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# ANALYSIS OF THE EFFECTS OF BODY ARMOR AND LOAD-CARRYING EQUIPMENT ON SOLDIERS' MOVEMENTS

## Part II
## Armor Vest and Load-Carrying Equipment Assessment

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This is one of three reports of a study on the effects of the Personnel Armor System for Ground Troops (PASGT) vest and a prototype armor vest and two types of fighting loads on soldiers' movements. The fighting loads were the All-Purpose Lightweight Individual Carrying Equipment (ALICE) and the tactical load-bearing vest. Twelve male soldiers performed seven planar movements and a walking task while wearing the vests and fighting loads with either a T-shirt and shorts or the Temperate Battledress Uniform (BDU). Two measurement methods were applied to quantify the extent of the movements, one of which was a video- and computer-based technique. This report contains results of the effects of the vest and fighting load designs on the planar movements, as quantified using the video technique. It was found that the prototype vest imposed less restriction on movement than the PASGT vest did. Range of motion with the tactical load bering vest was also equal to or better than that with the ALICE. A second report (NATICK/TR-98/002) contains comparisons of the data acquired on the planar movements using the two measurement techniques, and a third report (NATICK/TR-98/004) contains findings from the video-based analysis of gait.

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## PREFACE

The study reported here was conducted under U.S. Army Soldier Systems Command, Natick Research, Development and Engineering Center contract DAAK60-93-D-0005 with GEO-CENTERS, INC., Newton Centre, MA. The work was performed at the Center for Military Biomechanics Research, Natick Research, Development and Engineering Center. Carolyn K. Bensel of the Center was the project officer for the contract. This project is part of the 6.2 program 1L162723AH98AAKOO (Aggregate Code T/B1368) — Biomechanical Approach to Soldier-CIE Integration, which is being carried out by Dr. Bensel and other members of the Center.

This report is one of a series of three. The references for the other reports are:

Woods, R. J., Polcyn, A. F., O'Hearn, B. E., Rosenstein, R. A., and Bensel, C. K. (1997). *Analysis of the effects of body armor and load-carrying equipment on soldiers' movements. Part I: Technique comparisons* (Tech. Rep. NATICK/TR-98/002). Natick, MA: U.S. Army Natick Research, Development and Engineering Center.

Woods, R. J., Polcyn, A. F., O'Hearn, B. E., Rosenstein, R. A., and Bensel, C. K. (1997). *Analysis of the effects of body armor and load-carrying equipment on soldiers' movements. Part III: Gait analysis* (Tech. Rep. NATICK/TR-98/004). Natick, MA: U.S. Army Natick Research, Development and Engineering Center.

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ANALYSIS OF THE EFFECTS OF BODY ARMOR AND LOAD-CARRYING EQUIPMENT ON SOLDIERS' MOVEMENTS
Part II: Armor Vest and Load-Carrying Equipment Assessment

# Introduction

A major concern in assessing the acceptability of items of protective clothing and equipment for use by soldiers is the extent to which the items may restrict body movements, thereby impeding mission performance. Research sponsored by this laboratory in the 1950s identified tests of gross motor activities that are sensitive to the effects of different clothing ensembles (Saul and Jaffe, 1955). These methods have since been applied by this laboratory in a number of studies of military clothing and equipment items, including armor vests (Bensel, Fink, and Mellian, 1980; Bensel and Lockhart, 1975; McGinnis, 1972) and load-carrying equipment (Bensel et al., 1980; Bensel and Lockhart, 1975). The tests of gross motor performance yield quantitative measures of the maximum extent of movement about joints of the body (Saul and Jaffe, 1955). Traditionally, the measurements have been made mainly with gravity goniometers and meter sticks. In this study, the same tests were used to assess two types of armor vests and two types of load-carrying equipment, but ranges of body movement were also measured with newer, video-based techniques.

### Armor Vests and Load-Carrying Equipment Studied

Two items tested in this study were the standard-issue, fragmentation protective vest that is part of the Personnel Armor System for Ground Troops (PASGT) and the standard-issue, fighting load components of the All-Purpose Lightweight Individual Carrying Equipment (ALICE). These items, along with a second type of armor vest, were also included in the study by Bensel et al. (1980). Bensel et al. found that, in general, use of the vests and the fighting load decreased the extent of body movements compared with wearing the regular duty uniform alone. However, the specific impact of adding either an armor vest or the fighting load varied as a function of the part of the body involved in the movement. For example, the armor vests, which had stand-up collars, limited the extent of head rotation and head flexion, whereas the fighting load did not. Use of the fighting load did restrict the raising of the arms in the body's sagittal plane, as did use of an armor vest; wearing of both the fighting load and an armor vest resulted in the greatest restriction of the arm movement.

An armor vest and load-carrying equipment not tested in previous studies of gross motor activities were also included in the present research. The armor vest is a prototype of a so-called "multiple threat" vest, a vest developed to provide protection against a wider range of ballistic threats than the PASGT vest does. The prototype is identical in appearance to the PASGT. However, the two vests differ in the materials used to provide the ballistic protection. The material in the PASGT consists of layers of Kevlar cloth. The ballistic protection in the prototype, multiple-threat vest is provided by rigid, metal plates that are attached to a fabric backing. Because of these differences in materials, the prototype vest is more flexible than the PASGT. Additional descriptive information on both the PASGT and the prototype vests is presented in the appendix.

In addition to the ALICE fighting load, load-carrying equipment referred to as the Tactical Load-Bearing Vest (TLBV) was included in the present study. The TLBV has been adopted as a standard item by the Army and will eventually replace the ALICE as the means for ground troops to carry basic loads. Both the ALICE and the TLBV are designed with pockets or cases to accommodate a canteen, an entrenching tool, and ammunition. However, the ALICE and the TLBV differ with regard to the location of these items. With the ALICE, the items are placed in cases that are suspended from a belt worn around the waist. With the TLBV, the canteen and the entrenching tool are worn in cases attached to a waist belt, whereas pockets for the ammunition and the grenades are located on the front of the vest, above the level of the waist. The ALICE and the TLBV gear are further described in the appendix.

## Purposes of the Study

This study was the first conducted in this laboratory using video-based measurement techniques to analyze soldiers' movements as affected by clothing and equipment. It addressed some issues associated with introduction of the new techniques, specifically how body range of motion data acquired using these techniques compared with data acquired using the traditional measurement methods of gravity goniometers and meter sticks. The study was also an investigation of the effects that armor vests and load-carrying equipment have on soldiers' movements. Seven planar movements were studied using both the traditional and the video-based techniques, and walking gait was analyzed using the video-based techniques. Results of the comparison of the traditional and the video-based measurement techniques are presented in Woods, Polcyn, O'Hearn, Rosenstein, and Bensel (1997a). Another report (Woods et al., 1997b) contains findings from the video-based analysis of walking gait as affected by wearing of an armor vest and load-carrying gear.

