# Evaluation of the Low Intensity Threat Environment Armor Plate and Third Generation Plate Carrier System for the United States Marine Corps

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The study protocol was approved by the Naval Health Research Center Institutional Review Board in compliance with all applicable Federal regulations governing the protection of human subjects. Research data were derived from an approved Naval Health Research Center, Institutional Review Board protocol number NHRC.2018.0014

## EXECUTIVE SUMMARY

PURPOSE: To compare a new low intensity threat environment armor plate and third generation plate carrier system (PC GEN III+LW) to the currently fielded enhanced small arms protective insert armor plate and legacy plate carrier system (Legacy+ESAPI) for combat effectiveness, comfort and fit.

METHODS**:** Activ-duty Marines from 3rd Battalion, 1st Marine Division aboard Camp Pendleton (San Diego, CA) were recruited for this effort. To analyze the effect of each body armor configuration on subsequent changes to metrics of physiology (heart rate and caloric expenditure), countermovement jump performance (peak force, peak power, and modified reactive strength index), and subjective opinion (comfort, maneuverability, and fatigue) data were collected during various training activities. These activities included field ruck march training, unit physical training, and culmination exercises over several weeks.

RESULTS: The PC GEN III+LW body armor arrangement resulted in a significantly lighter absolute and relative load when compared to the Legacy+ESAPI personal protective configuration. Although relative and absolute loads were lighter when wearing the PC GEN III+LW, the body's physiological response to each activity (average heart rate and caloric expenditure) were not significantly different. Nevertheless, Marines wearing the PC GEN III+LW expressed greater performance changes in peak power and modified reactive strength index during the countermovement jump task. From a subjective standpoint, Marines preferred the PC GEN III+LW body armor for its overall comfort, maneuverability, and subsequent perception of fatigue. However, Marines expressed recurrent themes requesting ergonomic alterations of the PC GEN III+LW to include a kangaroo pouch, an updated/strengthened buckle system, and more robust hook-and-loop closures.

CONCLUSIONS: In comparison to the Legacy+ESAPI personal protective equipment system, the PC GEN III+LW is lighter and offers improved subjective ratings of comfort, mobility and feelings of fatigue. These metrics support transitioning to the PC GEN III+LW. However, further modification to the system is required to support needs of the Infantry Marine.

**BACKGROUND:**

United States Marine Corps (USMC) assault loads are greater than the recommended weight of 22.7 kg (~ 30% of body weight) and commonly range from 44 kg for the rifleman to 61 kg for the squad leader; thus, emphasizing a need to decrease the weight of the load carried. As a result, for the past seven years NHRC has conducted a variety of load carriage studies evaluating various PPE and backpack systems (IRB protocol numbers: NHRC.2010.0007, NHRC.2011.0023, NHRC.2012.0012, NHRC.2013.0022, and NHRC.2013.0023) in support of the USMC's effort to lighten the load while adequately protecting the Marine. These studies outlined the negative relationship between load, task, and lumbar spine mechanics (Berry et al., 2017; Berry et al., 2018; Rodriguez-Soto et al., 2017; Rodriguez-Soto et al., 2017; Rodriguez-Soto et al., 2012). Moreover, carrying over 55 kg has been shown to increase the risk of injury by placing the spine in a rigid forward-flexed position which amplifies spinal compression (Neuschwander et al., 2010; Rodriguez-Soto et al., 2012). There is a growing occurrence of low back pain that is associated with heavy load carriage in military populations (Roy, Knapik, Ritland, Murphy, & Sharp, 2012; Ulaska, Visuri, Pulkkinen, & Pekkarinen, 2001). Thus, lightening the load may help reduce injury rates by limiting the total tissue stress placed on an individual.

Marines are required to carry standard equipment as well as wear personal protective equipment (PPE) which can weigh between 10-25 kg. Emerging technology to limit the impact of

excessive loads placed on the individual Marine has led to the development and manufacture of lighter weight armor plates, including the low intensity threat environment (LW) plate. The LW plate is constructed to be 40% lighter than the traditional enhanced small arms protective insert (ESAPI) currently in use by USMC. While one drawback of the LW armor plate is decreased ballistic protection, the LW plate remains a viable protection option in a majority of current threat environments. Moreover, the expected advantages for adopting the LW armor plate are: increased mobility, reduced injury risk, and fatigue mitigation.

