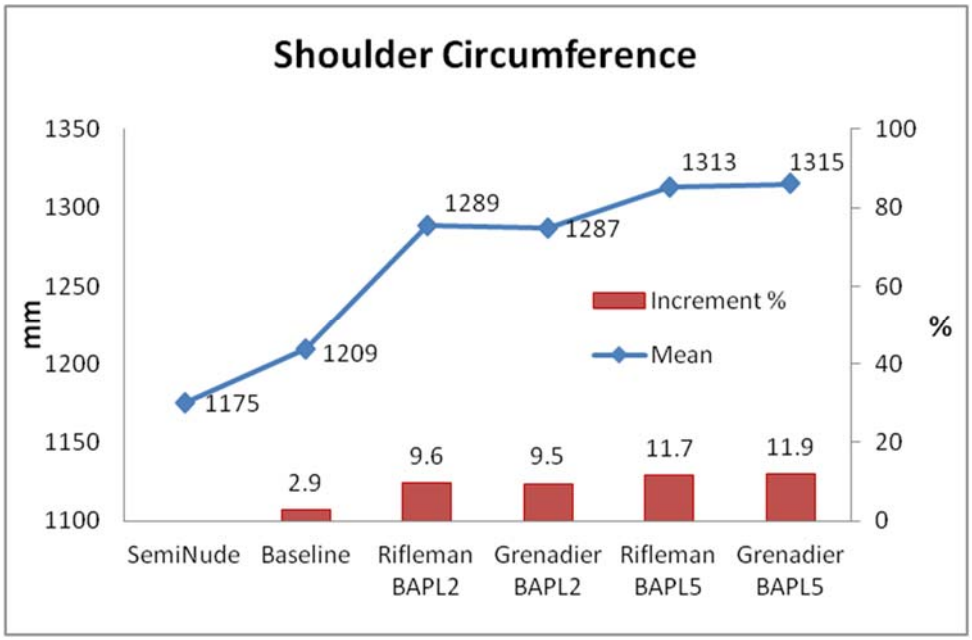


Figure 39: Percent increment relative to Semi-Nude and average Shoulder Circumference for each configuration.

Stature

Stature is the vertical distance from a standing surface to the top of the head (Figure 40). 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 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 methods described above are used, and care is taken not to compress the CIE, in this case the ACH.

Figure 40: Stature measurement (Semi-Nude on left, encumbered on right)

A repeated measures ANOVA was conducted to investigate whether the various CIE configurations have an effect on size increments for Stature relative to the Semi-Nude configuration and to each of the other configurations. The results are listed in Table 9 and shown graphically with percent increments between configurations in Figure 41. The averaged delta values among configurations were statistically different, $F(4, 120)=89.71$, $p<.01$. The delta for the Baseline configuration ($M=37.5$ mm) was statistically smaller than the deltas for the four loaded configurations, $p<.05$. There were no further statistical differences within or between the four loaded configurations. This difference between the Baseline configuration and the four loaded configurations was the addition of the ACH, which was the same in each loaded configuration.

Table 9: Summary statistics and mean deltas for Stature for each configuration

	Semi-Nude (mm)	Baseline (mm)	BAPL 2 (mm)		BAPL 5 (mm)	
			Rifleman	Grenadier	Rifleman	Grenadier
Δ from Semi-Nude	-	^{B}37.5	^{A}61.1	^{A}58.3	^{A}57.7	^{A}57.6
Δ SD	-	7.2	11.7	9.7	12.7	11.0
Mean	1742	1779	1803	1800	1799	1799
SD	87	86	85	85	84	85
Min	1552	1591	1617	1622	1623	1622
25th	1691	1726	1751	1752	1752	1750
50th	1746	1787	1810	1807	1801	1806
75th	1814	1842	1875	1869	1869	1867
Max	1880	1920	1946	1943	1940	1945
Range	328	329	329	321	317	323

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

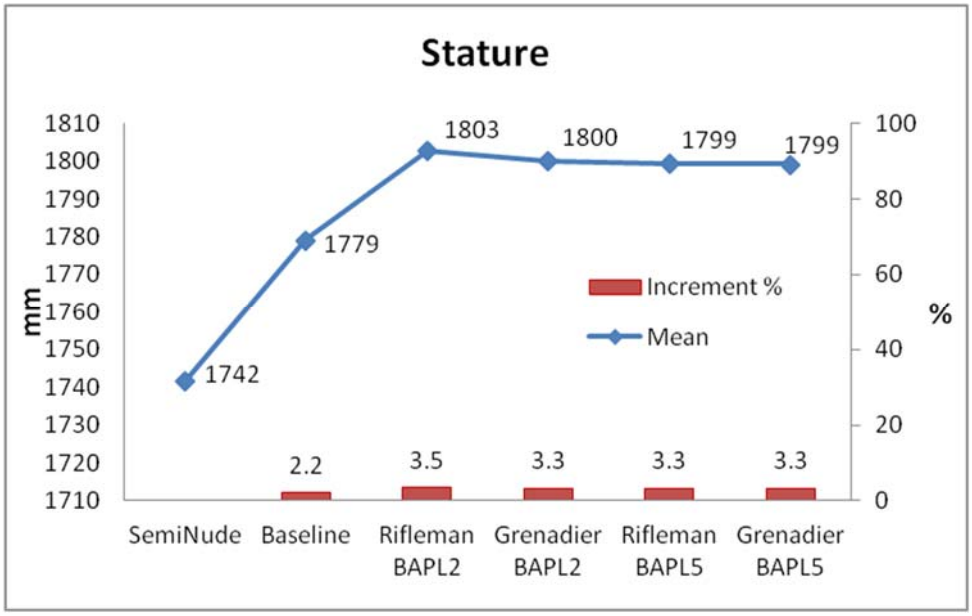


Figure 41: Percent increment relative to Semi-Nude and average Stature for each configuration.

Vertical Trunk (USA) Circumference

Vertical Trunk Circumference (USA measurement) 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 (Figure 42). The TP stands in the anthropometric standing position with feet about 10 cm apart to allow the placement of a tape in the crotch (passing to the right of the scrotum) and then the TP brings their heels together. 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 to hold the tape over the right upper breast with the left hand. 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. The measurer attempts to maintain the same plane of measurement as when measuring TPs in 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 42: Vertical Trunk (USA) Circumference measurement (Semi-Nude on left, encumbered on right)

A repeated measures ANOVA was conducted to investigate whether the various CIE configurations have an effect on size increments at the Vertical Trunk (USA) Circumference location relative to the Semi-Nude configuration and to each of the other configurations. The results are listed in Table 10 and shown graphically with percent increments between configurations in Figure 43. The averaged delta values among configurations were statistically

different, F(4, 120)=172.71, p<.01. The delta at Baseline (M=32.6 mm) was significantly smaller than all the other loaded configurations, p<.05. There was a statistical difference between Rifleman and Grenadier configurations within the same BAPL, where the 2G configuration (M=136.0 mm) was significantly greater than the 2R (M=113.1 mm) configuration and the 5G configuration (M=176.5 mm) was significantly greater than the 5R (M=151.9 mm) configuration p<.05. In addition, within the same duty position, both BAPL 5 configurations were significantly greater than the BAPL 2 configurations for their respective positions.

Table 10: Summary statistics and mean deltas for Vertical Trunk (USA) Circumference for each configuration

	Semi-Nude (mm)	Baseline (mm)	BAPL 2 (mm)		BAPL 5 (mm)	
			Rifleman	Grenadier	Rifleman	Grenadier
Δ from Semi-Nude	-	^{D}32.6	^{C}113.1	^{B}136.0	^{B}151.9	^{A}176.5
Δ SD	-	28.6	44.7	42.5	46.2	40.4
Mean	1680	1717	1794	1816	1832	1857
SD	82	73	65	63	67	75
Min	1486	1541	1659	1686	1667	1712
25th	1649	1675	1744	1770	1790	1804
50th	1679	1721	1794	1834	1832	1879
75th	1737	1767	1842	1859	1879	1904
Max	1854	1862	1915	1936	1954	1975
Range	368	321	256	250	287	263

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

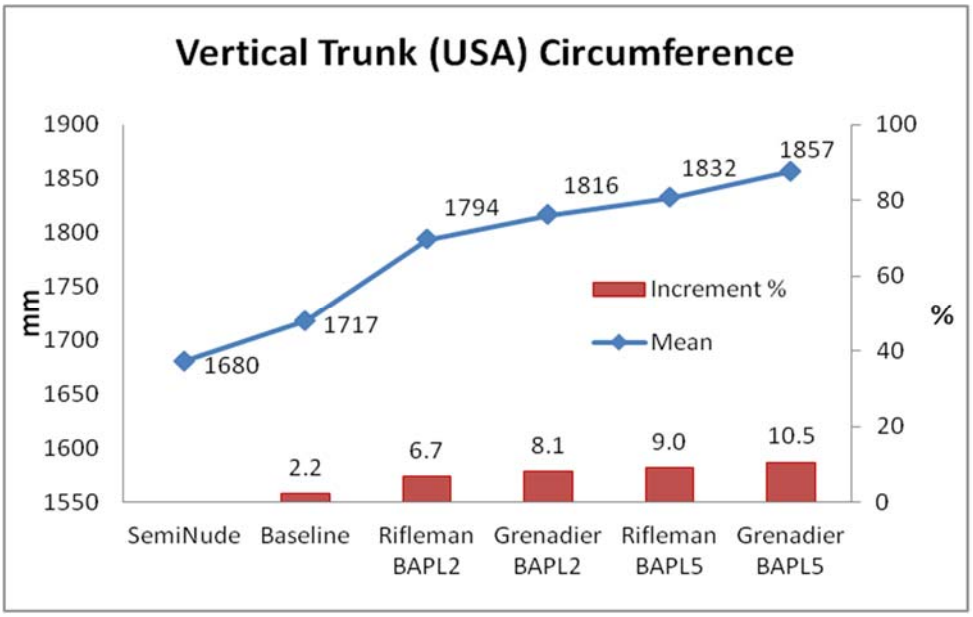


Figure 43: Percent increment relative to Semi-Nude and average Vertical Trunk (USA) Circumference for each configuration.

Waist (Omphalion) Breadth

Waist (Omphalion) Breadth is the horizontal breadth of the waist at the level of the Omphalion (Figure 44). 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 measurer follows the above method and takes care not to compress the CIE. Waist landmarks from the Semi-Nude are transferred to the encumbered configurations using a laser level transfer rod and adhesive markers.

Figure 44: Waist (Omphalion) Breadth measurement (Semi-Nude on left, encumbered on right)

A repeated measures ANOVA was conducted to investigate whether the various CIE configurations have an effect on size increments at the Waist (Omphalion) Breadth location relative to the Semi-Nude configuration and to each of the other configurations. The results are listed in Table 11 and shown graphically with percent increments between configurations in Figure 45. The averaged delta values among all configurations were statistically different, $F(4, 120)=878.88$, $p<.01$. The delta at Baseline ($M=1.9$ mm) was statistically smaller than all the other loaded configurations, $p<.05$. All four loaded configurations were different from one another. The 5G configuration ($M=299.8$ mm) was the largest, followed by the 2G ($M=275.3$ mm), the 5R ($M=248.9$ mm), and then the 2R ($M=215.6$ mm) configurations, $p<.05$. Regardless of BAPL, the Grenadier configurations were greater than the Rifleman configurations. In addition, within the same duty position, both BAPL 5 configurations were greater than the BAPL 2 configurations for their respective positions.

Table 11: Summary statistics and mean deltas for Waist (Omphalion) Breadth for each configuration

	Semi-Nude (mm)	Baseline (mm)	BAPL 2 (mm)		BAPL 5 (mm)	
			Rifleman	Grenadier	Rifleman	Grenadier
Δ from Semi-Nude	-	[E]1.9	[D]215.6	[B]275.3	[C]248.9	[A]299.8
Δ SD	-	5.9	37.8	26.1	39.7	43.0
Mean	307	309	523	583	556	607
SD	26	28	31	16	20	29
Min	263	257	421	549	489	499
25th	287	288	515	571	557	603
50th	305	307	534	584	562	611
75th	326	327	542	596	567	622
Max	354	359	555	613	580	648
Range	91	102	134	64	91	149

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

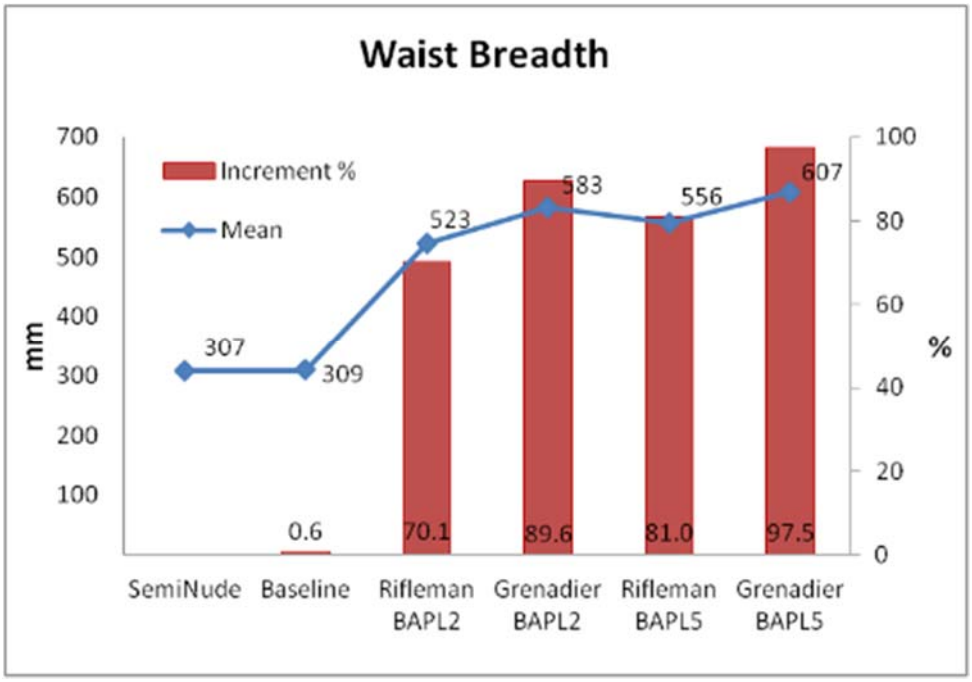


Figure 45: Percent increment relative to Semi-Nude and average Waist (Omphalion) Breadth for each configuration

Waist (Omphalion) Circumference

Waist (Omphalion) Circumference is the horizontal circumference of the waist at the level of Omphalion encompassing the Waist (Omphalion) landmarks (Figure 46). 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 Baseline and loaded measurements. All measurements are made at the maximum point of quiet respiration.

Figure 46: Waist (Omphalion) Circumference measurement (Semi-Nude on left, encumbered on right)

A repeated measures ANOVA was conducted to investigate whether the various CIE configurations have an effect on size increments at the Waist (Omphalion) Circumference location relative to the Semi-Nude configuration and to each of the other configurations. The results are listed in Table 12 and shown graphically with percent increments between configurations in Figure 47. The average delta values among configurations were statistically different, $F(4, 120)=1081.55$, $p<.01$. The delta at Baseline ($M=15.2$ mm) was significantly smaller than all the loaded configurations, $p<.05$. All four loaded configurations were significantly different from one another. The 5G configuration ($M=779.8$ mm) was the largest, followed by the 2G ($M=674.2$ mm), the 5R ($M=620.7$mm), and the 2R ($M=500.4$ mm) configurations, $p<.05$. Regardless of BAPL, Grenadier configurations were greater than the Rifleman configurations. In addition, within the same duty position, both BAPL 5 configurations were greater than the BAPL 2 configurations for their respective positions.

Table 12: Summary statistics and mean deltas for Waist (Omphalion) Circumference for each configuration

	Semi-Nude (mm)	Baseline (mm)	BAPL 2 (mm)		BAPL 5 (mm)	
			Rifleman	Grenadier	Rifleman	Grenadier
Δ from Semi-Nude	-	[E]15.2	[D]500.4	[B]674.2	[C]620.7	[A]779.8
Δ SD	-	11.4	91.4	67.9	73.8	91.4
Mean	855	871	1356	1530	1476	1635
SD	70	74	83	63	47	79
Min	744	757	1051	1385	1351	1419
25th	808	811	1330	1485	1448	1617
50th	834	854	1368	1527	1484	1641
75th	901	914	1403	1566	1505	1668
Max	989	1007	1488	1664	1575	1774
Range	245	250	437	279	224	355

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

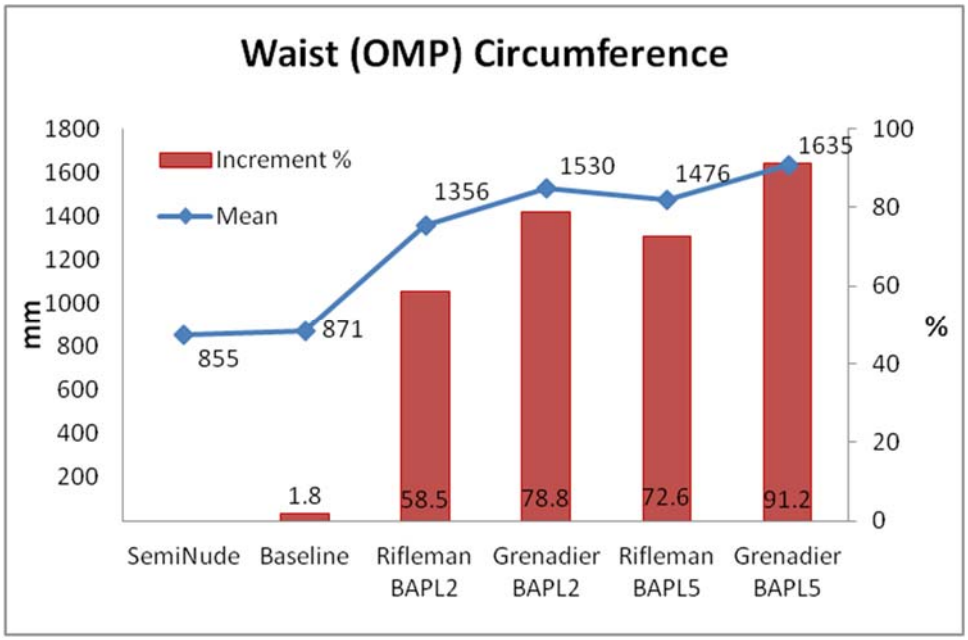


Figure 47: Percent increment relative to Semi-Nude and average Waist (Omphalion) Circumference for each configuration

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 (Figure 48). The TP is in the anthropometric standing position, but with the right hand on the chest. 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 maintain contact between the caliper and the skin, or CIE without compressing the CIE. The Semi-Nude landmarks are transferred to the various CIE layers using adhesive markers. The measurements are taken at the maximum point of quiet respiration.

Figure 48: Waist (Omphalion) Depth measurement (Semi-Nude on left, encumbered on right)

A repeated measures ANOVA was conducted to investigate whether the various CIE configurations have an effect on size increments at the Waist Depth location relative to the Semi-Nude configuration and to each of the other configurations. The results are listed in Table 13 and shown graphically with percent increments between configurations in Figure 49. The averaged delta values among all configurations were statistically different, $F(4, 120)=467.69$, $p<.01$. The delta at Baseline ($M=5.7$ mm) was significantly smaller than all the other loaded configurations, $p<.05$. Within the four loaded configurations, the 5G ($M=220.6$ mm) configuration was significantly greater than 2R ($M=136.9$ mm), 2G ($M=198.2$ mm), and 5R ($M=159.1$ mm) configurations, $p<.05$. Regardless of BAPLs, the Grenadier configurations were greater than the Rifleman configurations. Within the same duty positions, 5G was significantly greater than 2G, but there was no statistical difference between the 2R and 5R configurations.

Table 13: Summary statistics and mean deltas for Waist (Omphalion) Depth for each configuration

	Semi-Nude (mm)	Baseline (mm)	BAPL 2 (mm)		BAPL 5 (mm)	
			Rifleman	Grenadier	Rifleman	Grenadier
Δ from Semi-Nude	-	^{D}5.7	^{C}136.9	^{B}198.2	^{C}159.1	^{A}220.6
Δ SD	-	6.4	39.4	24.2	20.5	28.1
Mean	218	223	355	416	377	438
SD	18	20	38	26	23	29
Min	188	192	239	359	334	371
25th	208	210	338	399	358	423
50th	214	219	362	415	375	431
75th	229	233	375	427	388	462
Max	253	266	410	465	428	496
Range	65	74	171	106	94	125

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

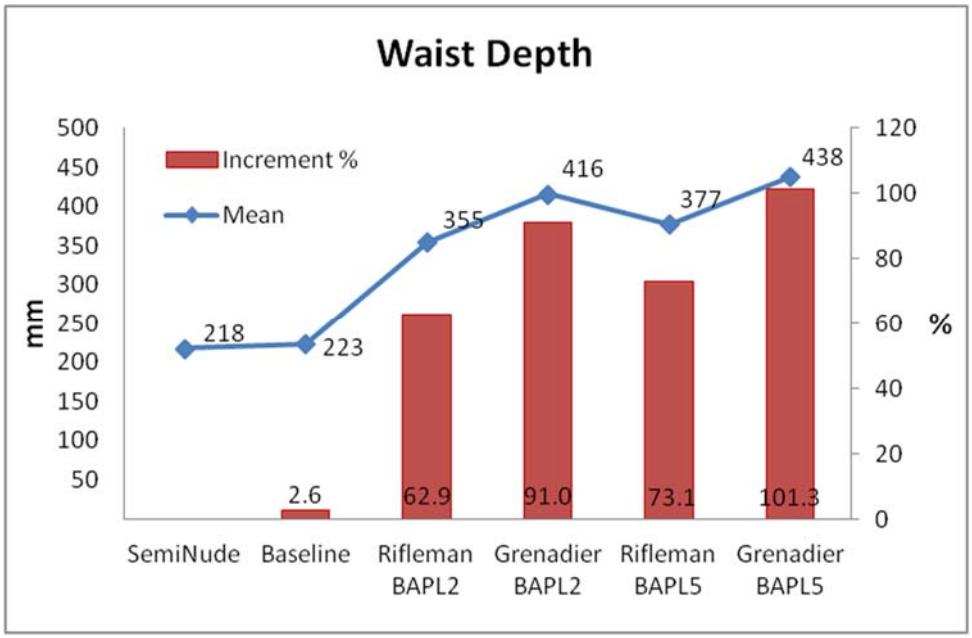


Figure 49: Percent increment relative to Semi-Nude and average Waist (Omphalion) Depth for each configuration.