The purpose of the portion of the study reported here was to compare range of motion for the two designs of armor vests and the two designs of load-carrying equipment. This investigation was limited to simple planar movements measured in previous studies (Saul and Jaffe, 1955; Bensel et al., 1980). As reported in Woods et al. (1997a), the traditional and the video-based measurement techniques yielded similar findings regarding the relative effects of the armor vests and the load-carrying equipment on range of body motion. Therefore, the findings reported here are limited to those obtained using one of the measurement techniques, the video-based method. Soldiers were tested in 18 clothing and equipment configurations. For half of the configurations, the Temperate Battledress Uniform (BDU) coat and trousers were worn as the torso clothing. For the other half, a T-shirt and gym shorts were worn. Thus, data were acquired under conditions in which anatomical landmarks were covered by clothing, as well as under conditions in which body landmarks were relatively unobscured.

The principal reason for including the two base clothing conditions was to determine whether the video-based data, which is derived from digitizing of body landmarks, would differ from the traditional measurements under conditions in which the landmarks were covered by clothing (Woods et al., 1997a). However, the base clothing variable is also of interest in assessing armor vest and load-carrying equipment effects on movements because of the possible interaction of the base clothing with the armor and the load-carrying variables. In research that included analysis of a number of simple movements, Bensel, Teixeira, and Kaplan (1987) found differences between a T-shirt and shorts and the BDU in the extent of some body movements. Where differences were obtained, performance in a T-shirt and shorts was superior to performance in the BDU. Bensel et al. did not, however, investigate armor and load-carrying equipment effects in their research.

# Method

## Participants

Participation in this study was limited to individuals who could be accommodated in the one size in which the prototype vest was available, a size medium. Twelve male soldiers, who were assigned to the Enlisted Volunteer Platoon at the U.S. Army Soldier Systems Command, Natick, Massachusetts, met this criterion and volunteered to serve in the study. They were fully informed about the purposes and risks of the study and gave their written consent to participate in accordance with Army Regulation 70-25. The participants' demographic information is summarized in Table 1.

**Table 1**
*Participants' Characteristics (N = 12)*

| Statistic | Stature (cm) | Crotch Ht. (cm) | Chest Circum. (cm) | Waist Circum. (cm) | Age (yrs.) |
|---|---|---|---|---|---|
| *M* | 178.12 | 82.85 | 100.08 | 87.48 | 20.70 |
| *SD* | 6.55 | 3.17 | 6.93 | 7.62 | 1.54 |

## Clothing and Equipment Conditions

Two types of armor vest were used in the study. One was the Army's standard-issue, fragmentation protective vest, the PASGT vest. The other was a prototype of multiple threat body armor, which was developed to provide protection against a wider range of ballistic threats than the PASGT vest does. Two types of load-carrying gear were also included in the study. One was the Army's standard-issue fighting load that is part of the ALICE system. The other load-carrying equipment, recently adopted by the Army as a replacement for the ALICE fighting load, was the TLBV. The armor vests and the load-carrying items are described in the appendix.

Participants were tested under 18 combinations of clothing and equipment conditions. In half the conditions, the torso clothing consisted of a T-shirt and gym shorts, and the footwear was running shoes. In the other half, the coat and trousers of the standard-issue Temperate BDU were worn along with standard-issue, leather combat boots. Participants were tested wearing only these outfits and wearing the outfits with the armor vests and the load-carrying gear. The components of each of the 18 clothing and equipment conditions are listed in Table 2.

## Apparatus

An SVHS shuttered camcorder (Panasonic model AG450), which ran at 60 Hz, was used to videotape the participants as they performed seven planar movements. At the beginning of a test session, the camera was checked with a circular bubble level to ensure that it was level in the fore-aft and the lateral directions. A meter stick was also videotaped for use in establishing a scale factor during the tape digitizing process.

After the test sessions, the videotapes were encoded and digitized using specialized computer hardware and software (Peak Performance Technologies, Inc.), a color video monitor (Sony Trinitron model PVM-1341), and an SVHS video cassette recorder (Panasonic model AG7300). The digitizing was done manually by a trained anthropometrist. It consisted of marking previously established anatomical landmarks in the relevant video frames. The landmarks are identified below under the movement descriptions.

For the six movements that involved measurement of angular ranges of motion, two video frames were digitized; one captured the starting position for the movement and the other captured the maximum amplitude of the movement. Two points, chosen to describe the relevant body segment (e.g., arm, leg), were digitized in each frame. The first point was the approximate center of rotation for the movement and the second was a more distal point on the segment. Using the specialized computer software, the angles of the segment at the beginning of the movement and at the maximum displacement were calculated with respect to the horizontal. The difference between the initial and final angles was taken as the range of motion on that movement.

## Movements

The order in which the movements were performed was not varied throughout the testing. The movements are described here in the order in which they were carried out.

### *Movement 1: Standing Trunk Flexion*

From a standing position on a bench 29 cm high, the participant bent at the waist and, while keeping the knees straight, reached down with both arms toward the floor. Videotape was recorded from the sagittal view, and the points digitized were the third fingertip and a point marked on the floor. Lower scores on this movement indicate a greater amount of trunk flexion, or less distance between the fingertip and the floor.

**Table 2**
*Clothing and Equipment Conditions*

| No. | Components | No. | Components |
|---|---|---|---|
| 1. | T-shirt, Shorts, Running Shoes (Shorts) | 2. | Temperate Battledress Uniform, Combat Boots (Unif) |
| 3. | T-shirt, Shorts, Running Shoes *plus* PASGT Fragmentation Protective Vest (Shorts + PASGT Vest) | 4. | Temperate Battledress Uniform, Combat Boots *plus* PASGT Fragmentation Protective Vest (Unif + PASGT Vest) |
| 5. | T-shirt, Shorts, Running Shoes *plus* Prototype Ballistic Vest (Shorts + Proto Vest) | 6. | Temperate Battledress Uniform, Combat Boots *plus* Prototype Ballistic Vest (Unif + Proto Vest) |
| 7. | T-shirt, Shorts, Running Shoes *plus* ALICE Fighting Load (Shorts + ALICE Gear) | 8. | Temperate Battledress Uniform, Combat Boots *plus* ALICE Fighting Load (Unif + ALICE Gear) |
| 9. | T-shirt, Shorts, Running Shoes *plus* Tactical Load-Bearing Vest (Shorts + TLBV Gear) | 10. | Temperate Battledress Uniform, Combat Boots *plus* Tactical Load-Bearing Vest (Unif + TLBV Gear) |
| 11. | T-shirt, Shorts, Running Shoes *plus* PASGT Fragmentation Protective Vest *plus* ALICE Fighting Load (Shorts + PASGT Vest + ALICE Gear) | 12. | Temperate Battledress Uniform, Combat Boots *plus* PASGT Fragmentation Protective Vest *plus* ALICE Fighting Load (Unif + PASGT Vest + ALICE Gear) |
| 13. | T-shirt, Shorts, Running Shoes *plus* PASGT Fragmentation Protective Vest *plus* Tactical Load-Bearing Vest (Shorts + PASGT Vest + TLBV Gear) | 14. | Temperate Battledress Uniform, Combat Boots *plus* PASGT Fragmentation Protective Vest *plus* Tactical Load-Bearing Vest (Unif + PASGT Vest + TLBV Gear) |
| 15. | T-shirt, Shorts, Running Shoes *plus* Prototype Ballistic Vest *plus* ALICE Fighting Load (Shorts + Proto Vest + ALICE Gear) | 16. | Temperate Battledress Uniform, Combat Boots *plus* Prototype Ballistic Vest *plus* ALICE Fighting Load (Unif + Proto Vest + ALICE Gear) |
| 17. | T-shirt, Shorts, Running Shoes *plus* Prototype Ballistic Vest *plus* Tactical Load-Bearing Vest (Shorts + Proto Vest + TLBV Gear) | 18. | Temperate Battledress Uniform, Combat Boots *plus* Prototype Ballistic Vest *plus* Tactical Load-Bearing Vest (Unif + Proto Vest + TLBV Gear) |