Further reduction of load from PPE was accomplished via a lightened plate carrier, the third generation plate carrier system (PC GEN III), which was tested and refined as a result of previous work conducted by NHRC (NHRC.2013.0022). The PC GEN III is a modification of the second generation plate carrier system (PC GEN II denoted “Legacy”) aimed at providing improvements in the fit and mobility of the plate carrier by way of a slimmer and lighter design with comparable ballistic coverage. The PC GEN III includes a low-profile vest and integrated load bearing panel to support Reconnaissance, Military Police, and vehicle crewman MOSs at a 25% weight reduction when evaluated against the Legacy plate carrier. Lastly, the PC GEN III also features a quick-disconnect attachment system that allows for quick donning and removal of the plate carrier.

An evaluation of the combat effectiveness, mobility, and comfort of the PPE was requested by the Marine Corps System Command Infantry Combat Equipment prior to adoption and fielding of PC GEN III. Thus, the overall purpose of this effort was to compare the Legacy+ESAPI body armor configuration to the updated PC GEN III+LW personal protective equipment arrangement (Figure 1) for mobility and combat effectiveness during a variety of infantry specific combat tasks.

A.  B. 

Figure 1. Reference picture of (A) Legacy+ESAPI plate and (B) PC GEN III+LW. Legacy+ESAPI = Legacy plate carrier system with enhanced small arms protective insert armor plate, PC GEN III+LW = Third generation plate carrier with low intensity threat environment armor plate personal protective equipment configuration.

## METHODS:

### *Approach*

Active-duty Marines at 3rd Battalion, 1st Marine Division aboard Camp Pendleton (San Diego, CA) were recruited for this effort. To evaluate the effectiveness, comfort, and mobility of the Legacy+ESAPI and PC GEN III+LW PPE configurations, data was captured and compared between the two systems. Data collections occurred prior to, during, and following ruck marches (RM) in the field and physical training (PT) activities. Participant demographics can be found in Table 2, and are further broken down by each event. The metrics that were collected before and after each activity included: questionnaires, metrics of lower body performance, and physiological performance and health measures.

### *Training Activities*

*Ruck march/O-course*:

Four distinct RM were included in the evaluation of the two body armor systems. Each RM was performed over varying ground surfaces and involved both flat and mountainous terrain. In addition to the RM, activities A and D also included completion of the Marine standard obstacle course (O-course). The O-course was comprised of 14 jump, lift, and roll obstacles that the Marine was required to overcome. All obstacles were arranged in a straight line and spanned roughly 300 feet from start to finish. Dependent on the activity, completion of the O-course occurred at the halfway point (Activity A), or at the end (Activity D) of the RM. Total distances covered for each RM can be found in Table 1.

Table 1. Activity components and total distance of each ruck march training activity

| Activity | Distance |
|---|---|
| A. Hike, O-course | 5 miles |
| B. Hike | 3 miles |
| C. Hike | 5.5 miles |
| D. Hike, O-course | 1.75 miles |

O-Course = Marine standard obstacle course

*Physical Training*

Two unique physical training (PT) activities were included in the evaluation of each body armor system. The first PT activity (Activity E) was completed using a randomized crossover design allowing each Marine to complete the activity while wearing each PPE configuration. To conclude the activity, teams of four were tasked with a set of burpees (exercise 1) at the start line. Following completion of exercise 1, subjects advanced 10 yards and completed a set of push-ups (exercise 2) prior to returning to the start line. Once subjects returned to the start line, subjects were required to repeat this process while adding a new exercise in 10-yard increments until six

exercises had been completed. Exercises included in the activity were done for sets of ten in the following order: 1. burpees, 2. push-ups, 3. smurf jacks (jumping jacks while in a low squat position), 4. low crawl, 5. lunges, 6. buddy squats (squats while holding a partner over shoulders). Following completion of the sixth exercise, subjects were required to return to the start line before completing a ¼ mile causality carry marking the end of the activity. Throughout the entire activity, teams were also required to carry two 40-pound water canisters.