Weight (lb)

Weight is the maximum weight of a TP. The TP stands on the platform of the scale with weight distributed evenly on both feet (Figure 50). 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 lb. This is completed for all encumbered conditions.

Figure 50: Weight (lb) measurement (Semi-Nude on left, encumbered on right)

A repeated measures ANOVA was conducted to investigate whether the various CIE configurations have an effect on increments of Weight (lb) relative to the Semi-Nude configuration and to each of the other configurations. The results are listed in Table 14 and shown graphically with percent increments between configurations in Figure 51. The averaged delta values among all configurations were statistically different, $F(4, 120)=783.13$, $p<.01$. The delta at Baseline ($M=6.5$ lb) was significantly smaller than all the loaded configurations, $p<.05$. The 2G configuration ($M=47.3$ lb) was significantly greater than the 2R configuration ($M=37.0$ lb), and the 5G configuration ($M=56.5$ lb) was significantly greater than the 5R configuration ($M=47.4$ lb), $p<.05$. Within the same duty position, both BAPL 5 configurations were greater than the BAPL 2 configurations for their respective positions $p<.05$. There was no statistical difference between the 5R and the 2G configurations.

Table 14: Summary statistics and mean deltas for Weight (lb) for each configuration

	Semi-Nude	Baseline	BAPL 2		BAPL 5	
			Rifleman	Grenadier	Rifleman	Grenadier
Δ from Semi-Nude	-	^{D}6.5	^{C}37.0	^{B}47.3	^{B}47.4	^{A}56.5
Δ SD	-	0.9	3.2	3.0	8.3	3.0
Mean	173.99	180.53	211.01	221.25	221.35	230.54
SD	23.70	23.64	25.31	25.67	27.48	25.87
Min	127.00	133.50	160.25	170.25	167.75	178.25
25th	153.25	159.50	189.88	198.75	196.38	206.75
50th	178.00	185.25	213.50	224.25	223.25	235.50
75th	189.63	195.75	229.38	240.13	240.13	249.00
Max	224.75	231.50	265.00	275.75	272.50	284.00
Range	97.75	98.00	104.75	105.50	104.75	105.75

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

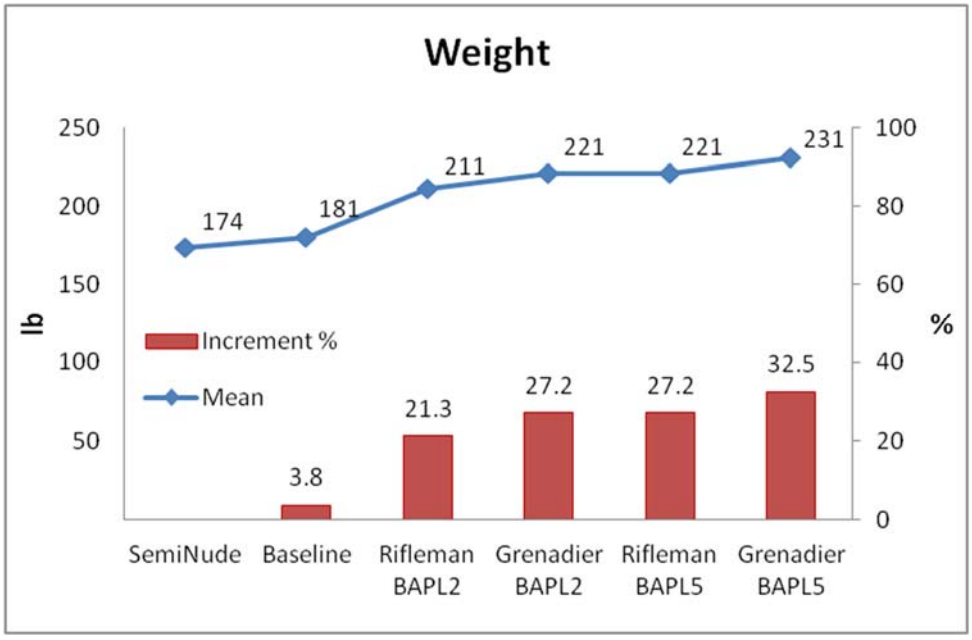


Figure 51: Percent increment relative to Semi-Nude and average Weight (lb) for each configuration.

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. The summary results and delta values are presented for each dimension.

Biacromial Breadth, Sitting

Biacromial Breadth, Sitting is the horizontal distance between the right and left Acromial landmarks on the tips of the shoulder (Figure 52). 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 either. Adhesive markers are placed at the location of the Acromial landmarks and are palpated and rechecked for each configuration.

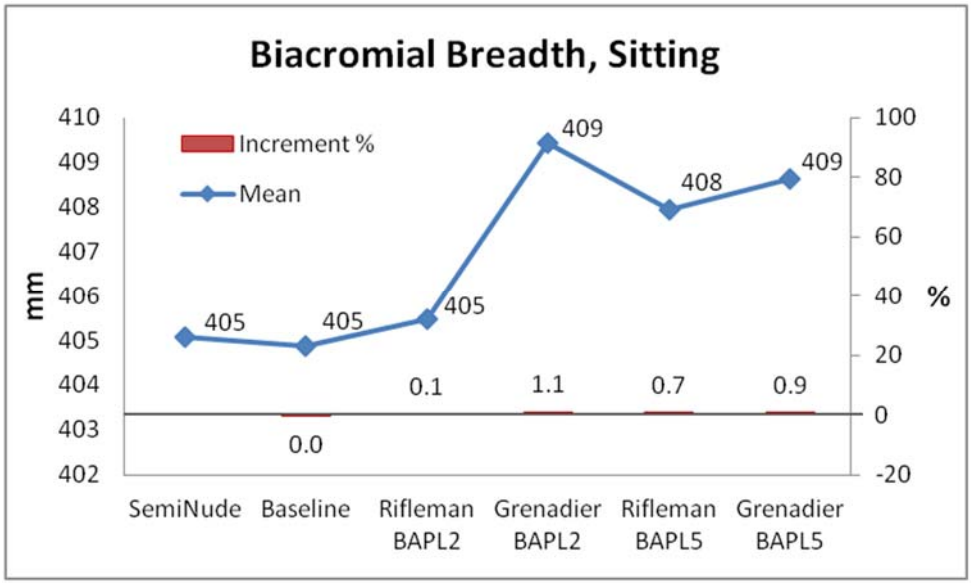
Figure 52: Biacromial Breadth, Sitting measurement (Semi-Nude on left, encumbered on right)

A repeated measures ANOVA was conducted to investigate whether the various CIE configurations have an effect on size increments at the Biacromial Breadth, Sitting location relative to the Semi-Nude configuration and to each of the other configurations. The results are listed in Table 15 and shown graphically with percent increments between configurations in Figure 53. The differences of the averaged delta values among configurations were not statistically significant, $F(4, 120)=2.46$, $p>.05$. When encumbered, the Acromial landmarks were covered only by the ACS, and neither the IOTV nor the SPCS covered the shoulder region. Thus,

the small differences (Table 15, Figure 53), 4 mm (405 mm-409 mm), are likely related to measuring error and/or slightly different arm postures when measured in the different configurations.

Table 15: Summary statistics and mean deltas for Biacromial Breadth, Sitting for each configuration

	Semi-Nude (mm)	Baseline (mm)	BAPL 2 (mm)		BAPL 5 (mm)	
			Rifleman	Grenadier	Rifleman	Grenadier
Δ from Semi-Nude	-	-0.2	0.4	4.4	2.9	3.5
Δ SD	-	8.9	11.7	13.9	15.5	13.5
Mean	405	405	405	409	408	409
SD	19	19	18	19	20	21
Min	374	368	370	370	369	361
25th	390	393	392	396	396	396
50th	404	402	408	409	409	405
75th	418	418	418	421	423	424
Max	456	457	452	460	456	467
Range	82	89	82	90	87	106



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 53: Percent increment relative to Semi-Nude and average Biacromial Breadth, Sitting for each configuration

Bideltoid Breadth, Sitting

Bideltoid Breadth, Sitting is the maximum horizontal distance between the lateral margins of the upper arms on the deltoid muscles (Figure 54). 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.

Figure 54: Bideltoid Breadth, Sitting measurement (Semi-Nude on left, encumbered on right)

A repeated measures ANOVA was conducted to investigate whether the various CIE configurations have an effect on size increments at the Bideltoid Breadth, Sitting location relative to the Semi-Nude configuration and to each of the other configurations. The results are listed in Table 16 and shown graphically with percent increments between configurations in Figure 55. The averaged delta values among configurations were statistically different, $F(4, 120)=41.94$, $p<.01$. The delta for the Baseline configuration ($M=14.2$ mm) was significantly smaller than all the four loaded configurations, $p<.05$. As shown in Table 16, both the 5R ($M=40.2$ mm) and 5G ($M=42.1$ mm) configurations were statistically greater than the 2R ($M=32.2$ mm) configuration ($p<.05$), but neither one was statistically different from the 2G configuration. There were no statistical differences between the Rifleman and Grenadier configurations within the same BAPL (i.e., between 2R and 2G and between 5R and 5G). This is likely because there was no CIE loaded on the arms and little difference in the CIE loaded on the side of the body.

Table 16: Summary statistics and mean deltas for Bideltoid Breadth, Sitting for each configuration

	Semi-Nude (mm)	Baseline (mm)	BAPL 2 (mm)		BAPL 5 (mm)	
			Rifleman	Grenadier	Rifleman	Grenadier
Δ from Semi-Nude	-	^{C}14.2	^{B}32.2	^{AB}37.3	^{A}40.2	^{A}42.1
Δ SD	-	14.0	15.8	18.1	18.4	19.2
Mean	481	495	513	518	521	523
SD	28	26	24	27	29	30
Min	407	448	476	472	456	464
25th	468	475	491	497	500	503
50th	483	495	510	520	521	527
75th	499	513	530	535	540	541
Max	531	541	564	576	579	583
Range	124	93	88	104	123	119

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

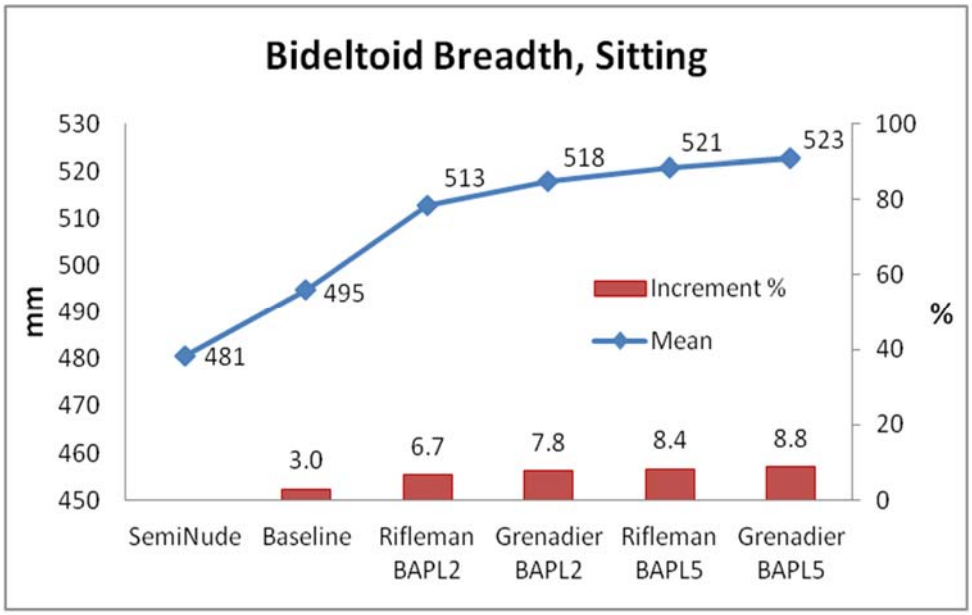


Figure 55: Percent increment relative to Semi-Nude and average Bideltoid Breadth, Sitting for each configuration.

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 (Figure 56). 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 measurements, a vertical board is attached to the buttock plate, and it is slid until it makes light contact at the most posterior point on the back of the CIE (this may or may not be at the buttock). 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 TPs back, as well as any equipment that may be worn at the knee.

Figure 56: Buttock-Knee Length measurement (Semi-Nude on left, encumbered on right)

A repeated measures ANOVA was conducted to investigate whether the various CIE configurations have an effect on size increments at the Buttock-Knee Length location relative to the Semi-Nude configuration and to each of the other configurations. The results are listed in Table 17 and shown graphically with percent increments between configurations in Figure 57. The averaged delta values among configurations were statistically different, $F(4, 112)=89.89$, $p<.01$. The delta at Baseline ($M=3.9$ mm) was significantly smaller than all four loaded configurations, $p<.05$. There were no significant differences between the deltas among the 2R ($M=54.7$ mm), 2G ($M=59.9$ mm), and 5R ($M=55.7$ mm) configurations. However, the delta for the 5G ($M=80.8$ mm) configuration was statistically greater than each of other configurations (Table 17). There was a magazine bag that was worn as a sling, across the shoulder and body for both Grenadier configurations. It caused drastically more standoff when worn with the IOTV (in

the 5G configuration) than when worn with the plate carrier (in the 2G configuration). This increased the distance between the board that was used for the back measurement point and the knee.

Table 17: Summary statistics and mean deltas for Buttock-Knee Length for each configuration

	Semi-Nude (mm)	Baseline (mm)	BAPL 2 (mm)		BAPL 5 (mm)	
			Rifleman	Grenadier	Rifleman	Grenadier
Δ from Semi-Nude	-	^{C}3.9	^{B}54.7	^{B}59.9	^{B}55.7	^{A}80.8
Δ SD	-	7.8	22.3	20.8	20.2	21.5
Mean	616	619	671	674	669	693
SD	33	33	39	37	39	40
Min	553	548	583	606	593	618
25th	588	594	649	643	648	669
50th	623	625	671	665	663	686
75th	638	637	693	693	693	722
Max	690	695	753	759	745	796
Range	137	147	170	153	152	178

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

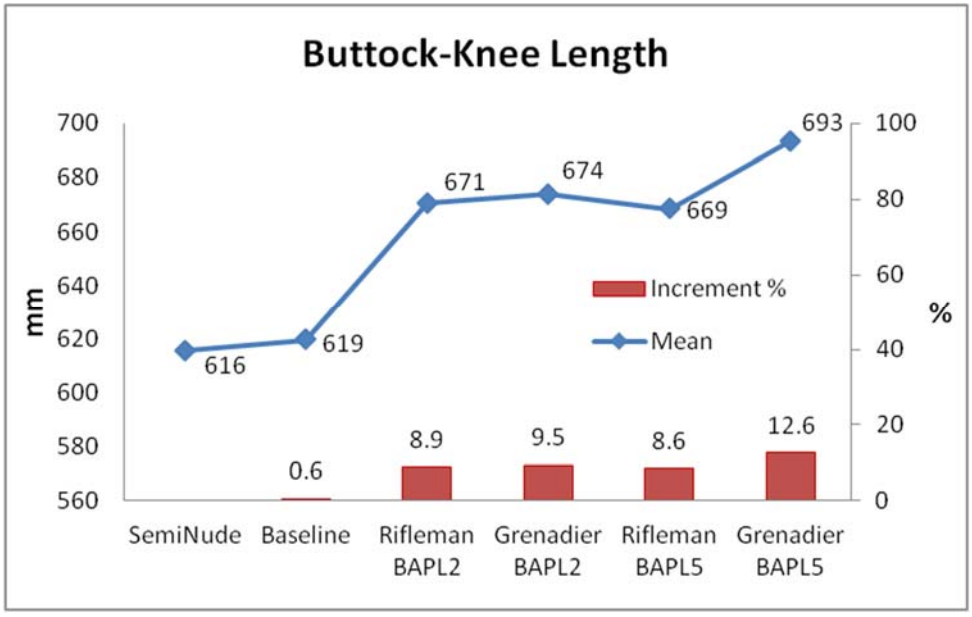


Figure 57: Percent increment relative to Semi-Nude and average Buttock-Knee Length for each configuration.

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) (Figure 58). 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 back, which may or may not be the buttock. The buttock plate is 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.

Figure 58: Buttock-Popliteal Length measurement (Semi-Nude on left, encumbered on right)

A repeated measures ANOVA was conducted to investigate whether the various CIE configurations have an effect on size increments at the Buttock-Popliteal Length location relative to the Semi-Nude configuration and to each of the other configurations. The results are listed in Table 18 and shown graphically with percent increments between configurations in Figure 59. The averaged delta values among all configurations were statistically different, $F(4, 112)=64.26$, $p<.01$. The results showed a similar trend to that from Buttock-Knee Length. The delta at Baseline ($M=0.6$ mm) was significantly smaller than all the loaded configurations, $p<.05$. As

shown in Table 18, there were no statistical differences between the deltas for 2R (M=54.1 mm), 2G (M=54.3 mm), and 5R (M=49.7 mm). The delta for the 5G (M=74.8 mm) configuration was statistically greater than the 2R, 2G, and 5R configurations ($p<.05$) (Table 18). There was a magazine bag that was worn as a sling, across the shoulder and body for both the Grenadier configurations. However, it caused drastically more standoff when worn with the IOTV (in the 5G configuration) than when worn with the plate carrier (in the 2G configuration). This increased the distance from the board that was used for the back measurement point to the back of the knee.

Table 18: Summary statistics and mean deltas for Buttock-Popliteal Length for each configuration

	Semi-Nude (mm)	Baseline (mm)	BAPL 2 (mm)		BAPL 5 (mm)	
			Rifleman	Grenadier	Rifleman	Grenadier
Δ from Semi-Nude	-	^{C}0.6	^{B}54.1	^{B}54.3	^{B}49.7	^{A}74.8
Δ SD	-	11.6	24.1	23.1	20.1	25.2
Mean	505	505	559	557	552	577
SD	27	31	37	36	36	37
Min	449	431	470	484	490	507
25th	486	488	530	539	536	554
50th	510	509	565	549	547	580
75th	526	525	580	579	576	598
Max	568	577	638	640	628	679
Range	119	146	168	156	138	172

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

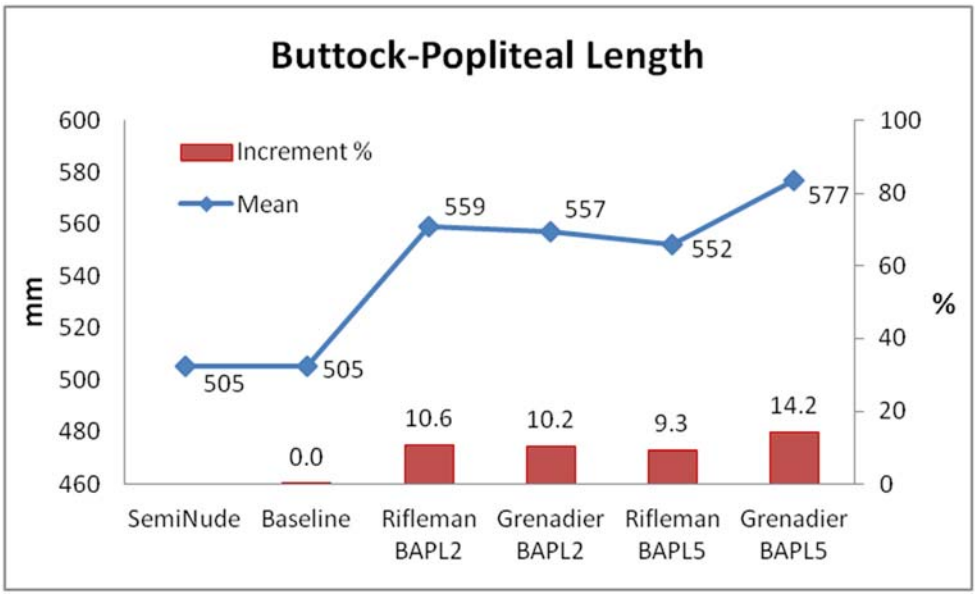


Figure 59: Percent increment relative to Semi-Nude and average Buttock-Popliteal Length for each configuration

Elbow Circumference, Sitting

Elbow Circumference, Sitting is the maximum circumference of the torso, including the arms, at the level of the inner elbows (Figure 60). The TP is in the Anthropometric Sitting position. The measurement is taken around the torso and elbows at the widest point. The measurers lets the tape fall along the crease of the inner elbows. The measurement is taken at the maximum point of quiet respiration. Care is taken to not compress the CIE. In some cases a longer or a second measuring tape is required to obtain encumbered measurements.

Figure 60: Elbow Circumference, Sitting measurement (Semi-Nude on left, encumbered on right)

A repeated measures ANOVA was conducted to investigate whether the various CIE configurations have an effect on size increments at the Elbow Circumference, Sitting location relative to the Semi-Nude configuration and to each other configurations. The results are listed in Table 19 and shown graphically with percent increments between configurations in Figure 61. The averaged delta values among all configurations were statistically different, $F(4, 120)=403.59$, $p<.01$. The delta at Baseline ($M=70$ mm) was significantly smaller than all the loaded configurations, $p<.05$. The 5G configuration ($M=438.5$ mm) was statistically greater than 2R ($M=366.4$ mm), 2G ($M=390.5$ mm), and 5R ($M=409.2$ mm) configurations, $p<.05$. When compared between Grenadier and Rifleman duty positions within the same BAPLs, the 5G was greater than the 5R, but there was no statistical difference between the 2G and 2R. Within the same duty position, both of the BAPL 5 configurations (5R and 5G) were greater than the BAPL 2 configurations (2R and 2G) for their respective positions.