*Movement 2: Ventral-Dorsal Head Flexion*

The participant sat upright in a chair and moved the head forward and down so that the chin was as close to the chest as possible. This was the starting position for the movement. While keeping the shoulders against the back of the chair, the head was then rotated as far back as possible. Videotape was recorded from the sagittal view. The points digitized were the right acromion (i.e., the outer point at the top of the right shoulder) and the most posterior point on the head. Higher scores on this movement indicate a greater extent of head flexion.

*Movement 3: Head Rotation*

From a standing position, the participant bent over at the waist until the head and chest were parallel to the floor and grasped the seat of a chair for support. While keeping the rest of the body stationary, the participant rotated the head as far to the left as possible. This was the starting position for the movement. The participant then rotated the head as far to the right as possible. The participant was positioned such that the top of the head faced the camera. The points digitized were the approximate axis of rotation of the head and the tip of the nose. Higher scores on this movement indicate a larger angular rotation of the head.

*Movement 4: Upper Arm Abduction*

The participant stood in the standard anatomical position, with the arms at the sides. This was the starting position for the movement. The right arm was then raised sideward and upward as far as possible while keeping the elbow stiff. Videotape was recorded from the coronal view with the participant facing the camera, and the points digitized were the center of the right humeral head and the center of the right elbow joint. Higher scores on this movement indicate a greater range of motion of the arm.

*Movement 5: Upper Arm Forward Extension*

The participant stood in the standard anatomical position, with the arms at the sides. This was the starting position for the movement. The participant then raised the right arm forward and as far up as possible with the elbow being kept stiff. Videotape was recorded from the sagittal view, and the points digitized were the right acromion and the center of the right elbow joint. Higher scores on this movement indicate a greater range of motion of the arm.

*Movement 6: Upper Leg Abduction*

The participant stood in the standard anatomical position with feet together and grasped an upright support. This was the starting position for the movement. Maintaining an erect posture, the participant then raised the right leg to the side as far up as possible while holding both knees stiff. Videotape was recorded from the coronal view with the subject facing away from the camera, and the points digitized were the center of the right hip joint and the center of the right knee joint. Higher scores on this movement indicate a greater range of leg motion.

### *Movement 7: Upper Leg Flexion*

The participant stood in the standard anatomical position with feet together and his back against a wall. This was the starting position for the movement. The participant then lifted the right upper leg up as far as possible while letting the lower leg bend freely at the knee. Videotape was recorded from the sagittal view, and the points digitized were the right greater trochanter and the center of the right knee joint. Higher scores on this test indicate a greater extent of leg flexion.

## Procedure

Before testing began, the participants were fitted for the clothing and equipment and familiarized with the movements to be performed. Each man then participated in six experimental sessions, either in the morning or in the afternoon of six days. The sessions for a participant were scheduled for the same time each day. A session lasted approximately 2.25 hr and involved testing three of the 18 clothing and equipment conditions. Each participant was exposed to the clothing and equipment conditions in a different random order. Ambient temperature in the test area was maintained at 19.4 °C.

For each condition, the participant performed two successive trials on all the planar movements and on a walking task while either the traditional or the video-based measurement methods were used. Then, he repeated this process while the other measurement method was used. (Findings related to comparison of the traditional and the video-based methods are presented in Woods et al., 1997a; results of analysis of the walking task are presented in Woods et al., 1997b.) The participant then spent approximately 5 min completing a questionnaire regarding the extent to which the clothing and equipment being worn hindered his performance. A 10-min rest followed during which any armor or load-carrying gear was removed. Testing resumed with the next condition and continued until three conditions were completed. For half the participants, testing of the conditions was always conducted using the traditional techniques first, followed by the video-based techniques; for the remaining participants, the video-based techniques were used first.

## Statistical Analyses

Each of the seven planar movements was analyzed separately. All analyses were carried out on a personal computer using SPSS/PC+, version 3.1. Analyses of variance

(ANOVAs) for repeated measures on three factors were performed. The factors were: Base Clothing (shorts, uniform), Armor Vest (no armor, PASGT vest, prototype vest), and Load-Carrying Equipment (no gear, ALICE gear, TLBV gear).

The raw data entered into the ANOVAs were the means of a participant's two trials for a clothing and equipment condition. The significance level for the analyses was set at $p < .05$. In those instances in which a main effect was found to be significant, Tukey's Honestly Significant Difference (*HSD*) procedure was applied as a post hoc test, with the significance level again set at $p < .05$.

# Results

The results of the ANOVA performed on each planar movement are summarized in Table 3. Table 4 lists the means for each level of the base clothing, the armor vest, and the load-carrying equipment variables. The results of the Tukey *HSD* tests performed on the significant armor and load-carrying equipment main effects are also included in Table 4.

### Standing Trunk Flexion

Standing Trunk Flexion was the only planar movement that involved bending at the waist. It was also the one movement on which lower scores indicated a greater extent of movement. As can be seen in Table 3, the ANOVA performed on the Standing Trunk Flexion data did not yield any significant interactions. However, all main effects were significant ($p < .05$). In terms of the base clothing variable, the use of a T-shirt and shorts resulted in significantly better performance than did use of the uniform. With regard to the effect of armor vest, the best scores were achieved when armor was not worn and the worst were associated with the PASGT vest. Scores for the PASGT differed significantly from scores for the two remaining conditions. On the other hand, performance with the prototype vest did not differ significantly from performance without armor (Table 4). For the load-carrying variable, the best performance was associated with the condition in which load-carrying gear was not worn. The scores for this condition differed significantly ($p < .05$) from the scores for the two conditions in which load-carrying gear was used. The worst scores were obtained with the ALICE gear, and these scores differed significantly not only from those for the no-gear condition, but also from scores for the TLBV gear (Table 4).