The second PT activity (Activity F) followed a cross-sectional design and was comprised of five 2-minute stations where the Marine had to complete a designated drill for the duration of the station. Subjects were split among the five exercise stations prior to the start of the activity. Following completion of the first 2-minute bout, subjects transitioned to the next station in a clockwise fashion until all exercises were finished. No rest was provided until all drills were complete. Exercises were chosen by the drill instructor and included: one-on-one ground fighting, burpees, flutter kicks, push-ups, and air squats. A diagram laying out each PT activity can be found in Figure 2.

*Load Distribution*

Body weight was recorded with and without the body armor system before each activity using the AND HV-150K (San Diego Scale Inc., San Diego, CA) industrial scale to calculate the absolute and relative load that was associated with each PPE configuration.

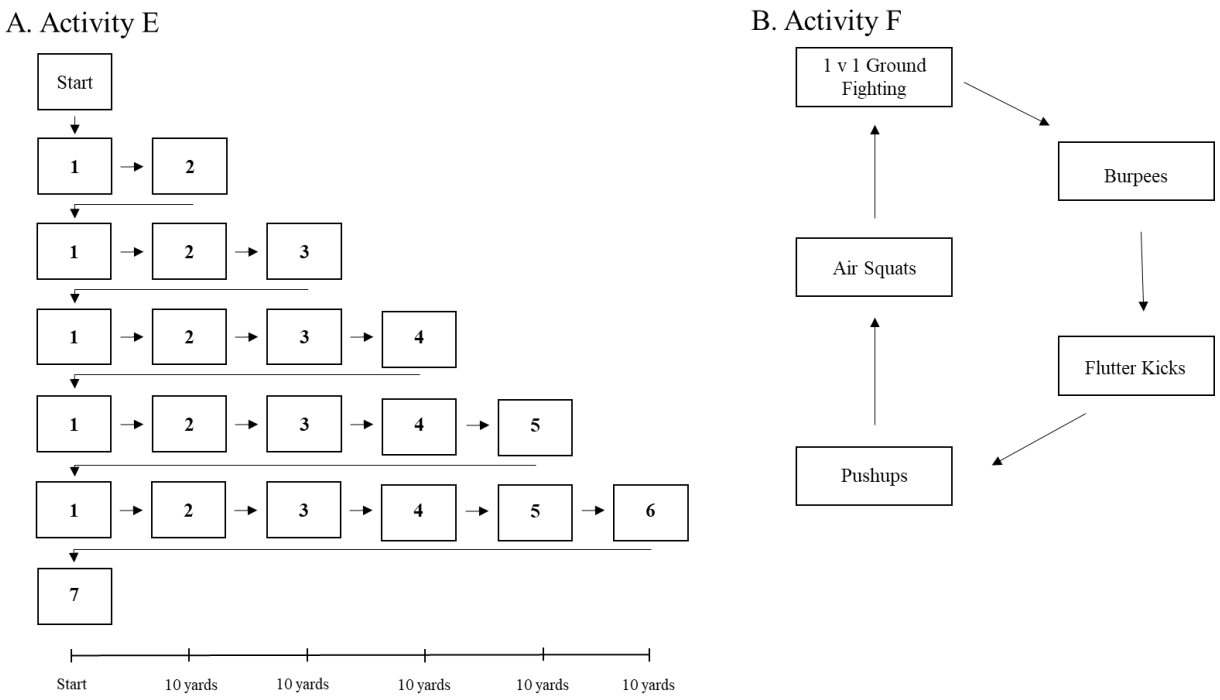



Figure 2. Sequence of exercises for physical training activity E (A) and F (B). Arrows indicate the direction of drill sequence. A) Physical training was completed in teams of 4. Numbers indicate the exercise completed: 1. burpees, 2. push-ups, 3. smurf jacks (jumping jacks while in a low squat position), 4. low crawl, 5. lunges, 6. buddy squats (squats while holding a partner over shoulders), 7. ¼ mile casualty carry while carrying two (40 lb.) jugs of water. B) Drills were performed in 2-minute bouts until all drills were completed.