Table 19: Summary statistics and mean deltas for Elbow Circumference, Sitting for each configuration

	Semi-Nude (mm)	Baseline (mm)	BAPL 2 (mm)		BAPL 5 (mm)	
			Rifleman	Grenadier	Rifleman	Grenadier
Δ from Semi-Nude	-	^{D}70.0	^{C}366.4	^{BC}390.5	^{B}409.2	^{A}438.5
Δ SD	-	44.9	81.5	74.7	78.6	75.7
Mean	1224	1294	1590	1615	1633	1663
SD	106	97	68	64	72	68
Min	1021	1126	1476	1450	1473	1504
25th	1140	1234	1551	1580	1586	1619
50th	1217	1283	1577	1622	1634	1663
75th	1302	1348	1639	1651	1690	1702
Max	1426	1568	1756	1738	1754	1778
Range	405	442	280	288	281	274

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

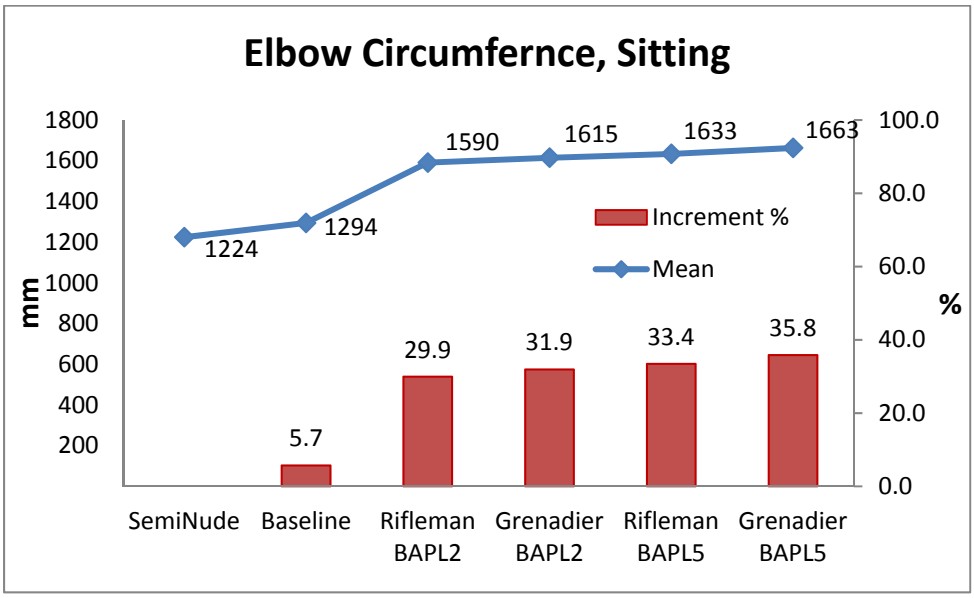


Figure 61: Percent increment relative to Semi-Nude and average Elbow Circumference, Sitting for each configuration.

Forearm-Forearm Breadth, Sitting

Forearm-Forearm Breadth, Sitting is the maximum horizontal distance between the outer sides of the forearms (Figure 62). 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. For the encumbered measurements, the above directions are followed for each CIE configuration. Care should be taken not to compress CIE.

Figure 62: Forearm-Forearm Breadth, Sitting measurement (Semi-Nude on left, encumbered on right)

A repeated measures ANOVA was conducted to investigate whether the various CIE configurations have an effect on size increments at the Forearm-Forearm Breadth, Sitting location relative to the Semi-Nude configuration and to each of the other configurations. The results are listed in Table 20 and shown graphically with percent increments between configurations in Figure 63. The averaged delta values among all configurations were statistically different, $F(4, 120)=124.58$, $p<.01$. The delta at Baseline ($M=24.7$ mm) was significantly smaller than all the loaded configurations, $p<.05$. There was a statistical difference between Rifleman and Grenadier configurations within the same BAPL where the 2G configuration ($M=145.4$ mm) was significantly greater than 2R ($M=117.2$ mm) configuration and the 5G configuration ($M=167.4$ mm) was significantly greater than the 5R ($M=143.7$ mm) configuration $p<.05$. In addition, within the same duty positions, BAPL 5 configurations were always greater than BAPL 2 configurations (5G>2G and 5R>2R), $p<.05$.

Table 20: Summary statistics and mean deltas for Forearm-Forearm Breadth, Sitting for each configuration

	Semi-Nude (mm)	Baseline (mm)	BAPL 2 (mm)		BAPL 5 (mm)	
			Rifleman	Grenadier	Rifleman	Grenadier
Δ from Semi-Nude	-	^{D}24.7	^{C}117.2	^{B}145.4	^{B}143.7	^{A}167.4
Δ SD	-	31.6	49.4	54.5	54.1	56.4
Mean	551	576	669	697	695	719
SD	56	53	35	32	34	42
Min	470	479	615	638	632	637
25th	505	535	642	680	670	698
50th	542	590	661	689	694	724
75th	591	616	683	711	713	735
Max	669	658	756	774	790	870
Range	199	179	141	136	158	233

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

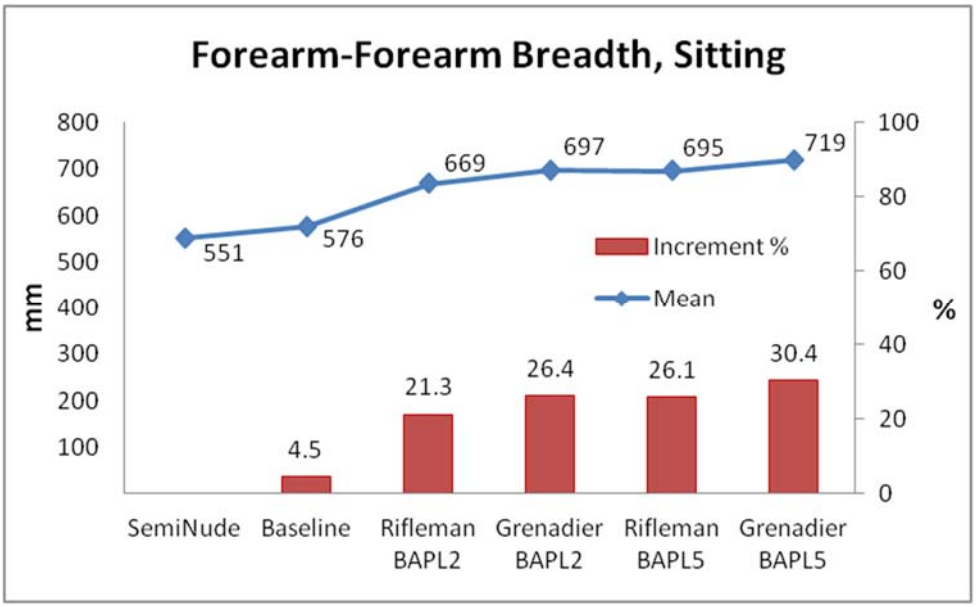


Figure 63: Percent increment relative to Semi-Nude and average Forearm-Forearm Breadth, Sitting for each configuration.

Hip Breadth, Sitting

Hip Breadth, Sitting is the horizontal distance between the Lateral Buttock landmarks on the sides of the hips (Figure 64). 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. For the encumbered measurement, the above method is followed 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.

Figure 64: Hip Breadth, Sitting measurement (Semi-Nude on left, encumbered on right)

A repeated measures ANOVA was conducted to investigate whether the various CIE configurations have an effect on size increments at the Hip Breadth, Sitting location relative to the Semi-Nude configuration and to each of the other configurations. The results are listed in Table 21 and shown graphically with percent increments between configurations in Figure 65. The averaged delta values among all configurations were statistically different, $F(4, 116)=57.95$, $p<.01$. The delta at Baseline ($M=18.3$ mm) was significantly smaller than all the loaded configurations, $p<.05$. There was a statistical difference between Rifleman and Grenadier configuration within the same BAPL, where the 2G configuration ($M=127.5$ mm) was significantly greater than the 2R ($M=90.5$ mm) configuration and the 5G configuration ($M=163.2$ mm) was significantly greater than the 5R ($M=106.2$ mm) configuration $p<.05$. Within the same duty positions, there was no statistical difference between the BAPL 5 and BAPL 2 configurations for their respective positions (Table 21).

Table 21: Summary statistics and mean deltas for Hip Breadth, Sitting for each configuration

	Semi-Nude (mm)	Baseline (mm)	BAPL 2 (mm)		BAPL 5 (mm)	
			Rifleman	Grenadier	Rifleman	Grenadier
Δ from Semi-Nude	-	^{D}18.3	^{C}90.5	^{AB}127.5	^{BC}106.2	^{A}163.2
Δ SD	-	12.9	46.0	55.9	36.6	46.0
Mean	371	390	462	499	478	534
SD	23	24	48	56	40	50
Min	328	339	386	389	415	430
25th	354	372	423	460	448	492
50th	370	389	466	501	463	544
75th	388	406	500	541	518	576
Max	424	437	569	608	563	633
Range	96	98	183	219	148	203

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

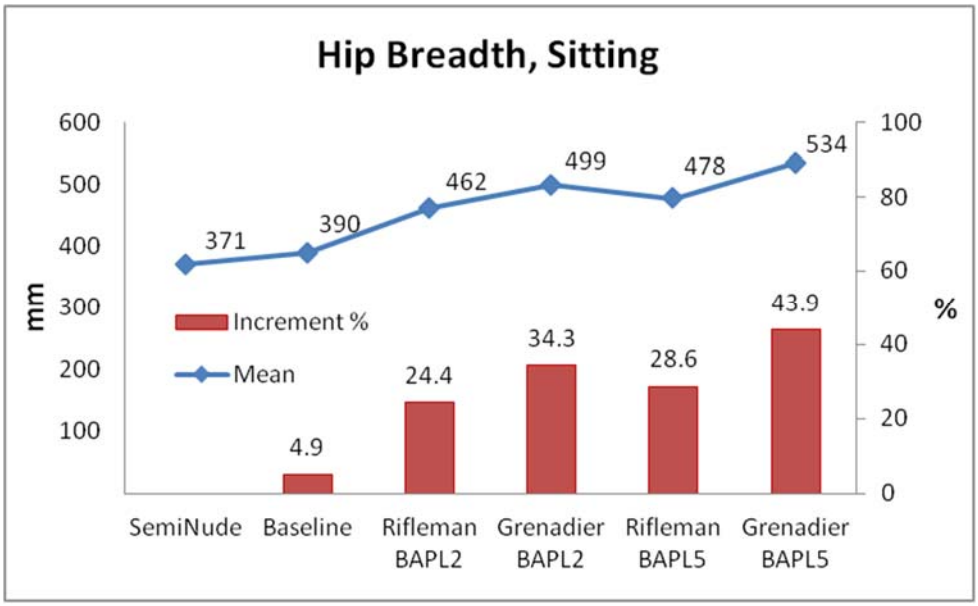


Figure 65: Percent increment relative to Semi-Nude and average Hip Breadth, Sitting for each configuration.

Sitting Height

Sitting Height is the vertical distance between a Sitting surface and the top of the head. The TP is in the Anthropometric Sitting position with the head in the Frankfort Horizontal plane (Figure 66). The measurer stands at the right rear of the TP and uses an anthropometer to measure the distance. The measurer uses sufficient pressure to compress the hair, but takes care not to compress the CIE (i.e., ACH). The measurement is made at the maximum point of quiet respiration.

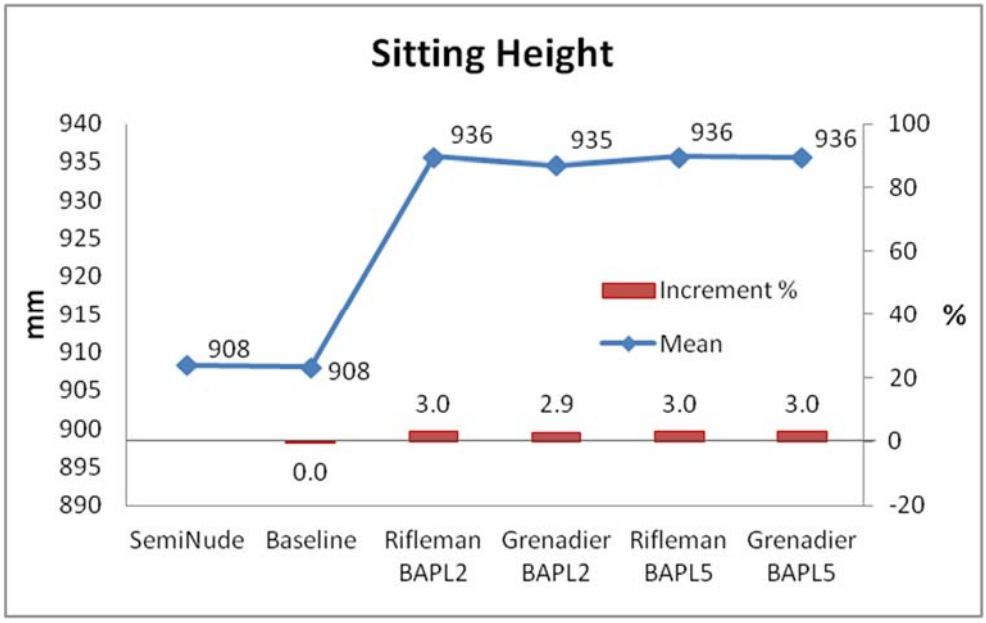
Figure 66: Sitting Height measurement (Semi-Nude on left, encumbered on right)

A repeated measures ANOVA was conducted to investigate whether the various CIE configurations have an effect on size increments at the Sitting Height location relative to the Semi-Nude configuration and to each of the other configurations. The results are listed in Table 22 and shown graphically with percent increments between configurations in Figure 67. The averaged delta values among all configurations were statistically different, $F(4, 120)=148.42$, $p<.01$. The delta for the Baseline ($M= -0.2$ mm) was statistically smaller than for all the loaded configurations, $p<.05$. There were no statistical differences between the four loaded configurations. This is likely because the only difference in CIE is the addition of the ACH.

Table 22: Summary statistics and mean deltas for Sitting Height for each configuration

	Semi-Nude (mm)	Baseline (mm)	BAPL 2 (mm)		BAPL 5 (mm)	
			Rifleman	Grenadier	Rifleman	Grenadier
Δ from Semi Nude	-	[B]-0.2	[A]27.4	[A]26.4	[A]27.4	[A]27.4
Δ SD	-	6.2	9.8	7.8	9.2	9.9
Mean	908	908	936	935	936	936
SD	38	38	37	37	37	37
Min	818	821	847	846	850	861
25th	892	890	919	920	919	920
50th	912	909	938	935	939	935
75th	934	934	954	958	956	961
Max	990	993	1022	1015	1019	1034
Range	172	172	175	169	169	173

A>B, 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 67: Percent increment relative to Semi-Nude and average Sitting Height for each configuration.

3.4 Head, Hand and Foot Anthropometry

All the measurements taken for the Head, Hand, and Foot are described in this section. These dimensions are grouped together, as all of them were measured only in the Semi-Nude configuration and one "encumbered" configuration. The CIE for Head, Hand and Foot is the same in all four loaded configurations, and the Baseline is the same as the Semi-Nude for SFG and ACH, and as the loaded configuration with boots. Table 23 gives summary results for each of these dimensions.

Table 23. Distribution of mean deltas between encumbered* and Semi-Nude measurements for single dimensions

Dimension	Condition	Mean (mm)	SD (mm)	Min (mm)	25th (mm)	50th (mm)	75th (mm)	Max (mm)	Range (mm)	Absolute Mean Δ (mm)	% Increment
Head Breadth	Semi-Nude	152	5	143	148	152	156	165	22	92	60.2
	Encumbered	244	6	238	238	247	247	264	26		
Head Circumference	Semi-Nude	567	14	543	561	563	577	611	68	195	34.3
	Encumbered	762	66	418	754	785	785	785	368		
Head Length	Semi-Nude	198	7	184	196	198	200	215	31	64	32.7
	Encumbered	262	6	256	256	265	265	283	28		
Hand Breadth	Semi-Nude	87	5	81	83	86	90	96	15	1	1.1
	Encumbered	88	5	78	84	88	92	97	19		
Hand Circumference	Semi-Nude	213	11	197	203	212	220	235	38	8	3.8
	Encumbered	221	10	209	213	216	227	242	33		
Hand Length	Semi-Nude	198	14	170	189	197	204	227	57	2	1.0
	Encumbered	200	13	179	189	201	208	231	52		
Wrist Circumference	Semi-Nude	172	10	154	167	170	177	198	44	22	12.8
	Encumbered	194	12	179	185	191	200	226	47		
Foot Breadth	Semi-Nude	103	5	97	99	101	105	115	18	11	10.7
	Encumbered	114	8	103	110	114	119	142	39		
Foot Length	Semi-Nude	268	16	241	258	265	275	306	65	40	14.9
	Encumbered	308	11	287	302	308	312	335	48		

*Encumbered configuration here consists of an ACH for the Head measurements, SFG for the Hand and Wrist measurements, and Army duty boots for the foot measurements.

Head Breadth

Head Breadth is the maximum horizontal breadth of the head above the ears. The TP sits with the head in the Frankfort Horizontal plane. The measurer stands behind the TP and uses a spreading caliper to measure euryon, right, and left (Figure 68). The measurer exerts sufficient pressure to obtain contact between the caliper and the skin. For the encumbered measurement (the TP wearing an ACH), the measurer carefully slides the calipers so that they are just touching the left and right edges to obtain the maximum Breadth of the ACH, even though this is in a slightly lower position than that for the Semi-Nude Head Breadth location.

Figure 68: Head Breadth measurement (Semi-Nude on left, encumbered on right)

Head Circumference

Head Circumference is the maximum circumference of the head above the supraorbital ridges and ears (Figure 69). 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 to obtain the maximum circumference of the head. For the encumbered measurements (the TP wearing an ACH), the measurer places the tape measure around the maximum perimeter of the ACH.

Figure 69: Head Circumference measurement (Semi-Nude on left, encumbered on right)

Head Length

Head Length is the distance from the Glabella landmark between the brow ridges to Opisthocranion (Figure 70). The TP sits with their 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), the Length of the ACH is measured from anterior rim to posterior rim.

Figure 70: Head Length measurement (Semi-Nude on left, encumbered on right)

Hand Breadth

Hand Breadth is the breadth of the right hand between the landmarks at Metacarpale II and Metacarpale V (Figure 71). The TP sits with the palm on a table and the distal phalanges on a flat surface 8 mm higher. The fingers are together, and the thumb is held away from the hand at about a 45° angle. The measurer presses the hand into firm contact with the table and instructs the TP to hold this position. The middle finger is parallel to the long axis of the forearm. The measurer stands in front of the TP and uses a sliding caliper to measure the breadth of the hand between the drawn landmarks at Metacarpale II and Metacarpale V, exerting only enough pressure to ensure that the caliper blades are on the landmarks. For the encumbered measurements (with the TP wearing SFG), the locations of the Metacarpale II and Metacarpale V are palpated without compressing the SFG.

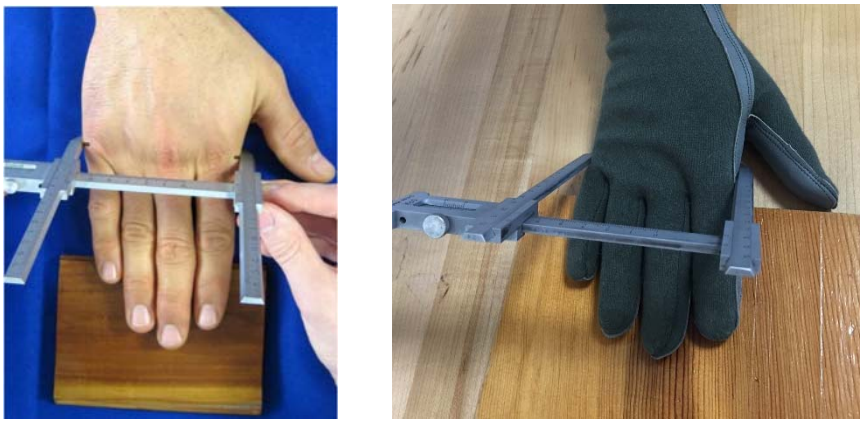


Figure 71: Hand Breadth measurement (Semi-Nude on left, encumbered on right)

Hand Circumference

Hand Circumference is the circumference of the right hand encompassing the Metacarpale II and Metacarpale V landmarks (Figure 72). The TP sits with the palm on a table and the distal phalanges on a flat surface 8 mm higher. The fingers are together, and the thumb is held away from the hand at about a 45° angle. The measurer presses the hand into firm contact with the table and instructs the TP to hold this position. The middle finger is parallel to the long axis of the forearm. The measurer places a tape measure under the Hand before positioning the TP. The measurer stands in front of the TP and passes the tape over the drawn landmarks at Metacarpale II and Metacarpale V and exerts only enough tension on the tape to maintain contact between the tape and the skin. For the encumbered measurements (with the TP wearing SFG), the measurement is taken over the SFG, and the underlying Metacarpale II and Metacarpale V are palpate. The measurement is obtained without compressing the SFG.

Figure 72: Hand Circumference measurement (Semi-Nude on left, encumbered on right)

Hand Length

Hand Length is the length of the right hand between the Stylion landmark on the wrist and the tip of the middle finger (Figure 73). The TP sits with the palm on a table and the distal phalanges on a flat surface 8 mm higher. The fingers are together, and the thumb is held away from the hand at about a 45° angle. The measurer presses the hand into firm contact with the table and instructs the TP to hold this position. The middle finger is parallel to the long axis of the forearm. The measurer stands at the left of the TP and places the fixed blade of a Poech sliding caliper on the Stylion mark. The beam of the caliper is held parallel to the long axis of the arm. The measurer exerts only enough pressure to ensure that the tips of the caliper are on the landmarks. For the encumbered measurement (with the TP wearing SFG), the measurer palpates for the Stylion landmark and marks it with an adhesive marker then obtains the measurement without compressing the SFG.