### Ventral-Dorsal Head Flexion

The ANOVA for the Ventral-Dorsal Head Flexion movement did not yield a significant main effect of base clothing ($p > .05$). However, the armor vest and the load-carrying equipment main effects were significant (Table 3). With regard to the armor main effect, the best performance was achieved when armor was not worn, with the scores for this condition differing significantly from the scores for the two conditions in which an armor vest was used. The worst performance occurred with the PASGT vest, and the scores for this condition differed from the scores for the no-armor and the prototype armor conditions (Table 4). Findings related to the load-carrying equipment variable revealed that the best performance on the Ventral-Dorsal Head Flexion movement occurred when load-carrying gear was not used. Scores for this condition differed significantly from the worst scores, which were those for the TLBV gear. The

**Table 3**
*Summary of ANOVAs for the Planar Movements*

| | | Movement $F$ ratio | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Source of Variance | *df* | 1. Trunk Flexion | 2. Head Flexion | 3. Head Rotation | 4. Arm Abduction | 5. Arm Extension | 6. Leg Abduction | 7. Leg Flexion |
| Subjects (*Ss*) | 11 | — | — | — | — | — | — | — |
| Base Clothing (B) | 1 | 10.85** | 4.31 | 0.01 | 6.60* | 0.71 | 5.30* | 93.06*** |
| *Ss* x B | 11 | (26.63) | (118.11) | (121.03) | (153.03) | (146.72) | (217.08) | (78.34) |
| Armor Vest (A) | 2 | 10.56*** | 33.82*** | 12.74*** | 34.63*** | 11.38*** | 3.49* | 1.75 |
| *Ss* x A | 22 | (15.14) | (129.77) | (212.72) | (87.54) | (104.68) | (46.88) | (71.76) |
| B x A | 2 | 0.77 | 2.34 | 2.09 | 1.00 | 0.36 | 0.34 | 1.19 |
| *Ss* x B x A | 22 | (7.61) | (29.74) | (126.69) | (62.94) | (45.92) | (47.09) | (47.13) |
| Load-Carrying Equipment (L) | 2 | 15.60*** | 6.90** | 3.89* | 63.98*** | 7.41** | 0.83 | 17.15*** |
| *Ss* x L | 22 | (19.95) | (60.73) | (107.93) | (64.54) | (104.35) | (72.66) | (71.96) |
| B x L | 2 | 0.49 | 6.55** | 0.39 | 0.78 | 0.33 | 0.98 | 0.78 |
| *Ss* x B x L | 22 | (5.09) | (49.07) | (140.91) | (62.19) | (48.49) | (83.42) | (36.49) |
| A x L | 4 | 0.13 | 0.70 | 1.25 | 2.23 | 1.57 | 0.42 | 1.31 |
| *Ss* x A x L | 44 | (9.77) | (89.72) | (187.42) | (74.29) | (80.34) | (66.98) | (38.01) |
| B x A x L | 4 | 1.89 | 1.78 | 1.95 | 0.18 | 2.50 | 3.07* | 1.33 |
| *Ss* x B x A x L | 44 | (9.60) | (78.62) | (58.39) | (49.76) | (38.11) | (37.30) | (28.34) |

*Note.* Values enclosed in parentheses represent mean square errors.
$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

**Table 4**
*Means on the Planar Movements for Each Level of the Base Clothing, Armor Vest, and Load-Carrying Equipment Variables*

| Movement | Base Clothing[a] | | Armor Vest[b] | | | Load-Carrying Equipment[b] | | |
|---|---|---|---|---|---|---|---|---|
| | Shorts | Unif | No Armor | PASGT Vest | Proto Vest | No Gear | ALICE Gear | TLBV Gear |
| 1. Standing Trunk Flexion (cm) | 43.96 A | 46.27 B | 43.74 X | 46.70 Y | 44.90 X | 43.05 a | 47.21 b | 45.09 c |
| 2. Ventral-Dorsal Head Flexion (deg) | 80.41 A | 77.34 A | 87.11 X | 71.58 Y | 77.94 Z | 81.36 a | 78.73 ab | 76.54 b |
| 3. Head Rotation (deg) | 127.39 A | 127.40 A | 130.59 X | 120.32 Y | 131.27 X | 129.94 a | 125.13 b | 127.12 ab |
| 4. Upper Arm Abduction (deg) | 142.27 A | 137.94 B | 147.23 X | 134.53 Y | 138.57 Z | 148.78 a | 136.69 b | 134.85 b |
| 5. Upper Arm Forward Extension (deg) | 173.54 A | 172.15 A | 177.54 X | 170.36 Y | 170.63 Y | 176.62 a | 170.80 b | 171.11 b |
| 6. Upper Leg Abduction (deg) | 64.93 A | 60.32 B | 63.65 X | 60.90 Y | 63.33 X | 63.66 a | 62.28 a | 61.94 a |
| 7. Upper Leg Flexion (deg) | 105.46 A | 93.84 B | 100.62 X | 98.15 X | 100.20 X | 103.56 a | 95.31 b | 100.10 a |

[a]Those levels that do not share the same letter were significantly different ($p < .05$) in the ANOVA.
[b]Those levels that do not share the same letter were significantly different ($p < .05$) on the Tukey *HSD* test.

intermediate scores, those for the ALICE gear, did not differ significantly from the scores for the other two conditions (Table 4).

In addition to the significant main effects of armor and load-carrying equipment, the Ventral-Dorsal Head Flexion movement yielded a significant first-order interaction ($p < .05$) between the base clothing and the load-carrying equipment variables (Table 3). This interaction is presented graphically in Figure 1. The significant finding appears to be attributable to the fact that, with the uniform serving as the base clothing, the extent of head flexion when load-carrying equipment was not worn was approximately equal to that achieved when either type of carrying gear was used. On the other hand, when a T-shirt and shorts were worn, performance was better without the load-carrying equipment than with it. Furthermore, it can be seen in Figure 1 that the mean score when the ALICE gear was worn with a T-shirt and shorts was highly similar to the mean score when the ALICE gear was worn with the uniform. The means for the TLBV gear were also approximately equal under the two base clothing conditions.

## Head Rotation

For Head Rotation, the other head movement included in this study, there was again no significant main effect of base clothing ($p > .05$), and the main effects of armor vest and of load-carrying equipment were significant (Table 3). Furthermore, there were no significant interactions on the Head Rotation movement. With regard to the armor effect, the poorest performance occurred when the PASGT vest was worn. The scores for the PASGT differed significantly from the scores for the no-armor and the prototype armor vest conditions, but performance with the prototype vest did not differ significantly from performance without armor (Table 4). In terms of the effects of load-carrying equipment on Head Rotation, the best scores were achieved when load-carrying equipment was not worn, and the worst were associated with the ALICE gear. The scores for the no-gear and for the ALICE gear conditions differed significantly ($p < .05$). The intermediate scores, those for the TLBV gear, did not differ significantly from the scores for the other two load-carrying conditions (Table 4).