*Physiological Measures*

Marines were fitted with a Polar Team Pro (Polar Team Pro Sensor, Polar Electro Inc., Bethpage, NY) heart rate strap to collect heart rate and estimated caloric expenditure. The Polar system was equipped with a soft strap and a small heart rate capture device (approximately 1” by 2” rectangular size) that secures under the t-shirt, body armor, and blouse worn as standard issue Marine Corps uniform.

To measure changes in lower body muscular strength and power, volunteers were asked to complete three countermovement jumps without the body armor on a ForceDecks dual force plate system (Vald Performance Pty Ltd., Queensland, Australia) before and after each activity. For the

countermovement jump, Marines were instructed to stand with hands on hips and perform maximal effort jumps with a self-selected depth and resetting their stance following each jump. Following completion of the three jumps, the top two trials were averaged and used for further analysis. Metrics used for evaluation included jump height, peak power, and reactive strength index modified (RSImod).

*Marine Questionnaires*

Before each activity, Marines were asked to provide a subjective rating of pain. Following each training activity, participants were asked to give individual ratings of perceived exertion (RPE, Modified Borg scale 1-10), fatigue state, pain, perception of mobility restrictions, and general comments of the system they were assigned to wear during the training activity. The pre- and post-activity questionnaires can be found in Appendix A and B.

*Statistical Analysis*

All statistical procedures were completed using R version 3.6.1 (Vienna, Austria). Due to the overall design of the research project, two separate statistical analyses were completed to determine differences between the two plate carrying systems. First, a 2 (body armor) x 5 (activity) ANOVA was conducted to determine any differences associated with body armor type for Activities A-D, and F. Second, a 2 (body armor) x 2 (activity) Mixed Design ANOVA was completed to determine differences associated with body armor type for the repeated measures design of Activity E (E-1 and E-2). Upon a significant finding, Benjamin-Hochberg adjusted *post*

*hoc* contrasts were conducted to determine where differences were significant. All statistical tests were set with an alpha level of .05.

**RESULTS:**

*Subjects*

Two hundred and forty-one active-duty Marines from 3rd Battalion, 1st Marine Division were recruited in the evaluation of the PC GEN III+LW body armor system. Of the 241 participants, 40 Marines were involved in the crossover portion of the study (Activity E). There were no differences ($p > 0.05$) between each PPE configuration when comparing age, height, or weight. Subject demographics for each activity can be found in Table 2.

Table 2**.** Demographic breakdown of each training activity

| Activity | n | Age (years) | Height (in) | Body Weight (lb.) |
|---|---|---|---|---|
| A. Hike, O-course | 44 | 21.7 ± 2.5 | 69.8 ± 2.8 | 171.7 ± 16.8 |
| B. Hike | 22 | 22.9 ± 2.6 | 70.9 ± 2.3 | 184.5 ± 22.2 |
| C. Hike | 41 | 21.8 ± 2.2 | 69.9 ± 3.7 | 176.3 ± 25.4 |
| D. Hike, O-course | 70 | 20.3 ± 1.6 | 69.1 ± 2.6 | 164.3 ± 20.9 |
| E-1. PT¥ | 40 | 21.5 ± 2.7 | 69.2 ± 2.9 | 172.0 ± 24.6 |
| E-2. PT¥ | 40 | 21.5 ± 2.7 | 69.2 ± 2.9 | 172.0 ± 24.6 |
| F. PT | 24 | 21.4 ± 2.1 | 69.8 ± 3.2 | 167.0 ± 28.9 |

Data are represented as Means ± SD
O-course = Marine standard obstacle course
PT = physical training
¥ Activity followed a repeated measures design allowing Marines to perform the same physical training activity with both body armor systems.

*Load Distributions*

Comparison of the two body armor systems for the cross-sectional analysis resulted in a statistically lighter relative load for the PC GEN III+LW configuration during activity A ($p = .01$),

C ($p < .001$), and D ($p = .004$) after all standardized gear was attached via modular lightweight load carrying equipment (Figure 3). When all activities were combined, Marines assigned to wear the PC GEN III+LW system carried a ~3.9% lighter absolute load ($p < .001$) resulting in a ~2.6% lighter relative load ($p < .001$). A repeated measures ANOVA revealed that during activity E, the PC GEN III+LW exhibited significantly lighter relative loads when compared to the Legacy+ESAPI plate carrier ($p < .001$, Figure 3).