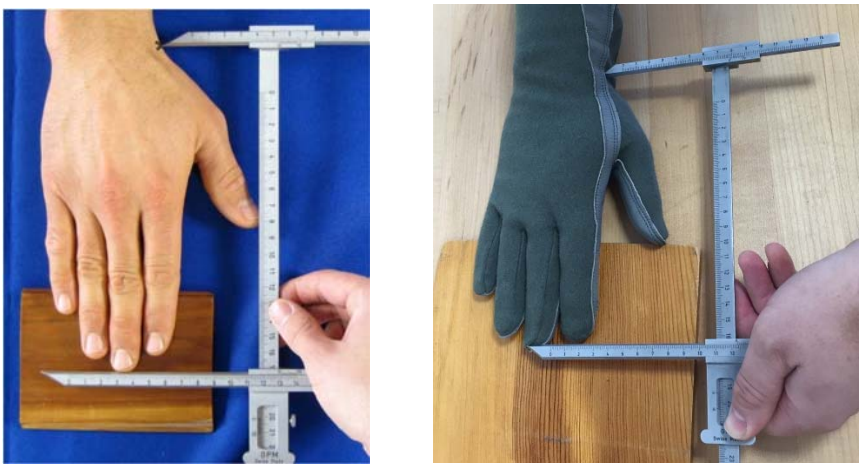


Figure 73: Hand Length measurement (Semi-Nude on left, encumbered on right)

Wrist Circumference

Wrist Circumference is the circumference of the wrist at the level of Stylion landmark and perpendicular to the long axis of the forearm (Figure 74). The TP stands with the upper arm relaxed and the elbow flexed 90° with the palm up. The measurer stands in front of the TP and uses a tape to measure the circumference of the wrist perpendicular to the long axis of the forearm. The upper edge of the tape will run just below the bony prominence at Stylion, and the lower edge of the tape will run just above the pisiform bone at the bottom of the little finger side of the hand. The measurer exerts only enough tension on the tape to maintain contact between the tape and the skin. For the encumbered measurement (with the TP wearing SFG), the measurement is taken over the SFG without compressing it.

Figure 74: Wrist Circumference measurement (Semi-Nude on left, encumbered on right)

Foot Breadth

Foot Breadth is the maximum breadth of the right foot. The TP stands erect with both feet in an Anthropometric Foot box (Figure 75) 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. 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 75: Foot Breadth measurement (Semi-Nude on left, encumbered on right)

Foot Length

Foot Length is the maximum length of the right foot. The TP stands erect with the right and left foot in an anthropometric foot box (Figure 76). 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. 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 longest phalanx. For the encumbered measurement (the TP wearing duty boots), the measurement is obtained and care is taken not to compress the boot.

Figure 76: Foot Length measurement (Semi-Nude on left, encumbered on right)

3.5 Anthropometric Maximum Measurements

To assist with the characterization of the dismounted Soldier, several additional dimensions were recorded that highlighted locations on the body that were determined to be maximal breadths, depths, and circumferences. When these were identified they were landmarked with adhesive markers. The heights of these landmarks were recorded and used to capture the breadths, circumferences and depths at these locations. These dimensions were measured in only the four loaded configurations (2R, 2G, 5R, and 5G) because the reference landmarks were located at specific maximum protrusions on IOTV/SPCS with no related Semi-Nude or Baseline landmarks. They are described in this section. Note that the height measurements were used as reference locations only to locate the breadths, depths, and circumferences. The summary results and delta values are presented for each of the breadth, depth, and circumference dimensions.

MAX Backpack Height

MAX Backpack Height is the vertical height of the combat assault pack from the standing surface to where the maximum backpack depth occurred. This location was marked by an adhesive landmark, and an anthropometer was used to measure this height location from a standing surface. This location is used to capture the maximum breadth, depth and circumferences at this height. There is no Semi-Nude measurement for this variable.

MAX Waist Height

MAX Waist Height is the height location where the maximum breadth, depth, and circumference are observed while a TP is wearing CIE. This height measurement is recorded and marked with an adhesive marker as a reference point for taking the maximum breadth, depth, and circumference measurements.

MAX Waist Breadth

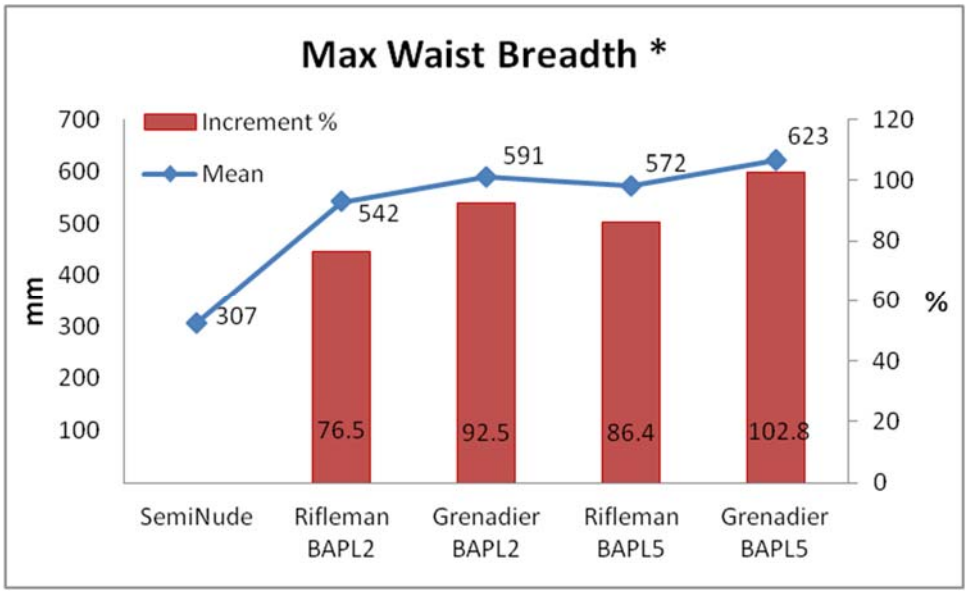
MAX Waist Breadth is the location of the Maximum Breadth of the Waist while the TP is wearing CIE. This location was earlier identified and marked using MAX Waist Height. Using a beam caliper this measurement is taken at the maximum horizontal breadth of the TP's CIE. Care is taken to not compress the CIE. There is no Semi-Nude landmark for this measurement, but Waist Breadth at Omphalion is a close surrogate for calculating the CIE deltas.

A repeated measures ANOVA was performed on the deltas to compare them among the four loaded configurations. The results are listed in Table 24 and shown graphically with percent increments between configurations in Figure 77. The configurations were significantly different, $F(3, 90)=388.75$, $p<.01$. All four were statistically different from one another. The 5G (M=315.2 mm) was the greatest, followed by the 2G (M=283.6 mm), the 5R (M=264.8 mm), and the 2R (M=234.5 mm) configurations, $p<.05$, respectively. The Grenadier configurations were statistically greater than the Rifleman configurations within the same BAPL (i.e., 2G > 2R and 5G > 5R). In addition, both BAPL 5 configurations were statistically greater than both BAPL 2 configurations within the same duty position (i.e., 5G > 2G and 5R > 2R).

Table 24: Summary statistics and mean deltas for MAX Waist Breadth relative to Semi-Nude Waist Breadth for each encumbered configuration

	Semi-Nude (mm)	BAPL 2 (mm)		BAPL 5 (mm)	
		Rifleman	Grenadier	Rifleman	Grenadier
Δ from Semi-Nude	-	[D]234.5	[B]283.6	[C]264.8	[A]315.2
Δ SD	-	19.5	21.8	21.8	27.5
Mean	307	542	591	572	623
SD	-	13	13	9	12
Min	-	510	551	556	602
25th	-	534	585	564	613
50th	-	544	595	574	620
75th	-	550	600	579	633
Max	-	570	613	590	648
Range	-	60	62	34	46

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



*Deltas were calculated using a surrogate dimension.

Figure 77: Percent increment relative to Semi-Nude Waist Breadth and average MAX Waist Breadth for each configuration

MAX Backpack Chest Circumference

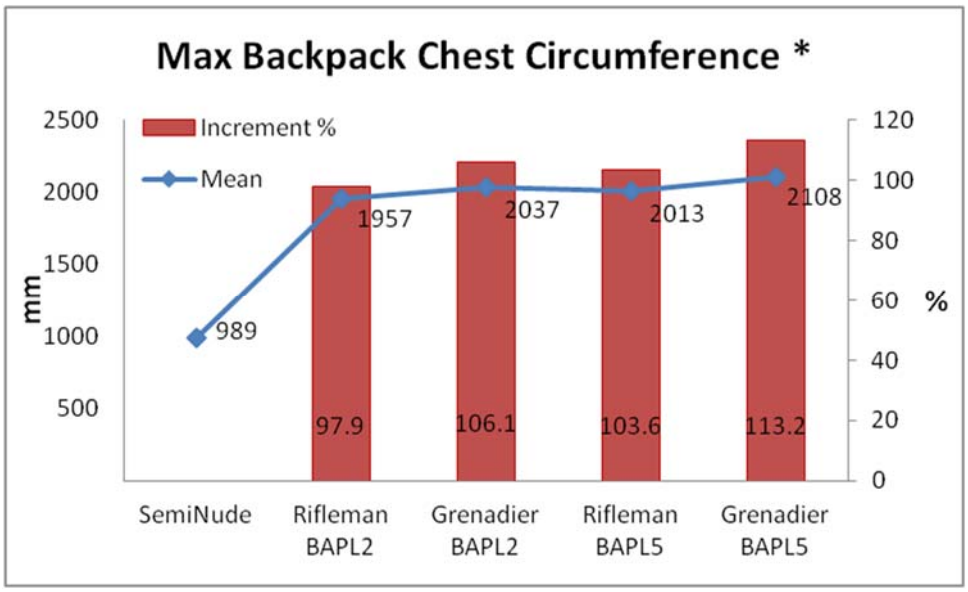
MAX Backpack Chest Circumference is the maximum circumference around the torso and the combat assault pack at the level of the maximum posterior protrusion where the MAX Backpack Height is marked. There is no Semi-Nude measurement at this location; however, the Semi-Nude Chest Circumference is a close surrogate for calculating deltas. Care is taken not to compress the CIE when taking this measurement. This measurement often needs the use of an additional tape measure to obtain the measurement.

A repeated measures ANOVA was performed on the deltas to compare them among the four loaded configurations. The results are listed in Table 25 and shown graphically with percent increments between configurations in Figure 78. The configurations were significantly different, $F(3, 90)=41.96$, $p<.01$. As shown in Table 25, the 2R (M=967.9 mm) configuration was the smallest, and the 5G (M=1118.9 mm) configuration was the greatest, $p<.05$. Both Grenadier configurations were statistically greater than the Rifleman configurations within the same BAPL (i.e., 2G > 2R and 5G > 5R). In addition, both BAPL 5 configurations were statistically greater than BAPL 2 configurations within the same duty position (i.e., 5R > 2R and 5G > 2G).

Table 25: Summary statistics and mean deltas for MAX Chest Circumference relative to Semi-Nude Chest Circumference for each configuration

	Semi-Nude (mm)	BAPL 2 (mm)		BAPL 5 (mm)	
		Rifleman	Grenadier	Rifleman	Grenadier
Δ from Semi-Nude	-	^{C}967.9	^{B}1048.2	^{B}1023.8	^{A}1118.9
Δ SD	-	87.1	101.7	98.8	126.0
Mean	989	1957	2037	2013	2108
SD	-	101	115	105	127
Min	-	1690	1744	1669	1803
25th	-	1938	1995	2011	2031
50th	-	1964	2049	2034	2157
75th	-	2005	2113	2064	2198
Max	-	2114	2204	2160	2305
Range	-	424	460	491	502

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



*Deltas were calculated using a surrogate dimension.

Figure 78: Percent increment relative to Semi-Nude Chest Circumference and average MAX Backpack Chest Circumference for each configuration

MAX Backpack Depth

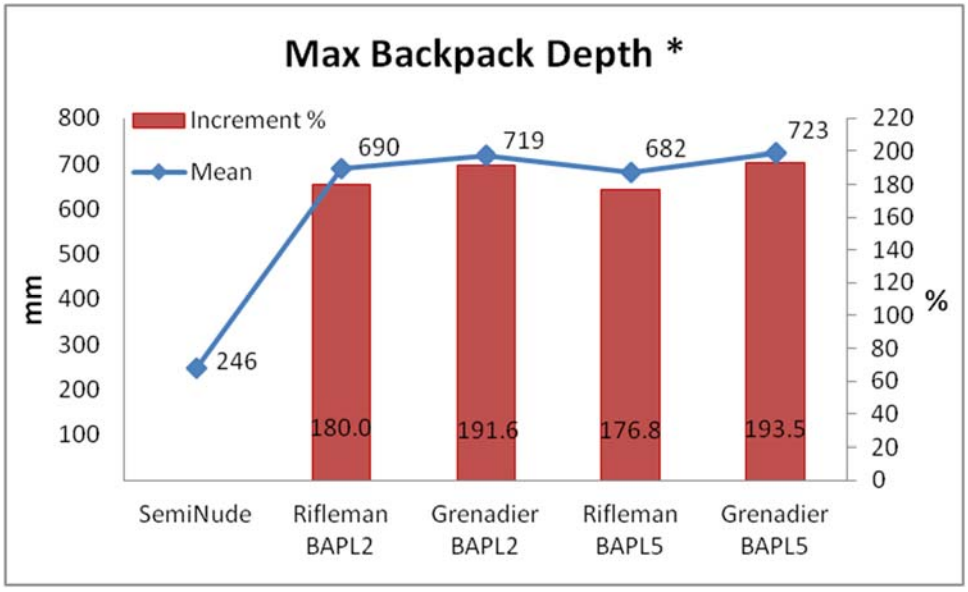
MAX Backpack Depth is the maximum depth of the combat assault pack while being worn by the TP. This is an encumbered measurement only. For this study, the maximum depth of the backpack was determined and then marked with a colored adhesive marker. Once the TP dons the backpack, the measurer uses a beam caliper that is placed parallel to the coronal plane, and the measurement is recorded. The fixed end of the caliper is placed against the adhesive marker on the backpack. Care is taken not to compress the CIE. The depth was based on the Maximum Chest Depth when TPs donned one of two loaded backpacks (Rifleman or Grenadier). As there is no Semi-Nude measurement linked to this measurement, the Semi-Nude Chest Depth is used as a close surrogate for calculating deltas.

A repeated measures ANOVA was performed that revealed that the deltas from the four loaded configurations were statistically significantly different, $F(3, 90)=29.26$, $p<.01$. The results are listed in Table 26 and shown graphically with percent increments between configurations in Figure 79. Regardless of BAPL, the Grenadier configurations 5G (M=477.16) and 2G (M=472.48) were statistically larger than the Rifleman configurations 5R (M=435.935) and 2R (M=443.94), respectively, $p<.05$. Within the same duty positions, there were no statistical differences between BAPL 2 and BAPL 5 for both Grenadier and Rifleman.

Table 26: Summary statistics and mean deltas for MAX Backpack Depth relative to Semi-Nude Chest Depth for each configuration

	Semi-Nude (mm)	BAPL 2 (mm)		BAPL 5 (mm)	
		Rifleman	Grenadier	Rifleman	Grenadier
Δ from Semi-Nude	-	^{B}443.9	^{A}472.5	^{B}435.9	^{A}477.2
Δ SD	-	24.9	37.4	26.7	37.5
Mean	246	690	719	682	723
SD	-	29	41	28	39
Min	-	604	630	621	639
25th	-	679	691	665	695
50th	-	691	722	685	727
75th	-	710	747	700	756
Max	-	750	791	739	783
Range	-	146	161	118	144

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



*Deltas were calculated using a surrogate dimension.

Figure 79: Percent increment relative to Semi-Nude Chest Depth and average MAX Backpack Depth for each configuration

MAX Waist Circumference

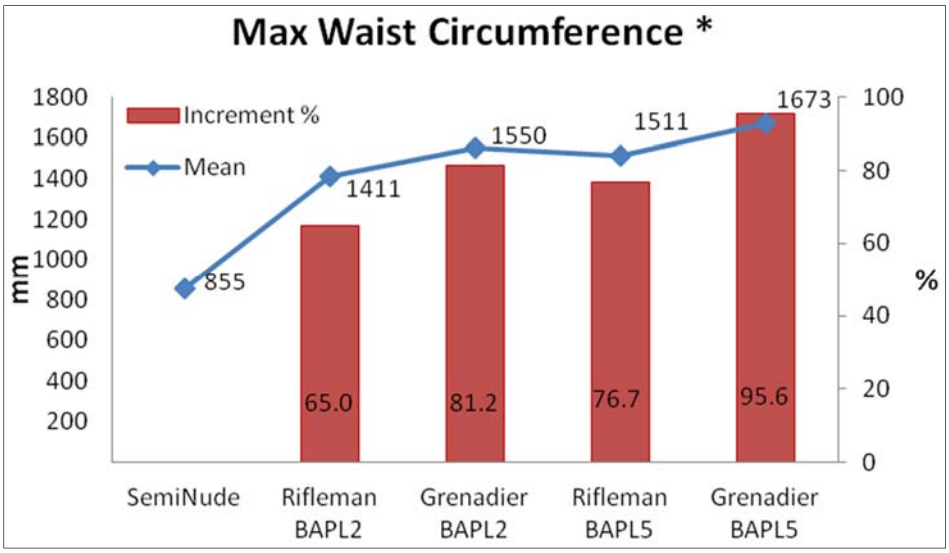
MAX Waist Circumference is the Maximum Waist Circumference taken around the torso while the TP is wearing CIE and in the Anthropometric Standing position. The measurement is obtained by taking the greatest horizontal Circumference at the Waist level region as visually assessed and landmarked at MAX Waist Height. The measurer takes care not to compress the CIE. As there is no Semi-Nude measurement linked to this measurement, the Semi-Nude Waist Circumference at Omphalion was used as a close surrogate for calculating deltas.

A repeated measures ANOVA was performed on the deltas to compare them among the four loaded configurations. The results are listed in Table 27 and shown graphically with percent increments between configurations in Figure 80. The configurations were significantly different, $F(3, 90)=545.47$, $p<.01$. All four were different from one another. The 5G (M=818.0 mm) was the largest configuration, followed by the 2G (M=694.9 mm), 5R (M=655.7 mm), and 2R (M=556.1 mm), $p<.05$. Regardless of BAPL, both Grenadier configurations were greater than the Rifleman configurations, and both BAPL 5 configurations were greater than both BAPL 2 configurations within the same duty positions (i.e., 5R > 2R and 5G > 2G).

Table 27: Summary statistics and mean deltas for MAX Waist Circumference relative to Semi-Nude Waist Circumference for each configuration

	Semi-Nude (mm)	BAPL 2 (mm)		BAPL 5 (mm)	
		Rifleman	Grenadier	Rifleman	Grenadier
Δ from Semi-Nude	-	^{D}556.1	^{B}694.9	^{C}655.7	^{A}818.0
Δ SD	-	39.4	55.8	40.0	34.2
Mean	855	1411	1550	1511	1673
SD	-	49	54	52	55
Min	-	1308	1454	1409	1581
25th	-	1376	1513	1483	1633
50th	-	1407	1550	1508	1676
75th	-	1436	1571	1539	1704
Max	-	1524	1664	1623	1777
Range	-	216	210	214	196

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



Deltas were calculated using a surrogate Semi-Nude dimension.

Figure 80: Percent increment relative to Waist Circumference at Semi-Nude and average MAX Waist Circumference for each configuration.

MAX Waist Depth

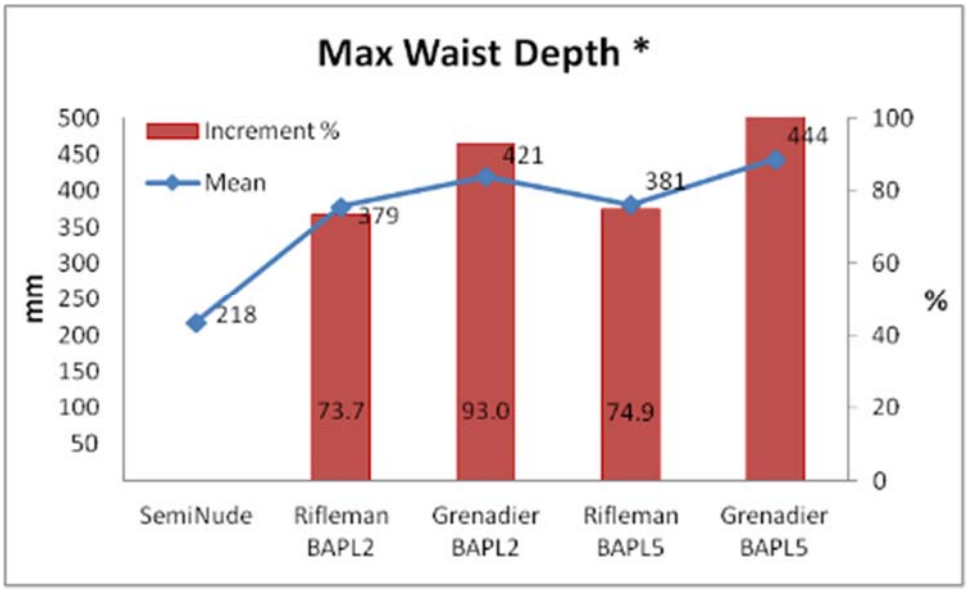
MAX Waist Depth is the maximum depth of the waist while a TP is wearing CIE in an Anthropometric Standing position. Using a beam caliper this measurement is taken at the maximum horizontal depth of the CIE as visually assessed and marked at MAX Waist Height. Measurers take care not to compress the CIE. Since there is 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 repeated measures ANOVA was performed on the deltas to compare them among the four configurations. The results are listed in Table 28 and shown graphically with percent increments between configurations in Figure 81. The configurations were significantly different, $F(3, 90)=137.27$, $p<.01$. The 5G ($M=226.46$ mm) configuration was significantly greater than the 2R ($M=160.8$ mm), 2G ($M=203.0$ mm), and 5R ($M=163.4$ mm) configurations, $p<.01$. Regardless of BAPL, both Grenadier configurations were greater than both Rifleman configurations. Within the same duty position, 5G was greater than 2G, but there was no statistical difference between the 2R and 5R configurations.