## Upper Arm Abduction

Analysis of the Upper Arm Abduction movement revealed a significant main effect of base clothing ($p < .05$), with scores when a T-shirt and shorts were worn being superior to those when the uniform was used. The armor vest and the load-carrying equipment main effects were also significant on the Upper Arm Abduction movement, but there were no significant interactions (Table 3). With regard to the armor effect, the best scores were achieved when armor was not used; scores under this condition differed significantly ($p < .05$) from the scores for the two conditions in which an armor vest was worn. The poorest performance was associated with the PASGT vest. Scores for

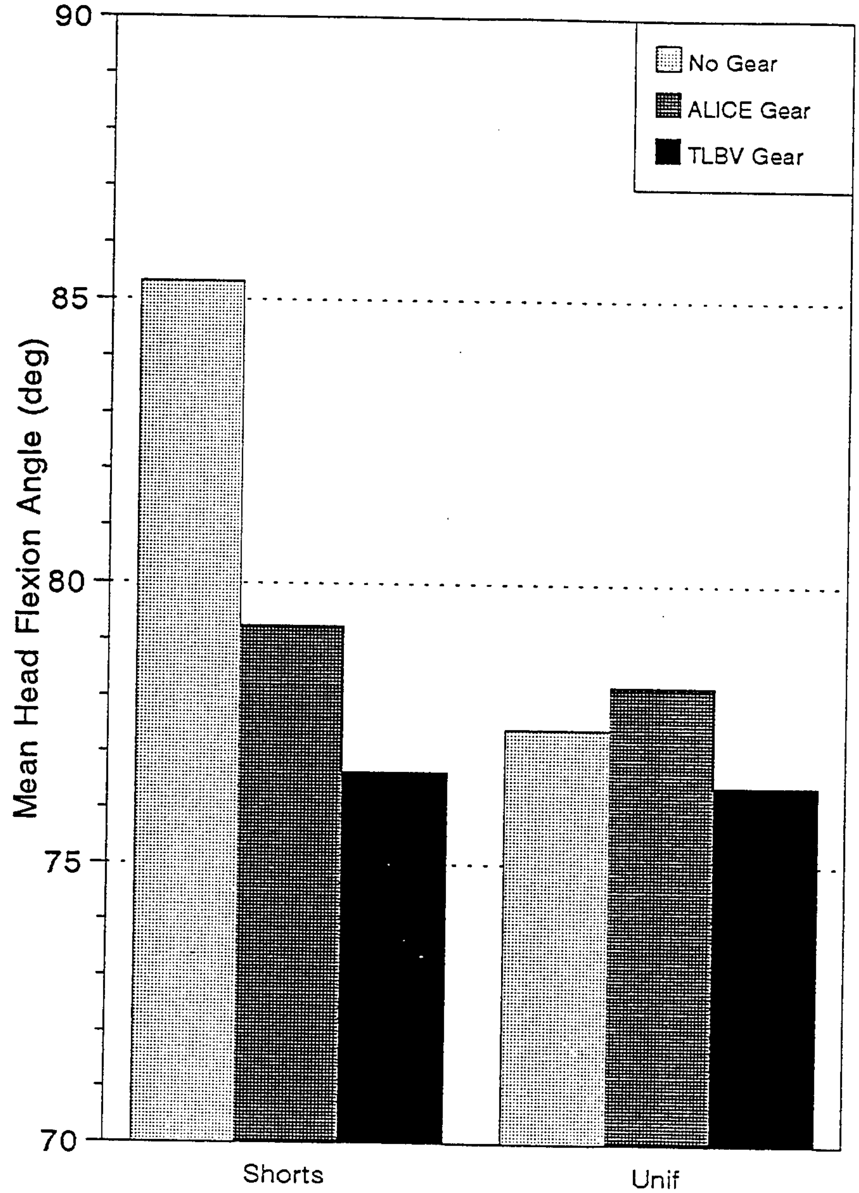


*Figure 1.* Mean Head Flexion angle for each load-carrying equipment condition under each base clothing condition.

this vest differed significantly not only from those for the no-armor condition, but also from the scores for the prototype vest (Table 4). The significant main effect ($p < .05$) of load-carrying equipment on Upper Arm Abduction was attributable to the fact that the best scores, those for the condition without load-carrying equipment, differed significantly from scores for both the ALICE and the TLBV gear. The scores for the two types of gear did not differ significantly from each other (Table 4).

## Upper Arm Forward Extension

Unlike the analysis of the Upper Arm Abduction data, the analysis of the Upper Arm Forward Extension data did not yield a significant main effect of base clothing ($p > .05$). However, both the armor and the load-carrying equipment main effects were again significant ($p < .05$), and no interactions achieved significance (Table 3). Of the three levels of the armor variable, performance was best without any armor. Scores under the no-armor condition differed significantly ($p < .05$) from the scores for the PASGT and the prototype armor vests. There was no significant difference between the scores for the two types of armor (Table 4). With regard to the load-carrying variable, the condition in which the gear was not worn resulted in the best performance on the Upper Arm Abduction movement. Scores for the no-gear condition differed significantly ($p < .05$) from scores for the two conditions in which load-carrying gear was used. However, there was no significant difference between scores for the ALICE and the TLBV gear (Table 4).

## Upper Leg Abduction

Of the seven planar movements included in this study, Upper Leg Abduction was the only one that was not significantly affected by the load-carrying equipment variable. However, the main effects of base clothing and of armor were significant ($p < .05$), as was the second-order interaction (Table 3). With regard to base clothing, scores for the T-shirt and shorts were better than those for the uniform. In terms of the armor effect, wearing the PASGT vest resulted in the poorest performance. Scores for this condition differed significantly ($p < .05$) from scores for the no-armor and the prototype armor conditions, which did not differ from each other (Table 4).

The significant interaction ($p < .05$) of base clothing, armor vest, and load-carrying equipment on the Upper Leg Abduction movement is presented graphically in Figure 2. The significant interaction appears to be attributable mainly to differences in the effects of the load-carrying variable on performance when participants were outfitted in the PASGT vest and a T-shirt and shorts as opposed to the PASGT vest and the uniform. In a T-shirt, shorts, and the PASGT vest, the participants obtained better scores when using the TLBV gear than when using the ALICE or when not using any load-carrying equipment. In the uniform and the PASGT vest, the participants obtained scores for the TLBV gear that were lower than the scores for the ALICE and for the no-gear conditions. Differences in performance associated with the prototype vest may also have contributed to the significant interaction. When a T-shirt, shorts, and the prototype vest were worn, scores for the ALICE gear were superior to those for the TLBV and for the no-gear conditions. When the uniform and the prototype vest were worn, scores for the ALICE were inferior to those for the TLBV and for the no-gear conditions.