*Physiological Measures*

Descriptive data on heart rate, caloric expenditure, and changes to lower body explosiveness can be found in Table 3. There were no statistical differences between the two systems for average heart rate or estimated caloric expenditure throughout each training activity ($p > 0.05$). However, when comparing changes in lower body jump performance between PPE configurations, significant interactions were present between peak power ($p = .02$) and RSImod ($p < .001$). Adjusted *post hoc* analysis revealed significantly higher RSImod scores in Marines wearing the PC GEN III+LW following activity C ($p = .009$). *Post hoc* analysis examining changes in peak power failed to reach statistical significance ($p > .05$).

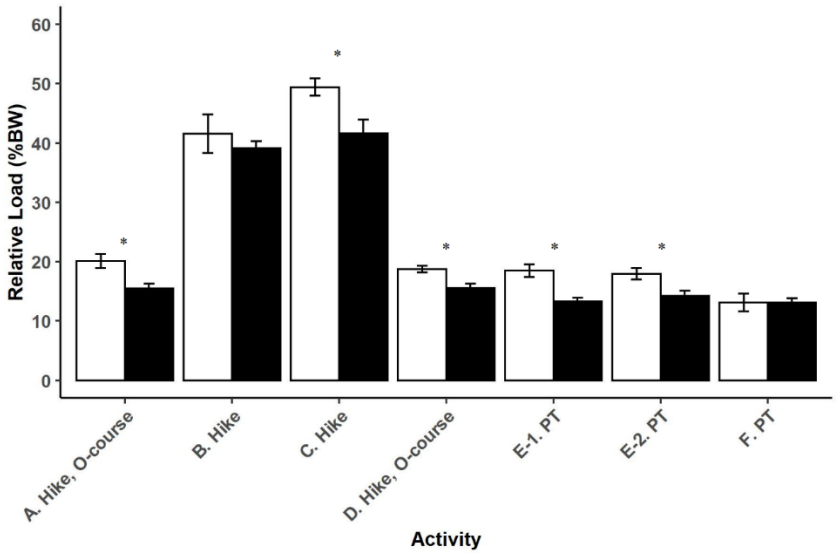



Figure 3. Comparison of the relative load placed onto the Marine when wearing (○) Legacy+ESAPI vs (●) PC GEN III+LW for each training activity. Legacy+ESAPI = Legacy plate carrier system with enhanced small arms protective insert armor plate. PC GEN III+LW = Third generation plate carrier with low intensity threat environment armor plate. * $p < .05$. Data are presented as means ± SE. O-course = Marine standard obstacle course. PT = physical training.

Table 3. Effect of personal protective equipment configuration on heart rate, estimated caloric expenditure, and lower body explosiveness during various training activities