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

	Semi-Nude (mm)	BAPL 2 (mm)		BAPL 5 (mm)	
		Rifleman	Grenadier	Rifleman	Grenadier
Δ from Semi-Nude	-	^{C}160.8	^{B}203.0	^{C}163.4	^{A}226.4
Δ SD	-	23.5	17.9	18.1	19.8
Mean	218	379	421	381	444
SD	-	26	21	25	27
Min	-	299	384	334	392
25th	-	367	406	360	424
50th	-	377	422	378	434
75th	-	400	430	401	464
Max	-	415	463	427	507
Range	-	116	79	93	115

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



Deltas were calculated using a surrogate Semi-Nude dimension.

Figure 81: Percent increment relative to Semi-Nude Waist Depth and average MAX Waist Depth for each configuration

Weight With Backpack (lb)

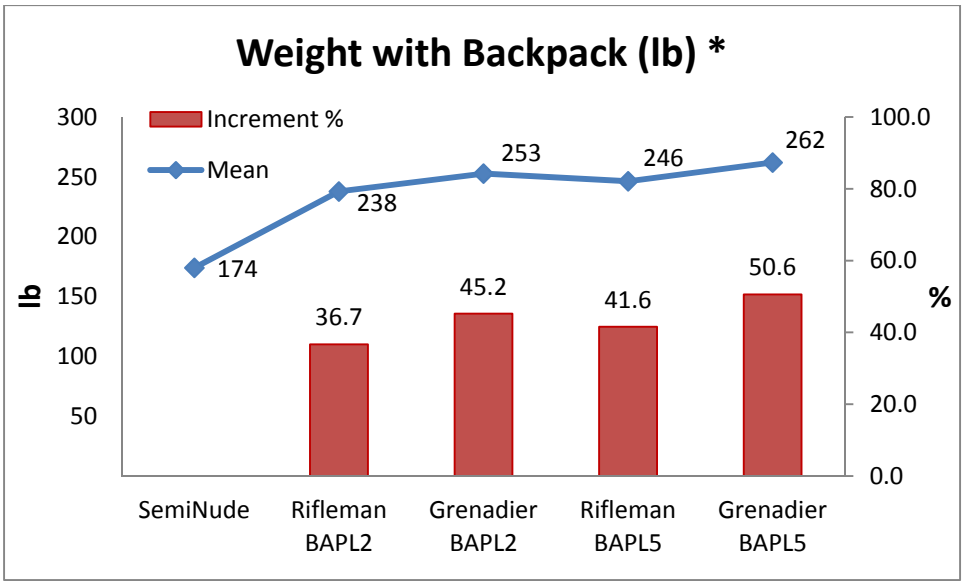
Weight with Backpack (lb) is the maximum weight of the TP while wearing a fully loaded combat assault pack in addition to CIE. The TP stands on the platform of the scale with weight distributed evenly on both feet. The measurer stands beside or in front of the TP and records the weight to the nearest $^{1}/_{10}^{th}$ lb. Weight (lb) from the Semi-Nude configuration was used as a reference point to calculate the increments caused by the CIE.

A repeated measures ANOVA was performed on the deltas to compare them among the four configurations. The results are listed in Table 29 and shown graphically with percent increments between configurations in Figure 82. The configurations were statistically different, $F(3, 90)=1175.7$, $p<.01$. All four configurations were statistically different from one another. The 5G (M=88.0 lb) configuration was the greatest difference from the Semi-Nude Weight, followed by the 2G (M=78.7 lb) configuration, the 5R (M=72.3 lb) configuration, and the 2R (M=63.8 lb), $p<.05$, respectively. Regardless of BAPL condition, the weight in both Grenadier configurations was statistically greater than for both Rifleman configurations, and the BAPL 5 configurations were greater than the BAPL 2 configurations within the same duty positions (i.e., 5R > 2R and 5G > 2G).

Table 29: Summary statistics and mean deltas for Weight (lb) with Backpack for each loaded configuration relative to Semi-Nude Weight without Backpack

	Semi-Nude	BAPL 2		BAPL 5	
		Rifleman	Grenadier	Rifleman	Grenadier
Δ from Semi-Nude	-	^{D}63.8	^{B}78.7	^{C}72.3	^{A}88.0
Δ SD	-	3.1	3.0	3.4	3.1
Mean	174	237.78	252.69	246.32	261.98
SD	-	25.25	25.66	25.90	25.88
Min	-	187.00	201.50	194.00	209.25
25th	-	216.63	231.63	222.38	238.50
50th	-	240.50	255.50	249.75	265.75
75th	-	256.25	271.88	265.88	280.63
Max	-	292.00	307.25	299.00	314.25
Range	-	105.00	105.75	105.00	105.00

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



Deltas were calculated using a Semi-Nude surrogate dimension.

Figure 82: Percent increment relative to Weight (lb) at Semi-Nude without Backpack and average Weight (lb) with Backpack for each loaded configuration

4. RANGE OF MOTION MEASUREMENTS AND RESULTS

This chapter provides a detailed description of each of the range of motion measurements, a summary of the statistical results from each measurement (including, a table of summary statistics relative to the Baseline configuration for each loaded configuration and statistically significant differences between the five test configurations and between BAPL and duty position), and the results from the subjective interference/restriction scale ratings provided by the TPs.

Each description provides details on how to complete the measurements for standardization beyond the clothing configurations used in this study. The measurement methods can be used in any evaluation regardless of the clothing configuration.

Cervical Rotation

The TP turns their head as far to the right as possible, looking over their shoulder, and then as far to the left as possible, over the other shoulder (Figure 83). The angle of the turn is measured in degrees. Note that this measurement is taken in a bent waist position, to allow the measuring device to work properly and to decrease measurer error; however, this position (while still operationally relevant for some military tasks, (i.e., scanning from a helicopter) may slightly reduce restriction from the gear.

Figure 83: Cervical Rotation

A repeated measures ANOVA was performed to examine the effect of various CIE configurations on Cervical Rotation relative to the Baseline configuration and to each of the loaded configurations. The results on the comparisons are listed in Table 30 and subjective restriction/interference ratings via frequencies and percentages for four loaded configurations are shown in Table 31. The Cervical Rotation measurements among configurations were statistically different, $F(4, 124)=9.75$, $p <.001$. As compared with the Baseline configuration (M=157.13°), the performance in four loaded configurations, 2R (M=149.21°), 2G (M=147.65°), 5R

(M=148.39°), and 5G (M=147.73°), were significantly degraded, $p<.05$. The degradation of four loaded configurations relative to Baseline were similar (5-6%) to one another with no statistical difference, $p>.05$. Given that the ACH was worn without any ancillary gear and the body armor collar was not worn with either the SPCS or the IOTV, these results indicate that the restriction in the loaded configurations was due to the ACH, as opposed to the body armor or other CIE. Thus, it is believed the restriction and limitations in TPs ability to turn their head was due to the additional weight of the helmet; the neck, which had to hold the weight, was no longer able to turn as far. This was corroborated by the TP comments.

In all four configurations, the TPs stated that the weight of the ACH made it difficult to control the movement of their heads, although the TPs were standing in a bent position, which may have affected the weight distribution of the helmet. Subjective restriction/interference ratings were generally in the "No Interference or degradation" to "Slight Interference; easily worked around" range (Table 31).

Table 30: Summary statistics for Cervical Rotation, in degrees, for each configuration

	Baseline	BAPL 2		BAPL 5	
		Rifleman	Grenadier	Rifleman	Grenadier
Mean	$^{A}157.13$	$^{B}149.21$	$^{B}147.65$	$^{B}148.39$	$^{B}147.73$
Δ from Baseline	-	7.92	9.48	8.73	9.40
Degradation of Mean	-	5%	6%	6%	6%
SD	11.92	10.55	10.84	11.22	12.71
Min	133.67	129.33	125.67	126.33	119.33
25th	147.17	141.92	140.25	139.33	140.33
50th	158.83	148.33	145.67	147.67	151.67
75th	165.58	156.17	156.08	158.75	157.08
Max	175.67	173.00	168.67	168.00	167.33

Δ from Baseline = $\bar{x}_{Baseline} - \bar{x}_{configuration}$; positive numbers indicate that TPs performed better wearing the Baseline than the loaded configuration, while negative numbers indicate that TPs performed better wearing the loaded configuration than the Baseline.

% degradation of mean = $(\bar{x}_{Baseline} - \bar{x}_{configuration)}/ \bar{x}_{Baseline})$.

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

Table 31: Frequency counts of interference/restriction scale for Cervical Rotation for each body armor configuration

Configuration	Frequency Count (and %) for Each Rating					Mean (SD)
	1	2	3	4	5	
BAPL 2: Rifleman (2R)	30 (94%)	2 (6%)	-	-	-	1.06 (0.25)
BAPL 2: Grenadier (2G)	28 (88%)	4 (13%)	-	-	-	1.13 (0.34)
BAPL 5: Rifleman (5R)	28 (88%)	3 (9%)	1 (3%)	-	-	1.16 (0.46)
BAPL 5: Grenadier (5G)	28 (88%)	4 (13%)	-	-	-	1.13 (0.34)

Percentages are rounded and may not add up to exactly 100.

Interference/restriction rating scale: 1 = No interference or degradation; 2 = Slight interference; easily worked around; 3 = Moderate interference, difficult, but able to work around; 4 = Severe interference, very difficult to work around; unacceptable; 5 = Extreme interference, unable to work around; unacceptable

Ventral-Dorsal Cervical Flexion

The TP bends the neck/chin as far forward, toward the chest, as possible and lifts the head straight back as far as possible (Figure 84). The angle of the movement is measured in degrees.

Figure 84: Ventral-Dorsal Cervical Flexion

A repeated measures ANOVA was performed to examine the effect of various CIE configurations on Vertral-Dorsal Cervical Flexion relative to the baseline configuration and to each of the loaded configurations. The results on the comparisons are listed in Table 32 and subjective restriction/interference ratings via frequencies and percentages for the four loaded configurations are shown in Table 33. The Vertral-Dorsal Cervical Flexion measurements among configurations were not statistically different, $F(4, 124)=0.85$ $p>.05$. All loaded configurations, 2R (M=123.39°), 2G (M=124.75°), 5R (M=124.14°), and 5G (M=122.02°), were not degraded relative to Baseline (M=124.76°). The difference ranged from 0-2%, with mean differences of less than 3°, $p>.05$. It should be noted that the collar was not worn with either of the body armor systems for this evaluation.

Table 32: Summary statistics for Ventral-Dorsal Cervical Flexion, in degrees, for each configuration

	Baseline	BAPL 2		BAPL 5	
		Rifleman	Grenadier	Rifleman	Grenadier
Mean	124.76	123.39	124.75	124.14	122.02
Δ from Baseline	-	1.37	0.01	0.63	2.74
Degradation of Mean	-	1%	0%	1%	2%
SD	13.71	11.21	12.97	17.04	15.73
Min	96.00	98.67	94.67	91.33	89.67
25th	115.42	119.00	116.75	115.50	112.67
50th	124.33	122.67	125.83	125.00	120.00
75th	136.17	130.00	131.33	135.17	132.33
Max	149.00	146.33	149.67	161.33	155.67

Δ from Baseline = $\bar{x}_{Baseline} - \bar{x}_{configuration}$; positive numbers indicate that TPs performed better wearing the Baseline than the loaded configuration, while negative numbers indicate that TPs performed better wearing the loaded configuration than the Baseline.

% degradation of mean = $(\bar{x}_{Baseline} - \bar{x}_{configuration})/ \bar{x}_{Baseline}$)

Subjective restriction/interference ratings were either "No interference or degradation" or "Slight interference; easily worked around" for all ratings/configurations (Table 33). Many TPs noted that the back/bottom edge of their ACH hit the back/neck soft armor or plate or that their chin hit the front plate/soft armor; however, TPs were already at or near their maximum movement so the impact on their performance was minimal.

Table 33: Frequency counts of interference/restriction scale for Ventral-Dorsal Cervical Flexion for each body armor configuration

Configuration	Frequency Count (and %) for Each Rating					Mean (SD)
	1	2	3	4	5	
BAPL 2: Rifleman (2R)	29 (91%)	3 (9%)	-	-	-	1.09 (0.30)
BAPL 2: Grenadier (2G)	28 (88%)	4 (13%)	-	-	-	1.16 (0.45)
BAPL 5: Rifleman (5R)	25 (78%)	7 (22%)	-	-	-	1.21 (0.42)
BAPL 5: Grenadier (5G)	25 (78%)	7 (22%)	-	-	-	1.21 (0.42)

Percentages are rounded and may not add up to exactly 100.

Interference/restriction Rating Scale: 1 = No interference or degradation; 2 = Slight interference; easily worked around; 3 = Moderate interference, difficult, but able to work around; 4 = Severe interference, very difficult to work around; unacceptable; 5 = Extreme interference, unable to work around; unacceptable

Thoracic/Lumbar Spine Rotation

The TP sits on a backless stool, with arms crossed against the chest, and twists or rotates at the waist and shoulders (not hips or legs) as far to the right as possible and then rotates as far to the left as possible (Figure 85).

Figure 85: Thoracic/Lumbar Spine Rotation

A repeated measures ANOVA was performed to examine the effect of various CIE configurations on Thoracic/Lumbar Spine Rotation relative to the Baseline configuration and to the loaded configurations. The results of the comparisons are listed in Table 34 and subjective restriction/interference ratings via frequencies and percentages for the four loaded configurations are shown in Table 35. There was a statistical difference for the Thoracic/Lumbar Spine Rotation measurements, $F(4, 124) = 15.93$, $p < .001$. Relative to the Baseline configuration ($M=126.06°$), TP performance in all four loaded configurations was significantly degraded from the Baseline, ranging from 13-22%, $p<.05$. The degradation in the 5R ($M=101.28°$) and 5G ($M=98.77°$) configurations were significantly worse than the 2R ($M=110.20°$) configuration, $p<.05$, but neither one was statistically different from the 2G ($M=106.62°$) configuration, $p>.05$. There were no statistical differences between the Rifleman and Grenadier configurations within the same BAPL (i.e., between 2R and 2G and between 5R and 5G).

Additionally, comparisons between BAPL 2 and BAPL 5, and between Rifleman and Grenadier, were performed with collapsed scores for each BAPL and duty position to determine the overall difference between BAPLs and duty positions. TP performance was further degraded in BAPL5 ($M=100.03°$) relative to BAPL2 ($M=108.42°$), $F(1, 31)=11.26$, $p<.01$, and in Grenadier ($M=102.07°$) relative to Rifleman ($M=105.75°$) duty position, $F(1,31)=4.58$, $p<.05$. Thus, performance degradation in Thoracic/Lumbar Spine Rotation is related to both BAPL and duty position.

Table 34: Summary statistics for Thoracic/Lumbar Spine Rotation, measured in degrees, for each configuration

	Baseline	BAPL 2		BAPL 5	
		Rifleman	Grenadier	Rifleman	Grenadier
Mean	[A]126.06	[B]110.20	[BC]106.62	[C]101.28	[C]98.77
Δ from Baseline	-	15.85	19.44	24.78	27.29
% Degradation of Mean	-	13%	15%	20%	22%
SD	14.39	20.15	18.52	17.00	17.43
Min	93.67	65.67	70.33	73.67	60.00
25th	115.42	101.33	97.08	91.58	89.58
50th	124.83	108.17	106.50	99.00	99.83
75th	138.42	125.58	113.75	107.50	107.00
Max	157.00	150.67	147.67	144.33	140.00

Δ from Baseline" = $\bar{x}_{Baseline} - \bar{x}_{configuration}$; positive numbers indicated that TPs performed better wearing the Baseline than the loaded configuration, while negative numbers indicate that TPs performed better wearing the loaded configuration than the Baseline.

"% degradation of Mean" = $(\bar{x}_{Baseline} - \bar{x}_{configuration)} / \bar{x}_{Baseline})$

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

As shown in Table 35, TP mean subjective ratings for both BAPL 2 configurations (2R and 2G) for this movement ranged from "No interference or degradation" to "Slight interference; easily worked around." Ratings for the BAPL 5 configurations were slightly higher. There were four ratings of "Severe interference, very difficult to work around; unacceptable" for configuration 5R and there was one rating of "Severe interference, very difficult to work around; unacceptable" and one rating of "Extreme interference, very difficult to work around; unacceptable" for 5G.

Table 35: Frequency counts of interference/restriction scale for Thoracic/Lumbar Spine Rotation for each body armor configuration

Configuration	Frequency Count (and %) for each Rating					Mean (SD)
	1	2	3	4	5	
BAPL 2: Rifleman (2R)	19 (59%)	12 (38%)	1 (3%)	-	-	1.44 (0.56)
BAPL 2: Grenadier (2G)	17 (53%)	12 (38%)	3 (9%)	-	-	1.56 (0.67)
BAPL 5: Rifleman (5R)	9 (28%)	14 (44%)	5 (16%)	4 (13%)	-	2.12 (0.98)
BAPL 5: Grenadier (5G)	4 (13%)	16 (50%)	10 (31%)	1 (3%)	1 (3%)	2.34 (0.87)

Percentages are rounded and may not add up to exactly 100.

Interference/restriction rating scale: 1 = No interference or degradation; 2 = Slight interference; easily worked around; 3 = Moderate interference, difficult, but able to work around; 4 = Severe interference, very difficult to work around; unacceptable; 5 = Extreme interference, unable to work around; unacceptable

Comments about the interference and restriction with configuration 2R included:

- Equipment (i.e., IFAK, M67 grenade, TAP) dragged across thighs or caught on thighs/hips as the TP turned.

- Body armor system (soft armor or front plate) dragged across thighs or caught on thighs/hips as the TP turned.
- Weight restricted turning motion.
- Compression of the armor system and/or rigidity of the plate restricted torso movement.

TP comments regarding configuration 2G included all those listed for 2R plus additional comments regarding the HE/DP grenades dragging across thighs or catching on thighs/hips as the TP turned. While TPs also noted the impact of weight on their ability to turn for both BAPL 2 configurations, it was noted more frequently in regard to configuration 2G then it was for 2R.

TP comments regarding configuration 5R included all those listed for 2R plus comments regarding the side plate catching on the TP's thighs/hips. There were more comments regarding the TAP and equipment hitting TPs' legs in the 5R configuration than with 2R. TP comments regarding 5G included all of the topics, as well as the increased focus on weight that was seen with the 2G comments. One TP stated "just everything is in the way." It should be noted that those TPs who did not have ideal fits in the body armor (i.e., either the armor was too long or the armor could not be tightened as much as desired) had a more difficult time performing this movement than those with better fits; this was especially true with BAPL 5, for which the XS was still somewhat loose and the length (in all sizes) was long on many TPs.

Thoracic/Lumbar Spine Lateral Flexion

The TP stands up straight, with their back against a wall, and a height measurement is taken at the bottom of the longest finger (Figure 86, left). The TP then leans to the side, sliding their hand down the side of the leg as far as possible, and a second measurement is taken at this point (Figure 86, right). A delta can be calculated, or the measurement from the floor for the max reach can be used.

Figure 86: Thoracic/Lumbar Spine Lateral Flexion

A repeated measures ANOVA was performed to examine the effect of various CIE configurations on Thoracic/Lumbar Spine Lateral Flexion relative to the baseline configuration and to each of the loaded configurations. The results are listed in Table 36 and subjective restriction/interference ratings via frequencies and percentages for the four loaded configurations are shown in Table 37. The Thoracic/Lumbar Spine Lateral Flexion measurements among configurations were statistically different, $F(4, 124)=22.52$, $p < .001$. For the purpose of this report, only the distance from the floor measurement was used for comparison. Thus, smaller heights off the floor indicate better reach performance. Relative to the Baseline (M=441.65 mm), the 5R and 5G configurations (M=473.17 mm, and M=483.22 mm, respectively) were significantly degraded, $p<.05$, while the 2R and 2G configurations (M=442.29 mm, and

M=449.08 mm, respectively) were not, p>.05. There were no statistical differences between the Rifleman and Grenadier configurations within the same BAPL (i.e., between 2R and 2G and between 5R and 5G), but there were significant differences within the same duty position for the different BAPLs; i.e., both BAPL 5 configurations were significantly worse than the BAPL 2 configurations for their respective positions.

Additionally, comparisons between BAPL 2 and BAPL 5, and between the Rifleman and Grenadier duty positions were performed with collapsed scores for each BAPL and duty position to determine the overall difference between BAPLs and duty positions. TP performance was significantly more degraded in BAPL 5 (M=478.19 mm) relative to BAPL 2 (M=445.69 mm), $F(1, 31)=51.11$, $p<.01$, and in Grenadier (M=466.15 mm) relative to Rifleman (M=457.73 mm) duty position, $F(1, 31)=7.51$, $p<.01$. Thus, both BAPL and duty position affected the performance degradation in the Thoracic/Lumbar Spine Lateral Flexion movement.

Table 36: Summary statistics for Thoracic/Lumbar Spine Lateral Flexion, in mm, for each configuration (height off floor)

	Baseline	BAPL 2		BAPL 5	
		Rifleman	Grenadier	Rifleman	Grenadier
Mean	^{B}441.65	^{B}442.29	^{B}449.08	^{A}473.17	^{A}483.22
Δ from Baseline	-	0.65	7.44	31.52	41.57
% Degradation of Mean	-	0%	2%	7%	9%
SD	47.86	48.14	49.05	47.76	54.95
Min	327.67	353.00	350.67	377.33	382.33
25th	409.25	404.58	426.92	447.67	445.17
50th	446.50	445.17	445.00	471.00	475.17
75th	473.83	471.17	474.67	496.17	511.75
Max	545.33	554.67	602.33	615.67	624.33

Reminder: Smaller heights off the floor indicate better reach performance
Δ from Baseline = $\bar{x}_{Baseline} - \bar{x}_{configuration}$; positive numbers indicated that TPs performed better wearing the Baseline than the loaded configuration, while negative numbers indicate that TPs performed better wearing the loaded configuration than the Baseline.
% degradation of Mean = $(\bar{x}_{Baseline} - \bar{x}_{configuration)/} \bar{x}_{Baseline})$
A>B, Superscripts of different letters indicate significant differences at the p<.05 level.