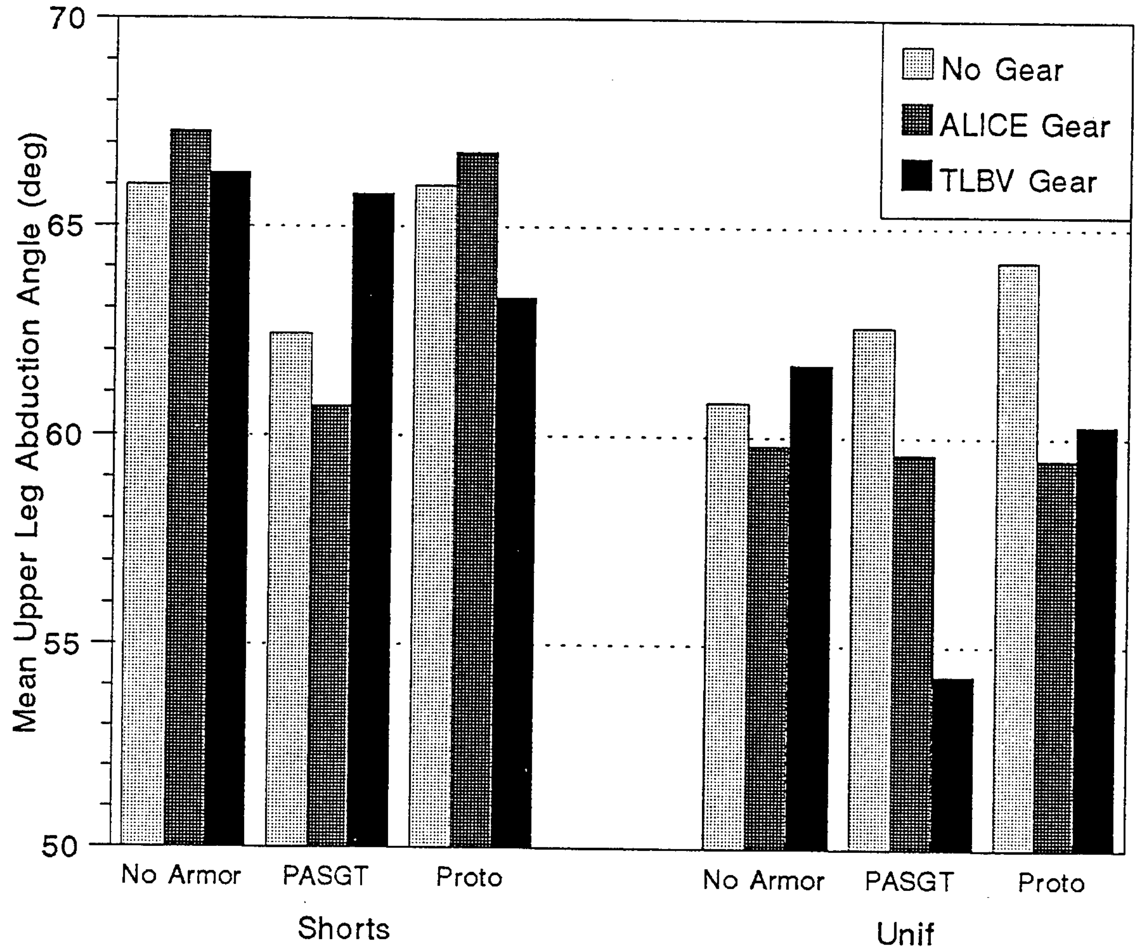


*Figure 2.* Mean Upper Leg Abduction angle for each load-carrying equipment condition under each base clothing and armor vest condition.

### Upper Leg Flexion

Unlike the Upper Leg Abduction data, analysis of the Upper Leg Flexion data did not reveal any significant interactions ($p > .05$). Furthermore, Upper Leg Flexion was the only one of the seven planar movements performed by the participants that did not yield a significant effect of armor vest. The base clothing and the load-carrying equipment main effects were significant ($p < .05$), however (Table 3). With regard to the significant base clothing effect, performance in a T-shirt and shorts was superior to performance in the uniform. In terms of the load-carrying equipment variable, the poorest performance was associated with the ALICE gear. Scores for the ALICE differed significantly from scores for the no-gear and the TLBV conditions, which did not differ significantly from each other (Table 4).

# Discussion

The testing of study participants in a T-shirt and shorts and in the Temperate BDU was of interest because of the possibility that the base clothing would interact with the armor vest and the load-carrying equipment variables to differentially affect performance of the planar movements. There were two instances in which a significant interaction involving this base clothing was obtained, Ventral-Dorsal Head Flexion and Upper Leg Abduction.

Base clothing interacted with the load-carrying equipment variable on the Ventral-Dorsal Head Flexion movement. With a T-shirt and shorts as the base clothing, the extent of head flexion was greater when load-carrying equipment was not worn than when it was. On the other hand, with the uniform as the base clothing, the extent of head flexion was unaffected by the presence or absence of load-carrying gear. Thus, in executing the head flexion movement, there is an advantage to use of a T-shirt and shorts, rather than the uniform, only when load-carrying gear is not also worn.

The other significant interaction involving base clothing involved both the armor and the load-carrying variables and was obtained on the Upper Leg Abduction movement. The relationship among means for the various levels of the independent variables indicates that load-carrying equipment has a more deleterious effect on leg abduction when it is used with the uniform and an armor vest than when it is used with a T-shirt, shorts, and an armor vest.

The analyses of the Head Flexion and the Upper Leg Abduction movements were the only ones to yield a significant interaction involving base clothing. Furthermore, the interaction between the armor and the load-carrying variables was not significant in the analyses of any of the movements. There were a number of instances, however, in which the analyses of the movements did reveal significant main effects on performance associated with the base clothing, the armor, or the load-carrying equipment variables.

### Base Clothing

Four of the seven planar movements were significantly affected by the base clothing worn. The movements were Standing Trunk Flexion, Upper Arm Abduction, Upper Leg Abduction, and Upper Leg Flexion. In each instance in which a significant main effect was obtained, performance with a T-shirt and shorts was superior to performance with the Temperate BDU. For the planar movements significantly affected by base clothing, the extent to which the uniform restricted body motion relative to that with a T-shirt and shorts varied with the movement; scores for the uniform ranged from 3% lower than those for a T-shirt and shorts (on Upper Arm Abduction) to 12% lower (on Upper Leg Flexion).

In their study that included comparison of the effects of a T-shirt and shorts and the Temperate BDU on range of motion, Bensel et al. (1987) tested study participants in the base clothing only, without armor vests or load-carrying equipment. Using traditional measurement techniques, Bensel et al. investigated the seven planar movements used in the present research, plus some additional ones. With one exception, the present study replicated the findings of Bensel et al. for the seven movements. The exception was Standing Trunk Flexion, which yielded a significant clothing effect in the present study, but not in the investigation by Bensel et al. There was a difference between the studies in the methodology used on the trunk flexion movement that may account for the difference in the findings. In the Bensel et al. study, participants stood on the floor. In the present study, participants stood on a low bench, 29 cm above the floor, and could, potentially, reach down beyond the standing surface. Because of this methodological difference, the Standing Trunk Flexion movement as performed in the present study may have been more sensitive to clothing effects than it was as performed in the study by Bensel et al.

In the present study and in the investigation by Bensel et al. (1987), analyses of the head movements did not reveal significant main effects of clothing. Thus, the Temperate BDU with its flat collar does not appear to restrict head movement relative to that achieved when the collarless T-shirt is worn. Both studies did find significant differences between clothing outfits on the Upper Arm Abduction movement. This movement, which requires raising the arms in the body's coronal plane, is likely to be affected by the length of the armhole opening of upper torso clothing.