| Activity | PPE | Heart Rate (Avg) | Calories (kcal) | Δ Jump Height (in.) | Δ Peak Power (W)† | Δ RSImod (a.u.)† |
|---|---|---|---|---|---|---|
| A. Hike, O-course | Legacy+ESAPI | 160.3 ± 7.4 | 1222 ± 166 | 0.3 ± 1.0 | 66.4 ± 241.2 | -0.02 ± 0.07 |
| | PC GEN III+LW | 159.1 ± 11.2 | 1338 ± 156 | -0.1 ± 1.2 | 62.1 ± 193.2 | -0.02 ± 0.05 |
| B. Hike | Legacy+ESAPI | 154.1 ± 17.2 | 732 ± 168 | 0.5 ± 1.2 | 267.5 ± 236.3 | 0.05 ± 0.05 |
| | PC GEN III+LW | 159.3 ± 14.5 | 760 ± 156 | 0.0 ± 1.9 | 48.5 ± 332.9 | 0.02 ± 0.11 |
| C. Hike | Legacy+ESAPI | • | • | -0.1 ± 1.5 | 161.5 ± 254.8 | -0.02 ± 0.05* |
| | PC GEN III+LW | • | • | 0.6 ± 1.8 | 227.4 ± 229.3 | 0.03 ± 0.04* |
| D. Hike, O-course | Legacy+ESAPI | 149.2 ± 19.2 | 331 ± 64 | 0.7 ± 1.4 | 317.9 ± 230.6 | 0.03 ± 0.05 |
| | PC GEN III+LW | 146.7 ± 17.1 | 351 ± 65 | 0.8 ± 1.2 | 280.4 ± 204.9 | 0.03 ± 0.04 |
| E-1. PT¥ | Legacy+ESAPI | 168.7 ± 9.9 | 306 ± 52 | -0.3 ± 1.3 | 160.4 ± 245.1 | -0.01 ± 0.05 |
| | PC GEN III+LW | 169.7 ± 7.9 | 305 ± 52 | 0.5 ± 0.9 | 218.5 ± 237.8 | 0.02 ± 0.05 |
| E-2. PT¥ | Legacy+ESAPI | 166.7 ± 7.7 | 278 ± 40 | 1.0 ± 1.0 | 281.7 ± 207.0 | 0.03 ± 0.04 |
| | PC GEN III+LW | 163.4 ± 12.7 | 272 ± 65 | 0.4 ± 0.7 | 175.8 ± 143.2 | 0.02 ± 0.03 |
| F. PT | Legacy+ESAPI | 121.8 ± 8.8 | 405 ± 63 | 0.0 ± 1.5 | 87.3 ± 167.2 | 0.01 ± 0.02 |
| | PC GEN III+LW | 122.0 ± 13.7 | 413 ± 139 | 0.3 ± 0.6 | 153.9 ± 160.6 | 0.03 ± 0.02 |

Data are represented as Means ± SD
PPE = personal protective equipment
Legacy+ESAPI = legacy plate carrier and enhanced small arms protective insert armor plate PPE configuration
PC GEN III+LW = third generation plate carrier and low intensity threat environment armor plate PPE configuration
O-course = Marine standard obstacle course
PT = physical training
RSImod = Reactive Strength Index Modified
• No data available due to equipment malfunction
* $p < .05$ for simple contrast of PPE
† $p < .05$ for interaction effect of PPE
¥ Activity followed a repeated measures design

*Marine Questionnaires*

Examination of the questionnaires following the cross-sectional analysis revealed the PC GEN III+LW was more comfortable ($p < .001$), allowed for increased maneuverability ($p < .001$), and resulted in decreased subjective ratings of fatigue ($p = .003$) (Figure 4). Results from the repeated measures ANOVA examining changes following Activity E revealed similar results for comfort ($p = .002$) and maneuverability ($p < .001$). However, differences in perception of fatigue were not found ($p > 0.05$). Assessment of perceived pain before and after each activity indicated greater pain increases in the shoulders ($p = .008$), chest ($p = .02$), and neck ($p = .03$) regions when wearing the Legacy+ESAPI configuration when compared to the PC GEN III+LW. Therefore, when all activities were combined, the PC GEN III+LW resulted in a smaller magnitude of change in shoulder, chest, and neck pain when compared to the Legacy+ESAPI. Hedge's *g* effect sizes comparing pre- to post-activity differences in pain can be found in Figure 5.