As shown in Table 37, over 50% of subjective ratings for both 2R and 2G were "No interference or degradation." Those TPs who experienced interference/restriction commented that it was due to the corner of the TAP and/or the side of the soft armor digging into their waist. With 5G and 5R the primary comments TPs gave were related to discomfort and interference caused by the side plates. It varied as to how the side plates caused discomfort. While it was primarily the right side plate (the side the TP was bending on), some TPs felt discomfort on the left side (in the ribs/ top edge of the side plate). With regard to the right side plate, TPs felt discomfort from the top edge (their ribs) and the bottom edge, where the plate would dig into their waist.
Both 5R and 5G had mean subjective ratings between "Slight interference; easily worked around" and "Moderate interference, difficult, but able to work around" with three TPs rating it as either "Severe" or "Extreme."

Table 37: Frequency counts of interference/restriction scale for Thoracic/Lumbar Spine Lateral Flexion movement for each body armor configuration

Configuration	Frequency Count (and %) for each Rating					Mean (SD)
	1	2	3	4	5	
BAPL 2: Rifleman (2R)	20 (63%)	12 (38%)	-	-	-	1.37 (0.49)
BAPL 2: Grenadier (2G)	17 (53%)	11 (34%)	4 (13%)	-	-	1.59 (0.71)
BAPL 5: Rifleman (5R)	5 (16%)	13 (41%)	11 (34%)	2 (6%)	1 (3%)	2.41 (0.95)
BAPL 5: Grenadier (5G)	5 (16%)	11 (34%)	13 (41%)	3 (9%)	-	2.43 (0.88)

Percentages are rounded and may not add up to exactly 100.

Interference/Restriction Rating Scale: 1 = No interference or degradation; 2 = Slight interference; easily worked around; 3 = Moderate interference, difficult, but able to work around; 4 = Severe interference, very difficult to work around; unacceptable; 5 = Extreme interference, unable to work around; unacceptable

Upper-Arm/Shoulder Abduction

The TP stands with chest and/or toes lightly touching a cabinet or wall in front of him. Both arms start at the TP's side, with palms facing inward toward the thighs. Both arms are raised out to the side and over the head without bending the elbows or wrists (Figure 87). Arms remain in the sagittal plane with the body and do not move forward or backward.

Figure 87: Upper-Arm/Shoulder Abduction

A repeated measures ANOVA was performed to examine the effect of various CIE configurations on Upper-Arm/Shoulder Abduction relative to the baseline configuration and to each of the loaded configurations. The results are listed in Table 38 and subjective restriction/interference ratings via frequencies and percentages for the four loaded configurations are shown in Table 39. The Upper-Arm/Shoulder Abduction measurements among the loaded configurations were statistically different, $F(4, 124) = 32.72$, $p < .001$. TPs were able to lift their arms significantly higher in the Baseline (M=163.69°) configuration than they were with any of the loaded configurations, 2R (M=151.82°), 2G (M=148.72°), 5R (M=147.91°), and 5G (M=140.98°), $p<.05$. The performance in 5G was further degraded than 2R, 2G and 5R, $p<.05$

Additionally, comparisons between BAPL 2 and BAPL 5, and between the Rifleman and Grenadier duty positions were performed with collapsed scores for each BAPL and duty position to determine the overall difference between BAPLs and duty positions. TP performance was significantly more degraded in BAPL 5 (M=144.44°) relative to BAPL 2 (M=150.27°), $F(1, 31)=6.45$, $p<.05$, and in the Grenadier duty position (M=144.85°) relative to the Rifleman duty position (M=149.87°), $F(1, 31)=33.99$, $p<.05$. Again, both BAPL and duty position affected the performance degradation in Upper-Arm/Shoulder Abduction.

Table 38: Summary statistics for Upper-Arm/Shoulder Abduction, in degrees, for each configuration

	Baseline	BAPL 2		BAPL 5	
		Rifleman	Grenadier	Rifleman	Grenadier
Mean	^{A}163.69	^{B}151.82	^{B}148.72	^{B}147.91	^{C}140.98
Δ from Baseline	-	11.87	14.97	15.78	22.71
% Degradation of Mean	-	7%	9%	10%	14%
SD	8.76	13.30	14.24	14.16	15.16
Min	145.67	127.33	122.33	114.00	114.33
25th	157.00	142.25	138.08	141.08	133.50
50th	163.67	150.50	149.17	147.00	139.50
75th	171.08	164.83	160.83	159.75	150.92
Max	178.67	173.00	174.67	177.33	171.00

Δ from Baseline = $\bar{x}_{Baseline} - \bar{x}_{configuration}$; positive numbers indicated that TPs performed better wearing the Baseline than the loaded configuration, while negative numbers indicate that TPs performed better wearing the loaded configuration than the Baseline.

"% degradation of Mean" = $(\bar{x}_{Baseline} - \bar{x}_{configuration)}/ \bar{x}_{Baseline})$

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

The subjective ratings followed the same trend as the measurement statistics. In configuration 5G, TPs reported significantly greater restriction and interference than in any of the other configurations (Table 39). Comments describing the restriction felt were primarily related to the shoulder straps; TPs commented that the strap of the armor dug into either their shoulder muscle or the side of their neck. The shoulder strap created more interference/restriction with the BAPL 5 configurations than the BAPL 2 configurations. A few TPs also commented that the weight of configuration 5G restricted and interfered with their ability to lift their arms.

Table 39: Frequency counts of the interference/restriction scale for Upper-Arm/ Shoulder Abduction for each body armor configuration

Configuration	Frequency Count (and %) for each Rating					Mean (SD)
	1	2	3	4	5	
BAPL 2: Rifleman (2R)	14 (44%)	17 (53%)	1 (3%)	-	-	1.59 (0.56)
BAPL 2: Grenadier (2G)	13 (41%)	16 (50%)	3 (9%)	-	-	1.69 (0.64)
BAPL 5: Rifleman (5R)	6 (19%)	20 (63%)	6 (19%)	-	-	2.00 (0.62)
BAPL 5: Grenadier (5G)	3 (9%)	23 (72%)	4 (13%)	2 (6%)	-	2.16 (0.68)

Percentages are rounded and may not add up to exactly 100.

Interference/ Restriction Rating Scale: 1 = No interference or degradation; 2 = Slight interference; easily worked around; 3 = Moderate interference, difficult, but able to work around; 4 = Severe interference, very difficult to work around; unacceptable; 5 = Extreme interference, unable to work around; unacceptable

Upper Arm/Shoulder Overhead Fingertip Reach, Extended

The TP stands with toes 20 cm away from the wall and reaches as high overhead as possible, leaning against the wall (Figure 88). Measurement is taken from the tip of the longest finger.

Figure 88: Overhead Fingertip Reach

A repeated measures ANOVA was performed to examine the effect of various CIE configurations on Upper Arm/Shoulder Overhead Fingertip Reach relative to the baseline configuration and to each of the loaded configurations. The results are listed in Table 40 and subjective restriction/interference ratings via frequencies and percentages for the four loaded configurations are shown in Table 41. The Upper Arm/Shoulder Overhead Fingertip Reach measurements were statistically different between configurations, $F(4, 124) = 44.32$, $p < .001$. Mean reaches at Baseline (M=2273.38 mm) were significantly higher than all the loaded configurations, $p<.05$. There was a statistical difference between Rifleman and Grenadier configurations within the same BAPL where the 2R (M=2253.29 mm) performed significantly better than 2G (M=2239.49 mm), and 5R (M=2246.14 mm) was significantly better than 5G (M=2231.47 mm), $p<.05$. Within the same Rifleman duty position, the performance in BAPL 2 was better than in BAP L5 configurations, $p<.05$. The difference between 2G and 5G was not statistically significant, but was approaching significance, $p=.10$.

Additionally, comparisons between BAPL 2 and BAPL 5, and between the Rifleman and Grenadier duty positions were performed with collapsed scores for each BAPL and duty position to determine the overall difference between BAPLs and duty positions. The highest performance degradation was seen with the Grenadier duty load (M=2238.48 mm) as opposed to the Rifleman duty load (M=2249.71 mm), $F(1, 31)=135.54$, $p<.01$, and with BAPL 5 (M=2238.80 mm) as opposed to BAPL 2 (M=2246.39 mm), $F(1, 31)=11.43$, $p<.01$. Again, both BAPL and duty position affected the performance degradation in Upper Arm/Shoulder Overhead Fingertip Reach.

Table 40: Summary statistics for Overhead Fingertip Reach, in mm, for each configuration

	Baseline	BAPL 2		BAPL 5	
		Rifleman	Grenadier	Rifleman	Grenadier
Mean	^{A}2273.38	^{B}2253.29	^{D}2239.49	^{C}2246.14	^{D}2231.47
Δ from Baseline	-	20.08	33.89	27.24	41.91
% Degradation of Mean	-	1%	1%	1%	2%
SD	119.14	121.01	122.52	122.06	120.99
Min	2029.67	2013.67	1990.00	2007.33	1997.00
25th	2195.92	2175.67	2159.00	2169.17	2157.25
50th	2288.50	2278.67	2259.83	2261.67	2248.17
75th	2357.08	2338.17	2330.92	2326.92	2304.58
Max	2509.33	2497.67	2491.33	2492.33	2479.00

Δ from Baseline = $\bar{x}_{Baseline} - \bar{x}_{configuration}$; positive numbers indicated that TPs performed better wearing the Baseline than the loaded configuration, while negative numbers indicate that TPs performed better wearing the loaded configuration than the Baseline.

% degradation of Mean = $(\bar{x}_{Baseline} - \bar{x}_{configuration)/} \bar{x}_{Baseline})$

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

The subjective ratings followed this same trend as the measurement statistics, although mean ratings for all four configurations were below "Slight interference; easily worked around" (Table 41). Comments regarding the restriction noted that it was primarily due to the shoulder straps digging into either the shoulder muscle or the side of their neck.

Table 41: Frequency counts of the interference/restriction scale for Overhead Fingertip Reach for each body armor configuration

Configuration	Frequency Count (and %) for each Rating					Mean (SD)
	1	2	3	4	5	
BAPL 2: Rifleman (2R)	22 (69%)	9 (28%)	1 (3%)	-	-	1.34 (0.55)
BAPL 2: Grenadier (2G)	12 (38%)	20 (63%)	-	-	-	1.63 (0.49)
BAPL 5: Rifleman (5R)	15 (47%)	15 (47%)	2 (6%)	-	-	1.59 (0.61)
BAPL 5: Grenadier (5G)	9 (28%)	21 (66%)	1 (3%)	1 (3%)	-	1.84 (0.77)

*Percentages are rounded and may not add up to exactly 100.

Interference/ Restriction Rating Scale: 1 = No interference or degradation; 2 = Slight interference; easily worked around; 3 = Moderate interference, difficult, but able to work around; 4 = Severe interference, very difficult to work around; unacceptable; 5 = Extreme interference, unable to work around; unacceptable

Upper Arm/Shoulder Forward Flexion Extension

The TP stands facing a cabinet or wall with chest and/or toes lightly touching the structure. Both arms start at the TP's side with palms facing back. The TP raises their hands in front without widening or narrowing the arm span (as best as can be done around the equipment being worn) (Figure 89). Elbows and wrists remain straight.

Figure 89: Upper Arm/Shoulder Forward Flexion Extension

A repeated measures ANOVA was performed to examine the effect of various CIE configurations on Upper Arm/ Shoulder Forward Flexion Extension relative to the baseline configuration and to each of the loaded configurations. The results are listed in Table 42 and subjective restriction/interference ratings via frequencies and percentages for the four loaded configurations are shown in Table 43. The Upper Arm/Shoulder Forward Flexion Extension measurements among configurations were statistically different, $F(4, 124) = 15.82$, $p < .001$. Significant performance degradations were seen for all loaded configurations when compared to the baseline (M=165.41°). There were no statistical differences between the TP performances for 2R (M=159.85°), 2G (M=157.21°), and 5R (M=158.45°), $p > .05$. The TPs performance was statistically more degraded for the 5G (M=153.71°) configuration compared to the 2R and 5R configurations, $p < .05$.

Additionally, comparisons between BAPL 2 and BAPL 5, and between the Rifleman and Grenadier duty positions were performed with collapsed scores for each BAPL and duty position to determine the overall difference between BAPLs and duty positions. TP performance was significantly further degraded in BAPL 5 (M=156.08°) relative to BAPL 2 (M=158.53°), $F(1, 31)=4.51$, $p<.05$, and in Grenadier (M=155.46°) relative to the Rifleman (M=159.15°) duty position, $F(1, 31)=19.70$, $p<.01$. Thus, both BAPL and duty position affected the performance degradation in Upper Arm/ Shoulder Forward Flexion Extension.

Table 42: Summary statistics for Upper Arm/Shoulder Forward Flexion Extension, in degrees, for each configuration

	Baseline	BAPL 2		BAPL 5	
		Rifleman	Grenadier	Rifleman	Grenadier
Mean	^{A}165.41	^{B}159.85	^{BC}157.21	^{B}158.45	^{C}153.71
Δ from Baseline	-	5.55	8.20	6.96	11.70
% Degradation of Mean	-	3%	5%	4%	7%
SD	8.95	10.78	9.54	10.03	10.87
Min	143.33	138.00	136.67	130.67	128.33
25th	158.17	151.33	152.17	153.08	147.92
50th	166.67	160.00	157.83	160.67	155.00
75th	171.42	169.50	162.50	165.17	163.00
Max	178.00	176.67	173.67	175.67	168.33

Δ from Baseline = $\bar{x}_{Baseline} - \bar{x}_{configuration}$; positive numbers indicated that TPs performed better wearing the Baseline than the loaded configuration, while negative numbers indicate that TPs performed better wearing the loaded configuration than the Baseline.
"% degradation of Mean" = $(\bar{x}_{Baseline} - \bar{x}_{configuration)}/ \bar{x}_{Baseline})$
A>B>C, Superscripts of different letters indicate significant differences at the $p<.05$ level.

As shown in Table 43, all the TPs rated the interference/restriction caused by both of the Rifleman configurations as either "No interference or degradation" or "Slight interference; easily worked around." The Grenadier configurations received a small number of ratings of "Moderate interference, difficult, but able to work around" or greater. TPs commented that the strap of the armor dug into either their shoulder muscle or the side of their neck. Many TPs also noted that they had to move their arms wide due to the M67 grenade, IFAK, or the TAP.

Table 43: Frequency counts of the interference/restriction scale for the Upper Arm/ Shoulder Forward Flexion Extension movement for each body armor configuration

Configuration	Frequency Count (and %) for each Rating					Mean (SD)
	1	2	3	4	5	
BAPL 2: Rifleman (2R)	16 (50%)	16 (50%)	-	-	-	1.50 (0.51)
BAPL 2: Grenadier (2G)	11 (34%)	16 (50%)	5 (16%)	-	-	1.81 (0.69)
BAPL 5: Rifleman (5R)	13 (41%)	19 (59%)	-	-	-	1.59 (0.50)
BAPL 5: Grenadier (5G)	11 (34%)	19 (59%)	1 (3%)	1 (3%)	-	1.78 (0.79)

Percentages are rounded and may not add up to exactly 100.

Interference/ Restriction Rating Scale: 1 = No interference or degradation; 2 = Slight interference; easily worked around; 3 = Moderate interference, difficult, but able to work around; 4 = Severe interference, very difficult to work around; unacceptable; 5 = Extreme interference, unable to work around; unacceptable

Upper Arm/Shoulder Forward Extended Reach

The TP stands with their heels 20 cm from a wall, while leaning their back against the wall. The TP reaches forward as far as possible with their right arm, fingers outstretched (Figure 90). TPs may lift their right shoulder off the wall, but the center of the back and left shoulder must stay touching the wall. A bulk measurement of 32 mm for the BAPL 2 and 44 mm for the BAPL 5 was subtracted from the reach distance to account for the additional stand-off from the wall created by wearing the armor systems. These measurements were taken using a caliper, measuring the thickness of the body armor system at the middle of the upper half of the back, to account for movement forward from where the TP leaned against the wall. No differences were found based on different sizes of armor, so a standard amount for each system was subtracted.

Figure 90: Upper Arm/Shoulder Forward Extended Reach

A repeated measures ANOVA was performed to examine the effect of various CIE configurations on Upper Arm/Shoulder Forward Extended Reach relative to the baseline configuration and to each of the loaded configurations. The results are listed in Table 44 and subjective restriction/interference ratings in frequencies and percentages for the four loaded configurations are shown in Table 45. The Upper Arm/ Shoulder Forward Extended Reach measurements among configurations were statistically different, $F(4, 124) = 12.52$, $p < .001$. Relative to the Baseline (M=999.38 mm) configuration, TP reach performance was statistically degraded in 2G (M=983.69 mm), 5R (M=974.15 mm) and 5G (M=966.44 mm), $p<.05$, but not significantly degraded in 2R (M=990.05 mm), $p>.05$. There were no statistical differences between the Rifleman and Grenadier configurations within the same BAPL (i.e., between 2R and 2G and between 2R and 5G), but within the same duty position, both BAPL 5 configurations were always significantly more degraded than the BAPL 2 configurations for their respective positions. It should be noted that in 2R, TPs were able to reach significantly farther than in either of the BAPL 5 configurations. Moreover, the reach with 5G was significantly shorter than any of the BAPL 2 configurations.

Comparisons between BAPL 2 and BAPL 5, and between the Rifleman and Grenadier duty positions were performed with collapsed scores for each BAPL and duty position to determine the overall difference between BAPLs and duty positions. TP performance was significantly further degraded in BAPL 5 (M=970.29 mm) relative to BAPL 2 (M=986.87 mm), $F(1, 31)=20.92$, $p<.01$, and in Grenadier (M=975.06 mm) relative to Rifleman (M=982.20 mm) duty position, $F(1, 31)=11.58$, $p<.01$. Thus, both BAPL and duty position affected the performance in Upper Arm/Shoulder Forward Extended Reach.

Table 44: Summary statistics for Upper Arm/Shoulder Forward Extended Reach, measured in mm, for each body armor configuration

	Baseline	BAPL 2		BAPL 5	
		Rifleman	Grenadier	Rifleman	Grenadier
Mean	^{A}999.38	^{AB}990.05	^{BC}983.69	^{CD}974.15	^{D}966.44
Δ from Baseline	-	9.32	15.69	25.23	32.94
% Degradation of Mean	-	1%	2%	2.5%	3.3%
SD	51.43	56.37	58.53	53.81	54.80
Min	902.00	881.00	879.00	877.00	869.33
25th	952.67	945.50	942.33	929.92	929.33
50th	998.33	991.83	978.83	959.00	958.83
75th	1042.92	1028.17	1023.08	1025.00	1018.00
Max	1108.33	1104.67	1125.67	1096.00	1075.00

Δ from Baseline = $\bar{x}_{Baseline} - \bar{x}_{configuration}$; positive numbers indicated that TPs performed better wearing the Baseline than the loaded configuration, while negative numbers indicate that TPs performed better wearing the loaded configuration than the Baseline.

"% degradation of Mean" = $(\bar{x}_{Baseline} - \bar{x}_{configuration)}/ \bar{x}_{Baseline})$

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

All four loaded configurations received subjective ratings of "No interference or degradation" by almost all of the TPs (Table 45). Only one TP rated the movement as having more than "Slight

interference; easily worked around," and that was only for configuration 5G. TP comments focused primarily on restriction of the shoulder straps, which dug into their shoulder or neck, and their shoulder rubbing against the scye (or arm hole opening) of the body armor vest.

Table 45: Frequency counts of interference/restriction scale for Upper Arm/Shoulder Forward Extended Reach for each body armor configuration

Configuration	Frequency Count (and %) for each Rating					Mean (SD)
	1	2	3	4	5	
BAPL 2: Rifleman (2R)	27 (84%)	5 (16%)	-	-	-	1.16 (0.37)
BAPL 2: Grenadier (2G)	22 (69%)	10 (31%)	-	-	-	1..31 (0.47)
BAPL 5: Rifleman (5R)	21 (66%)	11 (34%)	-	-	-	1.34 (0.48)
BAPL 5: Grenadier (5G)	19 (59%)	12 (38%)	1 (3%)	-	-	1.44 (0.56)

Percentages are rounded and may not add up to exactly 100.

Interference/ Restriction Rating Scale: 1 = No interference or degradation; 2 = Slight interference; easily worked around; 3 = Moderate interference, difficult, but able to work around; 4 = Severe interference, very difficult to work around; unacceptable; 5 = Extreme interference, unable to work around; unacceptable

Upper Arm/Shoulder Backward Extension

The TP stands facing a cabinet or wall with chest and/or toes lightly touching it. Both arms start at the TP's side. The TP turns their right palm so it faces outward and their thumb points behind them. The TP then raises their arm straight back, keeping their elbow and wrist straight (Figure 91).

Figure 91: Upper Arm/Shoulder Backward Extension

A repeated measures ANOVA was performed to examine the effect of various CIE configurations on Upper Arm/ Shoulder Backward Extension relative to the baseline configuration and to each of the loaded configurations. The results are listed in Table 46 and subjective restriction/interference ratings via frequencies and percentages for the four loaded configurations are shown in Table 47. The Upper Arm/Shoulder Backward Extension measurements among configurations were not statistically different, $F(4, 124) = 0.542$, $p > .05$. All loaded configurations, 2R (M=41.68°), 2G (M=42.66°), 5R (M=41.94°), and 5G (M=41.41°), were not degraded relative to the Baseline (M=41.52°) and ranged from 0-3% performance difference, with mean differences of less than 2°.

Table 46: Summary statistics for Upper Arm/Shoulder Backward Extension, in degrees, for each configuration

	Baseline	BAPL 2		BAPL 5	
		Rifleman	Grenadier	Rifleman	Grenadier
Mean	41.52	41.68	42.66	41.94	41.41
Δ from Baseline	-	-0.16	-1.14	-0.42	0.12
% Degradation of Mean	-	0%	3%	1%	0%
SD	6.60	6.52	6.47	6.16	6.14
Min	26.00	29.67	28.00	29.67	29.67
25th	39.00	38.17	39.58	39.17	37.83
50th	42.67	40.83	42.50	42.83	40.67
75th	46.67	45.58	46.17	45.58	44.50
Max	50.33	55.00	55.33	55.00	52.33

Δ from Baseline = $\bar{x}_{Baseline} - \bar{x}_{configuration}$; positive numbers indicated that TPs performed better wearing the Baseline than the loaded configuration, while negative numbers indicate that TPs performed better wearing the loaded configuration than the Baseline.