On the body itself, the arm-shoulder complex of joints is the origin of the angle generated as the arm is abducted. On the clothing, the origin of the angle formed during Upper Arm Abduction is the lowest point of the armhole opening. As the distance between this origin and the body's origin for the formation of the angle increases, Upper Arm Abduction is decreased. To permit unrestricted movement in the body's coronal plane, the underside of the arm and the corresponding surface of the sleeve must remain essentially parallel during arm movement. Lengthening of the armhole opening results in the formation of an acute angle between these two surfaces as the arm is abducted. The more limited the circumference of the sleeve and the extensibility of the fabric, the more the dorsal surface of the upper arm will be bound by the sleeve, and arm movement will thereby be restricted. The armhole openings of the BDU are longer than those of the T-shirt because the latter is designed to be worn next to the skin. Thus, the armhole openings of the BDU extend further down the side of the body, below the arm scye, than do the armholes of a T-shirt and likely restrict the extent of Upper Arm Abduction.

There are other factors that may interact with armhole dimensions to affect Upper Arm Abduction. One factor is the ease with which the sleeves of the clothing ride up the arm as the arm is abducted. The sleeves of a T-shirt are short. The sleeves of the BDU, on the other hand, extend to the wrist and are buttoned there and thus may limit the degree to which the arm can be abducted. In addition, the sleeves of the T-shirt are made of stretchable, cotton-knit material that should not impose restrictions on arm-shoulder movements.

Unlike Upper Arm Abduction, the Upper Arm Forward Extension movement was not significantly affected by the clothing variable either in the present study or in the study by Bensel et al. (1987). Upper Arm Forward Extension requires that the arm be moved at the shoulder in the sagittal plane. It is not likely that this movement would be affected by the armhole opening characteristics of the clothing used in these studies because the arm movement required is parallel to the plane of the armhole opening.

Both leg movements included in the present study were significantly affected by the base clothing worn, as they were in the study by Bensel et al. (1987). One of the movements, Upper Leg Abduction, requires the raising of the leg in the body's coronal plane, with the leg being kept straight at the knee. Clothing could limit this movement by binding the lateral surface of the upper leg. This appears to have been the case in the two studies given that performance in the shorts was superior to performance in the uniform with its long trouser legs. The second leg movement, Upper Leg Flexion, involves movement in the body's sagittal plane. The leg is bent at the knee and the upper leg is raised toward the chest as far as possible. Upper Leg Flexion would be expected to be sensitive to the binding of the ventral or dorsal surfaces of the upper leg by the clothing. It is likely that the longer trouser legs of the uniform bound the sensitive surface of the leg to a greater extent than the shorts did on both movements.

## Armor Vests

The armor variable had a significant effect on performance of six of the seven planar movements. These results mirror those found by Bensel et al. (1980). The movement that failed to reveal a significant effect in either study was Upper Leg Flexion. Both the PASGT and the prototype vests are designed to extend below the wearer's waist. The origin of the Upper Leg Flexion movement is approximately the greater trochanter (i.e., the top of the thigh) rather than the waist, and even unencumbered it is not possible to lift the leg in the sagittal plane such that the thigh is at the level of the waist or above. Therefore, it is expected that this movement would be unaffected by the armor variable in this study.

On the remaining six movements common to the Bensel et al. (1980) study and to the present one, both studies generally found that use of the PASGT vest restricted body motion significantly compared with use of the regular duty uniform alone. In this study, scores for the PASGT vest condition were approximately 5% to almost 20% lower than scores for the no-armor condition. Furthermore, performance with the PASGT vest was significantly worse than performance with the prototype armor vest on all movements except Upper Arm Forward Extension and Upper Leg Flexion. Not only was the prototype vest associated with superior performance relative to the PASGT, but there were three movements on which scores with the prototype did not differ significantly from scores for the no-armor condition. These were Standing Trunk Flexion, Head Rotation, and Upper Leg Abduction. Thus, on only one movement, Upper Arm Forward Extension, were scores for the two armor vests essentially equal to each other and significantly poorer than those achieved when an armor vest was not worn.

The PASGT and the prototype vests are of the same design. The prototype, which is available only in a size medium, is made from the same pattern used to produce the size medium PASGT. Thus, the two vests have the same dimensions. In addition, the shells of both vests are made of the same ballistic nylon cloth. However, the vests do differ in the ballistic filler materials used. Thirteen plies of Kevlar are used in the PASGT, whereas the filler materials in the prototype consist of metal platelets attached to a fabric backing. The platelets are laid out so that they do not overlap each other. Because of the differences in the filler materials, the prototype vest is more flexible than the PASGT. This greater flexibility appears to be the reason for the superior range-of-motion performance with the prototype.

### Load-Carrying Equipment

Upper Leg Abduction was the only movement that did not yield a significant effect of the load-carrying variable. On the remaining movements, performance without load-carrying gear was superior to performance with it. A significant difference between the two types of load-carrying gear was obtained on only two movements, Standing Trunk Flexion and Upper Leg Flexion. In both instances, use of the ALICE resulted in greater restriction of movement than use of the TLBV gear did.

Standing Trunk Flexion, which requires bending at the waist in the body's sagittal plane, should be sensitive to the bulk and rigidity of items worn at the waist. Both the ALICE and the TLBV gear include an identical waist belt. In this study, a canteen with cover and an entrenching tool with carrier were attached to the belt of the ALICE and of the TLBV. The canteen and the entrenching tool were placed on the front of the body toward the right and left sides of the body, respectively. The ALICE gear also included two ammunition cases that were attached to the front of the waist belt, one on each side of the buckle. With the TLBV gear, the ammunition was carried above the waist in pockets attached to the chest area on the vest. It appears that bending at the waist is restricted to a greater extent with the ALICE gear than with the TLBV because the ALICE has bulky, protruding, and rigid cases located at waist level. However, it was found in this study that performance when the TLBV was worn was significantly poorer than performance when load-carrying gear was not used. Therefore, the items worn at the waist in the TLBV configuration also restrict waist flexion to some extent.

Upper Leg Flexion, the other movement on which performance with the ALICE was significantly worse than performance with the TLBV gear, involves raising the upper leg toward the chest in the body's sagittal plane. The ammunition cases hanging down from the equipment belt again appear to be the potent factor in limiting the extent of leg flexion with the ALICE gear; as the upper leg is raised, the thigh contacts the bottom edges of the cases. Also, Upper Leg Flexion did not yield a significant difference between scores for the TLBV gear and scores when load-carrying gear was not worn. This is further evidence that it is the ammunition cases on the ALICE gear that restrict leg flexion, and not the canteen, entrenching tool or the waist belt itself, as these components are common to both the ALICE and the TLBV gear.

Neither arm movement revealed a significant difference between the scores for the two types of load-carrying equipment, but performance of both movements was significantly poorer when the gear was worn than when it was not used. Upper Arm Abduction and Upper Arm Forward Extension involve raising the arm in the body's coronal and sagittal planes, respectively. With the load-carrying gear, much of the load is borne on the shoulders and, thus, rotation at the shoulder joint could well be restricted relative to the extent of movement when load-carrying gear is not worn. Not only the load being carried, but the design of the carrying equipment itself, may restrict the arm movements. For example, on the ALICE, the suspenders attach only to the waist belt; the TLBV has panels of material on the front and back of the vest and the shoulder straps are connected to the panels, as well as to the waist belt. The ALICE waist belt may move more freely as the arm is raised than the combination of the TLBV vest and belt, regardless of the loads being worn on the gear. However, there is no evidence in the findings from the present study that the design differences between the ALICE and the TLBV differentially affect performance of the arm movements.