% degradation of Mean = $(\bar{x}_{Baseline} - \bar{x}_{configuration)} / \bar{x}_{Baseline})$

Subjective ratings were generally very positive, with over 70% of TPs giving the rating of "No interference or degradation" for all four loaded configurations (Table 47). Comments were generally related to the shoulder strap rubbing against the shoulder socket, neck or the TP having some resistance at the scapula, either from the soft armor or the back plate.

Table 47: Frequency counts of interference/restriction scale for Upper Arm/ Shoulder Backward Extension for each body armor configuration

Configuration	Frequency Count (and %) for each Rating					Mean (SD)
	1	2	3	4	5	
BAPL 2: Rifleman (2R)	29 (91%)	3 (9%)	-	-	-	1.10 (0.30)
BAPL 2: Grenadier (2G)	26 (81%)	6 (19%)	-	-	-	1.19 (0.40)
BAPL 5: Rifleman (5R)	24 (75%)	7 (22%)	1 (3%)	-	-	1.28 (0.52)
BAPL 5: Grenadier (5G)	23 (72%)	7 (22%)	2 (6%)	-	-	1.34 (0.60)

Percentages are rounded and may not add up to exactly 100.

Interference/ Restriction Rating Scale: 1 = No interference or degradation; 2 = Slight interference; easily worked around; 3 = Moderate interference, difficult, but able to work around; 4 = Severe interference, very difficult to work around; unacceptable; 5 = Extreme interference, unable to work around; unacceptable

Upper Arm/Shoulder Cross Body Reach

The TP sits approximately 20 cm away from a wall (a block can be used to keep back a consistent distance). The TP reaches over their left shoulder with their right hand, keeping their hand fully extended, attempting to reach the wall behind them (Figure 92). The distance between the wall and the TP's longest fingertip is measured. A bulk measurement is subtracted from the final measurement to account for additional distance when wearing body armor.

Figure 92: Upper Arm/Shoulder Cross Body Reach

A repeated measures ANOVA was performed to examine the effect of various CIE configurations on Upper Arm/Shoulder Cross Body Reach relative to the baseline configuration and to each of the loaded configurations. The results are listed in Table 48 and subjective restriction/interference ratings via frequencies and percentages for the four loaded configurations are shown in Table 49. The Upper Arm/Shoulder Cross Body Reach measurements among loaded configurations were statistically different, $F(4, 124) = 35.16$, $p < .001$. Larger measurement reflects increased restriction. TPs were able to reach significantly further in the Baseline (M=128.95 mm) configuration than they were in any of the loaded configurations, 2R (M=193.22 mm), 2G (201.78 mm), 5R (M=182.75 mm), and 5G (M=194.58 mm), ranged from 53-72 mm, $p<.05$. Additionally, 5R was further degraded than 2G, $p<.05$. There were no statistical differences between the duty positions within the same BAPL (i.e., between 2R and

2G and between 2R and 5G), and between the BAPLs within the same duty positions (i.e., between 2R and 5R and between 2G and 5G).

Comparisons between BAPL 2 and BAPL 5, and between the Rifleman and Grenadier duty positions were performed with collapsed scores for each BAPL and duty position to determine the overall difference between BAPLs and duty positions. The degradation of TPs performance was not statistically different between BAPL5 (M=188.67 mm) and BAPL2 (M=197.50 mm), $F(1, 31)=3.20$, $p>.05$, but was significantly worse in the (M=198.18 mm) relative to Rifleman (M=187.98 mm) duty position, $F(1, 31)=8.92$, $p<.05$. Thus, only duty position affected the performance degradation in Upper Arm/Shoulder Cross Body Reach.

Table 48: Summary statistics for Upper Arm/Shoulder Cross Body Reach, in mm, for each configuration

	Baseline	BAPL 2		BAPL 5	
		Rifleman	Grenadier	Rifleman	Grenadier
Mean	^{C}128.95	^{AB}193.22	^{A}201.78	^{B}182.75	^{AB}194.58
Δ from Baseline	-	64.27	72.83	53.80	65.64
% Degradation of Mean	-	50%	56%	42%	51%
SD	38.69	54.08	53.71	46.29	52.21
Min	50.67	113.67	96.33	90.00	99.00
25th	109.67	144.00	168.33	149.58	154.42
50th	130.50	182.67	196.33	194.00	199.67
75th	153.75	225.08	233.92	219.17	221.67
Max	210.67	318.67	303.00	250.67	317.33

Larger measurement reflects increased restriction

Δ from Baseline = $\bar{x}_{Baseline} - \bar{x}_{configuration}$; positive numbers indicated that TPs performed better wearing the Baseline than the loaded configuration, while negative numbers indicate that TPs performed better wearing the loaded configuration than the Baseline.

% degradation of Mean = $(\bar{x}_{Baseline} - \bar{x}_{configuration)}/ \bar{x}_{Baseline})$

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

Subjective mean ratings for both the BAPL 2 configurations were approaching "Slight interference, easily worked around" (Table 49). Mean ratings for the BAPL 5 configurations were just above "Slight interference, easily worked around." This was also one of the few movements that received a rating of "Extreme interference, unable to work around; unacceptable." This was by one TP and was only for configuration, 5G. Comments were focused on the shoulder strap and how it cut into their shoulder socket, bicep, armpit, and neck during the movement.

Table 49: Frequency counts of interference/restriction scale for Upper Arm/Shoulder Cross Body Reach for each body armor configuration

Configuration	Frequency Count (and %) for each Rating					Mean (SD)
	1	2	3	4	5	
BAPL 2: Rifleman (2R)	11 (34%)	16 (50%)	5 (16%)	-	-	1.81 (0.69)
BAPL 2: Grenadier (2G)	9 (28%)	16 (50%)	7 (22%)	-	-	1.94 (0.72)
BAPL 5: Rifleman (5R)	5 (16%)	19 (59%)	6 (19%)	2 (6%)		2.16 (0.77)
BAPL 5: Grenadier (5G)	6 (19%)	18 (56%)	5 (16%)	2 (6%)	1 (3%)	2.19 (0.93)

Percentages are rounded and may not add up to exactly 100.

Interference/ Restriction Rating Scale: 1 = No interference or degradation; 2 = Slight interference; easily worked around; 3 = Moderate interference, difficult, but able to work around; 4 = Severe interference, very difficult to work around; unacceptable; 5 = Extreme interference, unable to work around; unacceptable

Trunk Flexion - Standing

The TP stands on a raised platform, with their knees straight, and bends at the waist, attempting to touch the ground with arms and fingers outstretched (Figure 93). The distance between the ground and the TP's fingertips is measured. To standardize the measurement, based on any height platform, the flat portion of the platform is used as a "zero" point, and any reaches below that point are a negative number. For example, -55 mm means that the TP reached 55 mm past the platform that he/she is standing on.

Figure 93: Trunk Flexion while standing

A repeated measures ANOVA was performed to examine the effect of various CIE configurations on Trunk Flexion-Standing relative to the baseline configuration and to each of the loaded configurations. The results are listed in Table 50 and subjective restriction/interference ratings via frequencies and percentages for the four loaded configurations are shown in Subjective mean ratings for all the configurations ranged between "No interference" and "Slight interference, easily worked around" (Table 51). Both BAPL 2 configurations had over half the participants stating that there was "No interference," while configuration 5G had eight TPs rate the interference/restriction as "Moderate interference, difficult, but able to work around." Comments were focused on how the bottom edge of the body armor and gear would dig into the participants' stomachs. In some cases, especially with BAPL 5, TPs noted that the vest and gear would lift and hit their chin due to the longer length of the

body armor system. Overall, the bulk in the stomach area caused the most restriction and interference in TP movements.

Table 51. The Trunk Flexion-Standing measurements among configurations were statistically different, F (4, 124) = 9.6, p <.001. Larger measurement reflects increased restriction. There was a steady increase in restriction as additional gear and high levels of BAPL were utilized. TPs were able to reach significantly farther in the Baseline (M=-2.18 mm) configuration than they were in BAPL 5 configurations, 5R (M=42.83 mm) and 5G (M=62.42 mm), p<.05, but were not in BAPL 2 configurations, 2R (M=11.55 mm) and 2G (M=23.98 mm), p>.05. Because the SPCS (BAPL 2) is cut shorter than the IOTV (BAPL 5), it allows for more flexibility and movement at the waist, thereby allowing for significantly better performance in the BAPL 2 configurations. Both BAPL 5 configurations were always significantly more degraded than the BAPL 2 configurations for their respective positions. Furthermore, the additional HE/DP grenades placed on the front of the TAP on the Grenadier configurations interfered with the TPs' ability to bend forward. Accordingly, within the same BAPL, TP performance was further degraded in Grenadier duty position than Rifleman.

Additionally, comparisons between BAPL 2 and BAPL 5, and between the Rifleman and Grenadier duty positions were performed with collapsed scores for each BAPL and duty position to determine the overall difference between BAPLs and duty positions. TP performance was significantly further degraded in BAPL 5 (M=52.62 mm) relative to BAPL 2 (M=17.77 mm), F(1, 31)=20.12, p<.01, and in Grenadier (M=43.20 mm) relative to Rifleman (M=27.19 mm) duty position, F(1, 31)=29.81, p<.01. Thus, both BAPL and duty position affected the performance degradation in Trunk Flexion-Standing.

Table 50: Summary statistics for Trunk Flexion – Standing, in mm, for each body armor configuration

	Baseline	BAPL 2		BAPL 5	
		Rifleman	Grenadier	Rifleman	Grenadier
Mean	^{CD}-2.18	^{C}11.55	^{BD}23.98	^{B}42.83	^{A}62.42
Δ from Baseline	-	13.73	26.16	45.00	64.59
% Degradation of Mean	-	3%	7%	11%	16%
SD	89.51	97.47	90.67	102.68	104.11
Min	257.00	249.00	240.33	298.00	336.00
25th	36.75	84.92	60.25	91.33	112.67
50th	-19.67	-5.83	7.67	19.83	45.17
75th	-62.33	-48.17	-40.33	-23.00	-1.33
Max	-136.00	-143.67	-105.00	-95.00	-98.00

Note: The smaller the score/measurement, the better the performance; a score of 0 means the TP could reach to the level of the bottom of the feet; a negative score means that the TP could reach farther than the level of the bottom of the feet.

Δ from Baseline = $\bar{x}_{Baseline} - \bar{x}_{configuration}$; positive numbers indicated that TPs performed better wearing the Baseline than the loaded configuration, while negative numbers indicate that TPs performed better wearing the loaded configuration than the Baseline.

% degradation of Mean was calculated using the variance between the minimum and maximum Baseline score (257.00- (-136.00)=393) as the devisor and the delta from the Baseline as the dividend.

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

Subjective mean ratings for all the configurations ranged between "No interference" and "Slight interference, easily worked around" (Table 51). Both BAPL 2 configurations had over half the participants stating that there was "No interference," while configuration 5G had eight TPs rate

the interference/restriction as “Moderate interference, difficult, but able to work around.” Comments were focused on how the bottom edge of the body armor and gear would dig into the participants’ stomachs. In some cases, especially with BAPL 5, TPs noted that the vest and gear would lift and hit their chin due to the longer length of the body armor system. Overall, the bulk in the stomach area caused the most restriction and interference in TP movements.

Table 51: Frequency counts of interference/restriction scale for Trunk Flexion - Standing for each body armor configuration

Configuration	Frequency Count (and %) for each Rating					Mean (SD)
	1	2	3	4	5	
BAPL 2: Rifleman (2R)	26 (81%)	5 (16%)	1 (3%)	-	-	1.22 (0.49)
BAPL 2: Grenadier (2G)	20 (63%)	8 (25%)	4 (13%)	-	-	1.50 (0.72)
BAPL 5: Rifleman (5R)	16 (50%)	12 (38%)	2 (6%)	2 (6%)	-	1.69 (0.86)
BAPL 5: Grenadier (5G)	11 (34%)	13 (41%)	8 (25%)	-	-	1.91 (0.78)

Percentages are rounded and may not add up to exactly 100.

Interference/ Restriction Rating Scale: 1 = No interference or degradation; 2 = Slight interference; easily worked around; 3 = Moderate interference, difficult, but able to work around; 4 = Severe interference, very difficult to work around; unacceptable; 5 = Extreme interference, unable to work around; unacceptable

Trunk Flexion - Seated

The TP sits on a seat placed on a raised platform and bends at the waist, attempting to touch the ground with arms and fingers outstretched (Figure 94). The distance between the TP's fingertips and the floor is measured. To standardize the measurement based on any height platform, the flat portion of the platform is used as a "zero" point, and any reaches below that point are a negative number. For example, -55 mm means that the TP reached 55 mm past the platform that he/she is sitting on.

Figure 94: Trunk Flexion while seated

A repeated measures ANOVA was performed to examine the effect of various CIE configurations on Trunk Flexion-Seated relative to the baseline configuration and to each of the loaded configurations. The results are listed in Table 52 and subjective restriction/interference ratings in frequencies and percentages for the four loaded configurations are shown in Table 53. The Trunk Flexion-Seated measurements among configurations were statistically different, $F(4, 124) = 163.60$, $p < .001$. Larger measurement reflects increased restriction. TP performance and ability to reach toward the floor was degraded in all the loaded configurations assessed, with mean degradations between 36-72% of baseline performance. TPs were able to reach significantly further in the Baseline (M=-108.27 mm) than all loaded configurations, $p<.05$. All four loaded configurations were significantly different from one another. TP performance was the worst in the 5G configuration (M =50.32 mm), followed by 2G (M =23.69 mm), 5R (M =6.01 mm), and 2R (M =-29.09 mm), $p<.05$. Regardless of BAPL, TP performance was further degraded in the Grenadier configurations compared to the Rifleman configurations. In addition, within the same duty position, both BAPL 5 configurations were worse than the BAPL 2 configurations for their respective positions.

Additionally, comparisons between BAPL 2 and BAPL 5, and between the Rifleman and Grenadier duty positions were performed with collapsed scores for each BAPL and duty position to determine the overall difference between BAPLs and duty positions. TP performance was

significantly degraded in BAPL 5 (M=28.17 mm) relative to BAPL 2 (M=-2.7 mm), F(1, 31)=118.74, p<.01, and in Grenadier (M=37.01 mm) relative to Rifleman (M=-11.54 mm), F(1, 31)=165.59, p<.01. Thus, both BAPL and duty position affected the performance degradation in Trunk Flexion-Seated.

Table 52: Summary statistics for Trunk Flexion – Seated, in mm, for each body armor configuration

	Baseline	BAPL 2		BAPL 5	
		Rifleman	Grenadier	Rifleman	Grenadier
Mean	^{E}-108.27	^{D}-29.09	^{B}23.69	^{C}6.01	^{A}50.32
Δ from Baseline	-	79.18	131.96	114.28	158.59
% Degradation of Mean	-	36%	60%	52%	72%
SD	49.22	49.45	44.15	49.71	46.62
Min	-11.00	57.67	-39.33	98.00	158.33
25th	-72.92	20.00	-109.33	42.92	75.42
50th	-116.50	-35.00	-135.67	0.00	49.67
75th	-141.75	-75.00	-155.25	-34.08	17.00
Max	-208.33	-97.67	-198.33	-73.67	-31.67

Note: The smaller the score/measurement, the better the performance; a score of 0 means the TP could reach to the level of the bottom of the feet; a negative score means that the TP could reach further than the level of the bottom of the feet.

Δ from Baseline" = $\bar{x}_{Baseline} - \bar{x}_{configuration}$; positive numbers indicated that TPs performed better wearing the Baseline than the loaded configuration, while negative numbers indicate that TPs performed better wearing the loaded configuration than the Baseline.

% degradation of Mean was calculated using the variance between the minimum and maximum Baseline score (-11.00- (-208.33)=219.33) as the devisor and the delta from the Baseline as the dividend.

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

The subjective ratings matched the measurement results, with a mean rating for 5G approaching "Moderate interference, difficult, but able to work around" (Table 53). 2G had a mean rating between "Moderate" and "Slight interference, easily worked around" while 5R had a mean rating just above "Slight." Mean ratings were the lowest for configuration 2R, although that was still between "No interference or degradation" and "Slight interference, easily worked around." TP comments were primarily related to gear that was worn on the body armor (i.e., TAP and additional magazines, grenades, IFAK). However, in some cases, especially for the 5R configuration, TPs commented that the soft armor and/or front plate dug into the stomach, it was often unclear what the exact cause was, as TPs and testers had a difficult time differentiating between the two components of the armor. Another problem that was experienced exclusively with the BAPL 5 configurations, was that the top edge of the front plate would push into the TP's throat/neck.

Table 53: Frequency counts of interference/restriction scale for Trunk Flexion - Seated for each body armor configuration

Configuration	Frequency Count (and %) for each Rating					Mean (SD)
	1	2	3	4	5	
BAPL 2: Rifleman (2R)	15 (47%)	12 (38%)	5 (16%)	-	-	1.69 (0.74)
BAPL 2: Grenadier (2G)	4 (13%)	11 (34%)	13 (41%)	4 (13%)	-	2.53 (0.88)
BAPL 5: Rifleman (5R)	10 (31%)	10 (31%)	9 (28%)	3 (9%)	-	2.16 (0.99)
BAPL 5: Grenadier (5G)	2 (6%)	11 (34%)	11 (34%)	7 (22%)	1 (3%)	2.81 (0.97)

Percentages are rounded and may not add up to exactly 100.

Interference/ Restriction Rating Scale: 1 = No interference or degradation; 2 = Slight interference; easily worked around; 3 = Moderate interference, difficult, but able to work around; 4 = Severe interference, very difficult to work around; unacceptable; 5 = Extreme interference, unable to work around; unacceptable

High Knee/Knee Lift

The TP stands with their right side against a wall and raises their right knee as high as possible (Figure 95). The TP is allowed to use the wall for balance. A measurement is taken from the top of the knee. The TP's left heel must stay on the ground.

Figure 95: High Knee/ Knee Lift

A repeated measures ANOVA was performed to examine the effect of various CIE configurations on High Knee/Knee Lift relative to the baseline configuration and to each of the loaded configurations. The results on the comparisons are listed in Table 54 and subjective restriction/interference ratings via frequencies and percentages for the four loaded configurations are shown in

Table **55**. The High Knee/Knee Lift measurements among configurations were statistically different, $F(4, 124) = 7.04$, $p < .001$. As compared with the Baseline configuration (M=1185.21 mm), the performance in 2G (M=1163.71 mm), 5R (M=1152.78 mm), and 5G (M=1151.25 mm), were significantly degraded, $p<.05$, but not in 2R (M=1176.06 mm), $p>.05$. TP performance in 2R was statistically better than 2G, 5R and 5G, $p<.05$.

Additionally, comparisons between BAPL 2 and BAPL 5, and between the Rifleman and Grenadier duty positions were performed with collapsed scores for each BAPL and duty position to determine the overall difference between BAPLs and duty positions. TP performance was significantly degraded in BAPL 5 (M=1152.02 mm) relative to BAPL 2 (M=1169.89 mm), $F(1, 31)=8.97$, $p<.01$, and in the Grenadier (M=1157.48 mm) relative to the Rifleman (M=1164.42 mm) duty position, $F(1, 31)=5.37$, $p<.05$. For BAPL, there was a mean difference of almost 18 mm while the mean difference between Rifleman and Grenadier was approximately 7 mm. Both BAPL and duty position statistically affected the performance degradation in High Knee/Knee Lift, however it is unclear if this is an operationally relevant amount or not.

Table 54: Summary statistics for High Knee/Knee Lift, in mm, for each configuration

	Baseline	BAPL 2		BAPL 5	
		Rifleman	Grenadier	Rifleman	Grenadier
Mean	^{A}1185.21	^{A}1176.06	^{B}1163.71	^{B}1152.78	^{B}1151.25
Δ from Baseline	-	9.15	21.50	32.43	33.96
% Degradation of Mean	-	1%	2%	3%	3%
SD	83.38	86.19	87.34	97.68	91.39
Min	1024.00	1001.67	981.67	930.67	970.67
25th	1118.75	1120.75	1096.17	1069.83	1084.50
50th	1204.17	1182.00	1199.00	1190.00	1165.67
75th	1229.83	1237.50	1218.42	1223.17	1210.33
Max	1347.00	1338.00	1309.67	1323.00	1309.67

Δ from Baseline = $\bar{x}_{Baseline} - \bar{x}_{configuration}$; positive numbers indicated that TPs performed better wearing the Baseline than the loaded configuration, while negative numbers indicate that TPs performed better wearing the loaded configuration than the Baseline.

% degradation of Mean = $(\bar{x}_{Baseline} - \bar{x}_{configuration}) / \bar{x}_{Baseline})$

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

In general, the subjective ratings indicated there was minimal interference/restriction from the configuration (

Table 55). At least 66% of the TPs stated that there was “No interference or degradation” for each of the four loaded configurations. For the BAPL 2 configurations, TPs noted that their thigh often hit and became restricted by the soft armor, the bottom edge of the front plate, and/or the bottom edge/corner of the TAP. There were more comments regarding interference and restriction for the BAPL 5 configurations (as compared to the BAPL 2 configurations). TPs commented on all the same issues for BAPL 5 that they faced with BAPL 2, plus they also noted that they had to deal with the general weight of the configuration and how they must lift it with their leg to raise their knee and that the weight would cause them to become off balanced during the movement.

Table 55: Frequency counts of interference/restriction scale for High Knee/Knee Lift for each body armor configuration

Configuration	Frequency Count (and %) for each Rating					Mean (SD)
	1	2	3	4	5	
BAPL 2: Rifleman (2R)	27 (84%)	5 (16%)	-	-	-	1.16 (0.37)
BAPL 2: Grenadier (2G)	22 (69%)	10 (31%)	-	-	-	1.31 (0.47)
BAPL 5: Rifleman (5R)	21 (66%)	9 (28%)	2 (6%)	-	-	1.41 (0.61)
BAPL 5: Grenadier (5G)	21 (66%)	9 (28%)	2 (6%)	-	-	1.41 (0.61)

Percentages are rounded and may not add up to exactly 100.