The two head movements yielded similar findings insofar as scores with the ALICE gear did not differ significantly from those with the TLBV gear. However, on Ventral-Dorsal Head Flexion, there was no significant difference between performance with the ALICE and performance without any load-carrying equipment, whereas performance with the TLBV was significantly poorer than performance without any equipment. For the Head Rotation movement, on the other hand, scores with the TLBV did not differ significantly from scores without any equipment, but scores for the ALICE gear did. Head flexion with the TLBV may be limited by the protruding ammunition pockets in the chest area of the vest. The most obvious feature of the ALICE that would be likely to restrict head rotation is the suspenders, which pass over each shoulder. However, the TLBV also has shoulder straps. It is possible that the ALICE suspenders pass closer to the wearer's neck than the TLBV straps do, thereby imposing a somewhat greater limitation on head rotation.

# Conclusions

The findings from this study suggest that, in general, the greater the bulk an item of clothing or individual equipment adds about a given joint, the greater the restriction about that joint. Even the loose-fitting BDU coat and trousers constrain movement compared with a T-shirt and shorts.

Of the two types of armor vests evaluated in this study, the prototype clearly imposes less restriction than the PASGT does at a number of joints. Furthermore, depending upon the movement being executed, body motions are limited to no greater extent with the prototype vest than with the base clothing alone. Thus, the performance of field troops may well benefit from use of the prototype vest, rather than the PASGT. Further development of the prototype vest should be pursued if testing of its ballistic properties reveals that the prototype provides the required level of protection.

With regard to the load-carrying equipment tested, range of motion with the TLBV is equal to or better than that with the ALICE gear. The superiority of the TLBV gear is particularly noteworthy on movements that involve flexing at the waist and flexing of the legs, motions that are restricted with the ALICE because of the ammunition cases on the waist belt. In addition, there is no evidence that the TLBV limits arm movements to any greater extent than the ALICE gear does. The load is more evenly distributed over the torso with the TLBV than with the ALICE. Wearers may therefore find the TLBV to be more comfortable than the ALICE gear after prolonged use.

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APPENDIX

# DESCRIPTIONS OF ARMOR VESTS AND LOAD-CARRYING EQUIPMENT

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## Fragmentation Protective Vest, Personnel Armor System for Ground Troops (PASGT Vest)

The standard-issue, PASGT vest is made of 13 plies of ballistic filler. The filler is water-repellent treated Kevlar with a weight of 474.8 $g/m^2$. The inner and the outer shells are water-repellent treated ballistic nylon with a weight of 271.3 $g/m^2$. The layer that makes up the inner cover of the vest is olive green. The outer cover is in camouflage colors and design. The ballistic filler in the back of the vest is divided into four sections. The three, upper sections slide over each other and the lower section during body movement. The closure, which runs the length of the front of the vest, is formed with hook and pile fastener tape. The side overlaps are made flexible through the use of sewn-in, elastic webbing that is 3.8 cm wide. The vest also has a fragmentation protective, 3/4 stand-up collar, articulating shoulder pads with elastic webbing and snaps, two front pockets, and rifle butt patches at the shoulders. The ballistic materials in the PASGT vest provide protection from fragmenting munitions. In a size medium, this vest weighs 4.0 kg.

## Multiple-Threat Body Armor (Prototype Vest)

This prototype of a multiple-threat vest is identical in design to the PASGT vest. Like the PASGT, it has a 3/4 stand-up collar, a closure that runs the length of the front of the vest, side overlaps, articulating shoulder pads, two front pockets, and rifle butt patches. The inner and the outer shells are made of the same ballistic nylon material, in the same colors, that is used in the PASGT. However, the prototype and the PASGT vests differ in the ballistic filler used. Instead of Kevlar, the ballistic filler in the prototype consists of rigid, metal platelets attached to multiple layers of a fine denier, woven fabric. The woven fabric, which serves as a backing for the platelets, is on the side of the vest closest to the body and the platelets face away from the body. In the PASGT vest, the ballistic filler at the back of the vest is divided into sections. This is done to minimize constraints on the wearer when the torso is flexed. The ballistic filler in the prototype is not divided into sections. To minimize constraints on the wearer, the platelets are laid out such that no platelets overlap. The prototype is available only in a size medium, which is made from the same pattern used for the size medium PASGT vest. The weight of the vest is 3.5 kg.

## Fighting Load, All-Purpose Lightweight Individual Carrying Equipment (ALICE Gear)

This standard-issue, load-carrying gear includes an equipment belt that is worn around the waist and suspenders that cross over the shoulders and attach to the front and the back of the belt. Components of the fighting load are attached to the belt. These include two ammunition cases, an entrenching tool with a carrier, and a 1-quart canteen with a cover. Each ammunition case has two external pockets for fragmentation grenades. For this study, the canteen was filled with water and each ammunition case was loaded with weights totalling 1.6 kg to simulate the weight and the bulk of three, 30-round magazines of M16 ammunition. One of the two grenade pockets on each ammunition case was filled with weights totalling 0.5 kg, the weight of a fragmentation grenade. The total weight of the ALICE fighting load was 7.8 kg.

## Tactical Load-Bearing Vest (TLBV Gear)

The basic components of this load-carrying gear are a vest and a waist belt. The belt is the same one that is part of the ALICE fighting load. The vest, which is made of nylon, has a front opening that is secured by two, horizontal straps with plastic buckles. One strap is slightly above the level of the sternum and the other is slightly above the level of the waist. There are two parts to the vest: shoulder straps and a torso portion. The parts of the vest that pass over the shoulders are padded and have strips of webbing that are connected in the back and in the front by buckles to the torso portion of the vest. By use of the buckles and webbing, the vest can be raised and lowered on the torso. On the upper back of the vest, there is also a wide band of webbing, positioned horizontally, that is sewn to both shoulder straps and serves to keep the straps from slipping off the wearer's shoulders. Below the webbing is a panel of material that is secured to the front part of the vest by lacing. The purpose of this feature is to allow the wearer to adjust the circumference of the vest to conform to the circumference of the torso by using the lacing. Placed around the bottom edge of the vest are 10 loops. The waist belt is passed through the loops and thereby secured to the vest. Four ammunition pockets are sewn in a row on the front of the vest, at about the level of the chest. Two pockets are large enough to hold two, 30-round magazines each. Each of the other two pockets holds one, 30-round magazine. Two, smaller pockets are sewn below the ammunition pockets. Each of the smaller pockets accommodates one fragmentation grenade. Additional components of this load-bearing gear are an entrenching tool with a carrier and a 1-quart canteen with a cover. These are the same items that form part of the ALICE fighting load. As in the case of the ALICE, the entrenching tool and the canteen are attached to the waist belt. For this study, the canteen was filled with water. The larger ammunition pockets were each loaded with weights totalling 1.1 kg, the weight of two, 30-round magazines. Each of the smaller ammunition pockets was loaded with weights of 0.5 kg, the weight of one, 30-round magazine. Weights of 0.5 kg were placed in each grenade pocket. The total weight of this load-bearing gear was 9.1 kg.