Interference/Restriction Rating Scale: 1 = No interference or degradation; 2 = Slight interference; easily worked around; 3 = Moderate interference, difficult, but able to work around; 4 = Severe interference, very difficult to work around; unacceptable; 5 = Extreme interference, unable to work around; unacceptable

5. DISCUSSION AND SUMMARY

The results across all four loaded configurations (i.e., 2R, 2G, 5R, and 5G) indicate there were general increases in key circumference, breadth, and depth (i.e., bulk) measurements related to Soldier CIE that had a significant decrement on the Soldiers' range of motion for many body movements.

The anthropometry results are presented in sections (3.1 through 3.5) that group specific measurements together. Table 56 provides a generalized summary of the anthropometric results highlighting the significant differences between the Semi-Nude and all loaded configurations, between the two BAPLs, and between the two duty positions (see Sections 3.2, 3.3, and 3.5).

Seven specific anthropometric heights were measured in this study, but were used primarily for locating regions where the breadth, depth, and circumference measurements were taken. These heights and Buttock Circumference (Section 3.1) were measured only for the Semi-Nude and Baseline configurations because additional CIE would not add to those locations. The Baseline measurements for each of the seven heights were approximately 40 mm longer than the Semi-Nude measurements. This distance is the height of the duty boot, which was the only CIE affecting height that was added for these measurements. The other single measurement, Buttock Circumference, had a delta between Baseline and Semi-Nude that reflected only the ACU trouser, as no other CIE was added to this location during the study.

The differences between the Semi-Nude and encumbered measurements of the Head, Hands, and Feet (Section 3.4) were related to the wearing of the ACH for the Head measurements, the SFG for the Hand measurements, and the duty boots for the Foot measurements.

In general, all of the loaded configurations' deltas for the standing and seated measurements (Sections 3.2. and 3.3, respectively)—taken primarily for breadth, depth, and circumference—in each of the BAPL configurations were statistically greater than the Baseline delta. The only exception was for Chest Breadth, where there was no statistical difference between the Baseline measurement and 2R or within BAPLs (i.e., between Rifleman vs. Grenadier). These findings reflect little to no addition of CIE in the armpit/chest region. The larger measurements in BAPL 5 reflect the additional material of the IOTV in this area compared to the SPCS. All the other measurements appear to be a function of what CIE is present and where it is located on the body. In general, the 5G had the largest measurements for all the dimensions. In some cases these measurements were similar to the 5R. These similarities in measurements appear to be related to those dimensions where the only difference was the body armor worn (i.e., IOTV or SPCS) and no other CIE was present. This reasoning also appears to explain the similarities in some of the BAPL 2 dimensions between the Rifleman and the Grenadier. Where different CIE was located on the body for the Grenadier and the Rifleman, it appears that the 2G was generally larger than the 2R and sometimes similar to the 5R.

Table 56: Significant difference for anthropometric measurements in loaded configurations

Dimension	Semi-Nude measurements relative to:				BAPL 2 vs. BAPL 5	Rifleman vs. Grenadier
	2R	2G	5R	5G		
Chest Breadth	No Difference	Increased	Increased	Increased	Increased in BAPL 5	No Difference
Chest Circumference	Increased	Increased	Increased	Increased	Increased in BAPL 5	No Difference
Chest Depth	Increased	Increased	Increased	Increased	Decreased in BAPL 5	No Difference
Mid-Shoulder Height	Decreased	Decreased	No Difference	No Difference	Increased in BAPL 5	Decreased in Grenadier
Shoulder Circumference	Increased	Increased	Increased	Increased	Increased in BAPL 5	No Difference
Stature	Increased	Increased	Increased	Increased	No Difference	No Difference
Vertical Trunk (USA) Circumference	Increased	Increased	Increased	Increased	Increased in BAPL 5	Increased in Grenadier
Waist Breadth	Increased	Increased	Increased	Increased	Increased in BAPL 5	Increased in Grenadier
Waist (Omphalion) Circumference	Increased	Increased	Increased	Increased	Increased in BAPL 5	Increased in Grenadier
Waist Depth	Increased	Increased	Increased	Increased	Increased in BAPL 5	Increased in Grenadier
Weight(lb)	Increased	Increased	Increased	Increased	Increased in BAPL 5	Increased in Grenadier
Biacromial Breadth, Sitting	No Difference	No Difference	No Difference	No Difference	No Difference	No Difference
Bideltoid Breadth, Sitting	Increased	Increased	Increased	Increased	Increased in BAPL 5	Increased in Grenadier
Buttock-Knee Length	Increased	Increased	Increased	Increased	Increased in BAPL 5	Increased in Grenadier
Buttock-Popliteal Length	Increased	Increased	Increased	Increased	Increased in BAPL 5	Increased in Grenadier
Elbow Circumference, Sitting	Increased	Increased	Increased	Increased	Increased in BAPL 5	Increased in Grenadier
Forearm-Forearm Breadth, Sitting	Increased	Increased	Increased	Increased	Increased in BAPL 5	Increased in Grenadier
Hip Breadth, Sitting	Increased	Increased	Increased	Increased	Increased in BAPL 5	Increased in Grenadier
Sitting Height	Increased	Increased	Increased	Increased	No Difference	No Difference
MAX Waist Breadth	Increased	Increased	Increased	Increased	Increased in BAPL 5	Increased in Grenadier
MAX Backpack Chest Circumference	Increased	Increased	Increased	Increased	Increased in BAPL 5	Increased in Grenadier
MAX Backpack Depth	Increased	Increased	Increased	Increased	Increased in BAPL 5	Increased in Grenadier
MAX Waist Circumference	Increased	Increased	Increased	Increased	Increased in BAPL 5	Increased in Grenadier
MAX Waist Depth	Increased	Increased	Increased	Increased	Increased in BAPL 5	Increased in Grenadier
Weight with Backpack	Increased	Increased	Increased	Increased	Increased in BAPL 5	Increased in Grenadier

The last group of anthropometric measurements (Section 3.5) examined the breadth, depth and circumference in the chest and waist regions with the addition of an assault pack to the Rifleman load and to the Grenadier load. In general, the 5G dimensions were larger than the rest of the configurations. However, the MAX Waist Depth was statistically similar within both duty positions (i.e., between 2G and 5G and between 2R and 5R), reflecting the similarity in CIE at this location, and the MAX Backpack Depth (Chest) within the Rifleman position (i.e., between 2R and 5R) was statistically similar. Waist Breadth, Waist Circumference, and Weight were all significantly different for each configuration.

In general, the TPs were able to perform the range of motion movements significantly better in the Baseline configuration than in the loaded configurations. However, there were no significant differences across any of the configurations for Ventral-Dorsal Cervical Flexion and for Upper Arm/Shoulder Backward Extension. For Thoracic/Lumbar Spine Lateral Flexion and Trunk Flexion – Standing, there were no significant differences between the Baseline and the BAPL 2 configurations. For Upper Arm/Shoulder Forward Extended Reach and High Knee/Knee Lift, there were no significant differences between the Baseline and the 2R configuration. In most cases (the neck movements of Cervical Rotation and Ventral-Dorsal Cervical Flexion and Upper Arm/Shoulder Backward Extension being the exceptions). There was a main effect for both BAPL and duty position. The TPs scored significantly better in BAPL 2 than in BAPL 5 and significantly better in the Rifleman configurations than in the Grenadier configurations. Table 57 provides a generalized summary of the range of motion results highlighting the significant differences between the configurations. Comments, from the TPs during the subjective interference/restriction ratings, related to the neck movements focused on the weight of the ACH for all the loaded configurations. The lumbar spine movement comments focused on the bulk of the gear around the waist and lower torso, which was greater with the Grenadier configurations than with the Rifleman configurations (as was also seen in the anthropometric measurements).

When the TPs were encumbered with the gear outlined in this study, their body weights increased by 30-50 lb beyond the Baseline measurements depending on BAPLs and duty positions. In addition to its weight, this type of gear is not well distributed around the body of the Soldier, but is concentrated around the torso, especially on the front and the side of the abdominal area. Furthermore, Soldiers typically carry backpacks along with this poorly distributed gear. In this study, Modular Lightweight Load Carrying Equipment (MOLLE) mediums with a 72 h mission load, weighing 27-31 lb, were placed on the back of the torso of the TPs when outfitted in each of the four loaded configurations. This total weight of 57-81 lb beyond the Baseline configuration had a significant impact on various body dimensions and range of motion.

This study found that, when Soldiers were encumbered by specific CIE, their range of motion degraded from 6-27° for the majority of the goniometer measurements obtained and from 16-159 mm for the majority of reach measurements taken, depending upon the movement, the BAPL, and the duty position. Because so much of the bulk was added around the waist of the Soldier, movements that involve bending at the waist had the largest degradations from the Baseline configuration (i.e., Trunk Flexion - Standing and Seated).

Table 57: Significant difference for range of motion measurements in loaded configurations

Movement	Baseline measurement relative to:				BAPL 2 vs. BAPL 5	Rifleman vs. Grenadier
	2R	2G	5R	5G		
Cervical Rotation	Degraded	Degraded	Degraded	Degraded	No Difference	No Difference
Ventral-Dorsal Cervical Flexion	No Difference	No Difference	No Difference	No Difference	No Difference	No Difference
Thoracic/ Lumbar Spine Rotation	Degraded	Degraded	Degraded	Degraded	Degraded in BAPL5	Degraded in Grenadier
Thoracic/ Lumbar Spine Lateral Flexion	No Difference	No Difference	Degraded	Degraded	Degraded in BAPL5	Degraded in Grenadier
Upper Arm/ Shoulder Abduction	Degraded	Degraded	Degraded	Degraded	Degraded in BAPL5	Degraded in Grenadier
Upper Arm/ Shoulder Overhead Reach, Extension	Degraded	Degraded	Degraded	Degraded	Degraded in BAPL5	Degraded in Grenadier
Upper Arm/ Shoulder Forward Flexion Extension	Degraded	Degraded	Degraded	Degraded	Degraded in BAPL5	Degraded in Grenadier
Upper Arm/ Shoulder Forward Extended Reach	No Difference	Degraded	Degraded	Degraded	Degraded in BAPL5	Degraded in Grenadier
Upper Arm/ Shoulder Backward Extension	No Difference	No Difference	No Difference	No Difference	No Difference	No Difference
Upper Arm/Shoulder Cross Body Reach	Degraded	Degraded	Degraded	Degraded	No Difference	Degraded in Grenadier
Trunk Flexion - Standing	No Difference	No Difference	Degraded	Degraded	Degraded in BAPL5	Degraded in Grenadier
Trunk Flexion – Seated	Degraded	Degraded	Degraded	Degraded	Degraded in BAPL5	Degraded in Grenadier
High Knee/ Knee Lift	No Difference	Degraded	Degraded	Degraded	Degraded in BAPL5	Degraded in Grenadier

In summary, the anthropometric measurements that were most impacted by the configurations, i.e., those with the most significant incremental increases in body dimensions (discounting backpack and MAX measurements), were at the Waist (Omphalion):

- Waist Breadth (216 -300 mm or 70-98% increase)
- Waist Circumference (500-780 mm or 59-91% increase)
- Waist Depth (137-221 mm or 63-101% increase)

Additionally, the range of motion movements that were the most impacted by the configurations were:

- Thoracic/Lumbar Spine Rotation (16-27° degradation)
- Upper Arm/Shoulder Forward Extended Reach (25-33 mm degradation in the BAPL 5)
- Trunk Flexion Seated (79-159 mm degradation)
- Cross Body Reach (54-73 mm degradation)

6. CONCLUSIONS

In simplified terms, the more gear that is put on Soldiers, the larger they will be and the less range of motion they will have. Across both the anthropometric and the range of motion data, there were increases in bulk, thereby leading to increased size dimensions and decreased range of motion. This was seen both as the BAPL increased (from BAPL 2 to BAPL 5) and as the amount of equipment worn increased from the Rifleman to Grenadier duty positions. The increase in encumbered measurements can be linked to the degradation in range of motion performance, specifically in how much increase in bulk and degradation in range of motion varies by part of the body, configuration, and movement, as outlined in Chapters 4 and 5.

It is well known that the space occupied by the encumbered Soldiers in vehicles and/or at workstations, sitting or standing, is not enough and needs to be increased substantially, especially for breadth and depth related to any worn CIE. However, because few studies have ever looked at encumbered anthropometry, these clothed dimensions cannot be estimated from Semi-Nude dimensions. In the current study, encumbered anthropometric data provided unique information on size increments at specific locations (e.g., Waist at Omphalion) relative to Semi-Nude and Baseline configurations, as well as the actual measurements per BAPL and duty position. This information is expected to contribute significantly to future designs of CIE and to vehicles and workspace platforms to decrease Soldier load, improve performance and enhance Soldier comfort and survivability. Appendix B lists the mean and maximum delta values for each of the variables measured in this study.

6.1 Implications of Results for Future Research

For future testing, similar measurements outlined in this report would likely be recommended as important for assessing the amount of occupied space related to CIE and the effects on the Soldiers' range of motion. Specific measurements recommended for future studies will need to be addressed and identified based on the end goals of the program and equipment and on the CIE being worn.

The current study highlighted anthropometry and range of motion measurements related to specific Soldier gear. Any changes to these configurations or the introduction of newly designed equipment would need to be independently assessed. For example, it would not be necessary to provide body dimensions and range of motion scores, beyond Semi-Nude and Baseline configurations, on the lower legs if no additional equipment is worn in this region.

In addition, for a research program with similarly defined Soldier loads, as seen in this study, many of the same measurements would be recommended, with the exception (for range of motion measurements) of the Upper Arm/Shoulder Backward Extension movement. Additionally, if no collar/yoke was worn, then Cervical Rotation and Ventral Dorsal Cervical Flexion measurements would not be needed. For anthropometry, Biacromial Breadth in this study could be discarded in similar studies unless additional CIE is worn on the upper arm. These measures had minimal impact based on the configurations used in this study.

Finally, there were certain anthropometric measurements that changed from the Semi-Nude by the dimensions of the equipment only and were standard across configurations. These measurements, in future studies, would only need to be taken once or could be added to the Semi-Nude measurement without additional anthropometric measurements being taken. Examples of these measurements are:

- Body Weight (Body Weight and Weight with Backpack)
- Hand measurements (Hand Breadth, Hand Circumference, Hand Length, and Wrist Circumference)
- Foot Breadth and Foot Length

6.2 Implications of Results for Future Development

Data contained in this report highlighting the increased body dimensions and decreased range of motion due to Soldier CIE can be utilized by military equipment designers and requirements developers (both of clothing/equipment and military platforms). Designers and requirements developers need to remember:

1) Any clothing or equipment that is added needs to be developed not just for the individuals (in their Semi-Nude/Baseline configurations), but all the equipment that they wear.
2) These increased sizes need to be accounted for when developing next generation equipment and platforms.
3) The gear that Soldiers are wearing impedes their ability to move and perform physical tasks:
    a. Care should be taken with CIE design to minimize these performance decreases.
    b. Care should be taken with platform and workspace designers to create spaces where tasks, job duties, and missions can be easily carried out even with this decreased range of motion.
    c. Creating CIE that is too bulky can lead to safety hazards (e.g., snags, increased fatigue, and increased thermal burden).

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7. WORKS CITED

Boone, D. C., & Azen, S. P. (1979). Normal range of motion of joints in male subjects. *The Journal of Bone & Joint Surgery*, 61(5), 756-759.

Garlie, TN & Choi, HJ. (2014). Characterizing the size of the encumbered Soldier. (Technical Report (TR-14/019). Natick, MA: US Army Natick Research, Development and Engineering Center.

Gerhardt, J., Cocchiarella, L., & Lea, R. (2002). The Practical Guide to Range of Motion Assessment. Chicago: American Medical Association.

Gordon, C.C., Blackwell, C.L., Bradtmiller B., Parham, J.L., Barrientos, P., Paquette, S.P., Corner, B.D., Carson, J.M., Venezia, J.C, Rockwell, B., Mucher, M. and Kristensen, S. (2014). 2010-2012 Anthropometric survey of U.S. Army personnel: Methods and summary statistics. (Technical Report (Natick/TR-15-007)). Natick, MA: U.S. Army Natick Research, Development and Engineering Center.

Hotzman J., Gordon, C.C., Bradtmiller, B., Corner, B.D., Mucher, M., Kristensen, S., Paquette, S., & Blackwell, C.L. (2011). Measurer's Handbook: US Army and Marine Corps Anthropometric Surveys, 2010-2011. (Technical Report (Natick/TR-11/017)). Natick, MA: US Army Natick Research, Development and Engineering Center.

Johnson, RF. (1984). Anthropometry of the clothed US Army ground troop and combat vehicle crewman. (Technical Report (TR-84/034). Natick, MA: US Army Natick Research, Development and Engineering Center.

Mitchell, K.B. (2013). Development of Standard Methodology for Assessment of Range of Motion While Wearing Body Armor. NATICK/TR-13/033. Natick, MA: US Army Natick Research, Development and Engineering Center.

Paquette, S., Gordon, C., & Bradtmiller, B. (2009). Anthropometric survey (ANSUR) II Pilot Study: Methods and Summary Statistics. Natick, MA: US Army Natick Research, Development and Engineering Center.

Paquette, S., Case, H., Annis, J., Mayfield, T., Kristensen, S., & Mountjoy, D. (1999). The Effects of Multilayered Military Clothing Ensembles on Body Size: A Pilot Study. (Technical Report (TR-99-012). Natick, MA: US Army Natick Research, Development and Engineering Center.

Reference Memorandum, MCoE, ATZB-CIS, 13 Oct 10, subject: Body Armor Protection Levels (BAPLs).

APPENDIX A
EQUIPMENT LIST AND WEIGHTS

Equipment	Weight (lb)	Configuration			
Vests		**2R**	**2G**	**5R**	**5G**
IOTV (with Plates)					
XS	20.00				
S	24.16				
M	26.28			X	X
L	29.29				
XL	30.24				
Plate Carrier (with Plates)					
XS	12.76				
S	15.09				
M	16.83	X	X		
L	19.55				
XL	21.00				
Equipment					
ACH (with NVG Mount)					
ACH (S)	3.07				
ACH (M)	3.16	X	X	X	X
ACH (L)	3.41				
ACH (XL)	3.72				
TAP					
Unloaded TAP	1.58				
Grenadier TAP	17.43		X		X
Rifleman TAP	10.46	X		X	
TAP Gear					
30 round magazine	1.11	X	X	X	X
M67 (fragment) (1ea)	0.90	X	X	X	X
IFAK (worn)	1.12	X	X	X	X
14 HE/DP (M433) grenade	0.50		X		X
4 STAR (M661 green) grenade	0.50		X		X
Assault Packs					
Assault Pack Grenadier	31.38		X		X
Assault Pack Rifleman	26.53	X		X	
Accessories					
Glasses	0.07	X	X	X	X
Gloves	0.18	X	X	X	X

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APPENDIX B
MEAN AND MAXIMUM DELTA VALUES FOR ALL ANTHROPOMETRIC DIMENSIONS

Table B-1: Mean and Maximum delta values for standing and sitting dimensions

Dimension	Baseline (ACS)-Semi-Nude (mm)		Rifleman BAPL2-Semi-Nude (mm)		Grenadier BAPL2-Semi-Nude (mm)		Rifleman BAPL5-Semi-Nude (mm)		Grenadier BAPL5-Semi-Nude (mm)	
	Mean	Max	Mean	Max	Mean	Max	Mean	Max	Mean	Max
Weight (lb)	7	8	37	45	47	52	47	88	57	62
Weight with BKP			64	70	79	83	72	81	88	94
Stature	38	59	61	82	58	76	58	81	58	78
Mid-Shoulder Height	41	63	29	55	25	45	39	63	35	55
Shoulder Circumference	32	62	113	181	112	179	138	188	140	194
MAX Chest Circumference			968	1075	1048	1156	1024	1149	1119	1289
Chest Circumference	0	14	146	213	163	766	205	266	199	268
MAX Waist Circumference			556	632	695	830	656	726	818	892
Waist (Omphalion) Circumference	15	43	500	610	674	830	621	726	780	886
Buttock Circumference	61	93								
Vertical Trunk (USA) Circumference	33	96	113	200	136	200	152	269	177	251
MAX BKP Depth			444	499	473	542	436	488	477	532
Chest Depth	0	16	81	105	80	104	74	110	73	99
MAX Waist Depth			161	195	203	233	163	211	226	258
Waist Depth	6	22	137	188	198	233	159	208	221	261
Chest Breadth	3	13	9	41	13	39	34	63	31	61
MAX Waist Breadth			235	262	284	318	265	303	315	368
Waist Breadth	2	14	216	262	275	312	249	303	300	368
Sitting Height	0	12	27	50	26	46	27	41	27	44
MAX Waist Height, Sitting			55	129	42	127	60	127	59	148
Sitting Height	0	12	27	50	26	46	27	41	27	44
Waist Height, Sitting	-4	25	26	86	32	87	39	84	42	81
Knee Height, Sitting	40	59	40	59	40	59	40	59	40	59
Buttock-Knee Length	4	19	54	94	59	100	53	108	78	137
Buttock-Popliteal Length	0	19	53	104	53	103	47	97	72	145
Biacromial Breadth, Sitting	0	24	0	35	4	51	3	45	4	42
Bideltoid Breadth, Sitting	14	68	32	94	37	92	40	100	42	97
Forearm-Forearm Breadth, Sitting	25	85	117	211	145	235	144	263	167	310
Hip Breadth, Sitting	18	56	91	179	128	239	106	192	163	235
Elbow Circumference, Sitting	70	163	366	514	391	519	409	541	439	627

Table B-2: Mean and maximum delta values for head, hand and foot dimensions

Dimension	Baseline(ACS)-Semi-Nude (mm)		All Loaded Configurations (Measured Once)-Semi-Nude (mm)	
	Mean	Max	Mean	Max
Foot Length	40	56		
Foot Breadth	11	27		
Hand Circumference			8	15
Wrist Circumference			23	41
Hand Length			4	13
Hand Breadth			1	8
Head Circumference			195	227
Head Length			65	80
Head Breadth			92	104