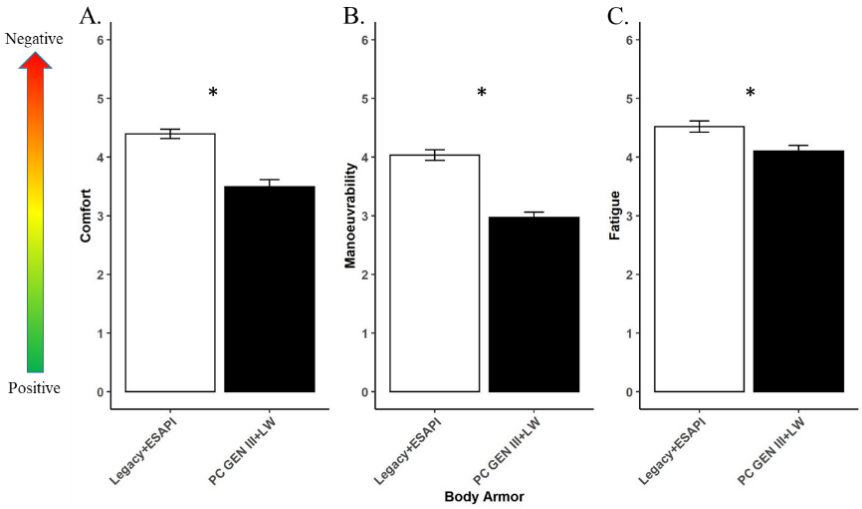



Figure 4. (A) Comfort, (B) maneuverability, and (C) fatigue ratings when wearing the (○) Legacy+ESAPI vs (●) PC GEN III+LW. Legacy+ESAPI = Legacy plate carrier system with enhanced small arms protective insert armor plate. PC GEN III+LW = Third generation plate carrier with low intensity threat environment armor plate. *$p < .05$. Data are presented as means ± SE.

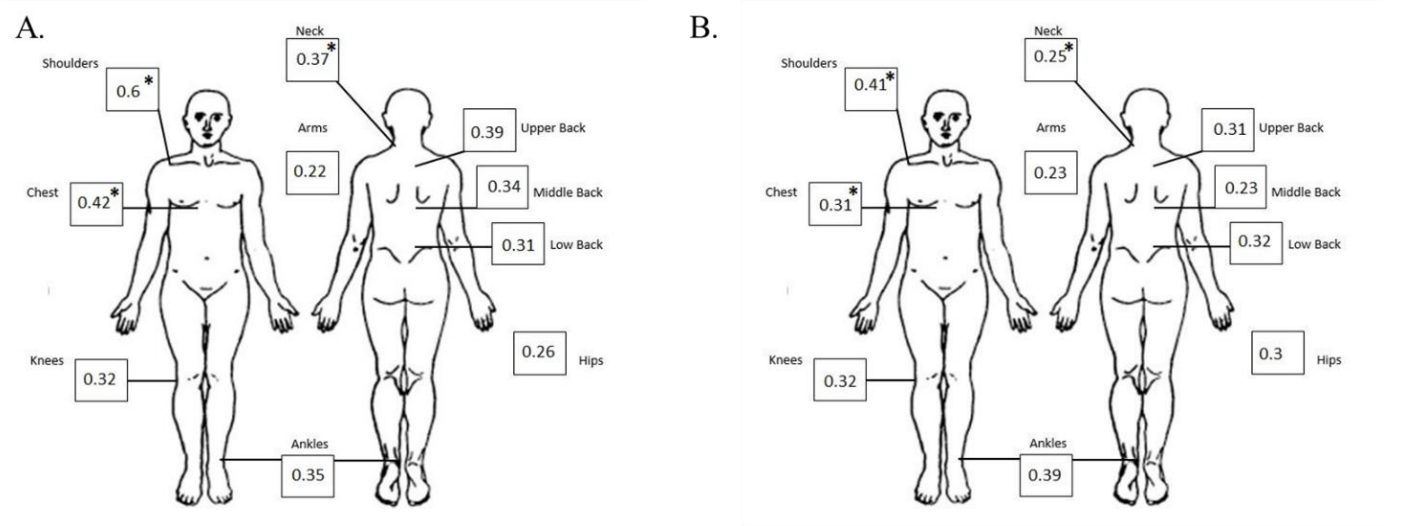



Figure 5. Comparison of changes in perceived pain when wearing the (A) Legacy+ESAPI vs (B) PC GEN III+LW. Legacy+ESAPI = Legacy plate carrier system with enhanced small arms protective insert armor plate. PC GEN III+LW = Third generation plate carrier with low intensity threat environment armor plate. * $p < .05$. Data are presented as Hedge's g effect size. Determination of the magnitude of effect is defined as: Small = 0.2, Medium = 0.5, Large = 0.8

Lastly, a breakdown of positive and negative comments for the PC GEN III+LW PPE system resulted in ~64% overall positive feedback and ~36% negative feedback (Figure 6).

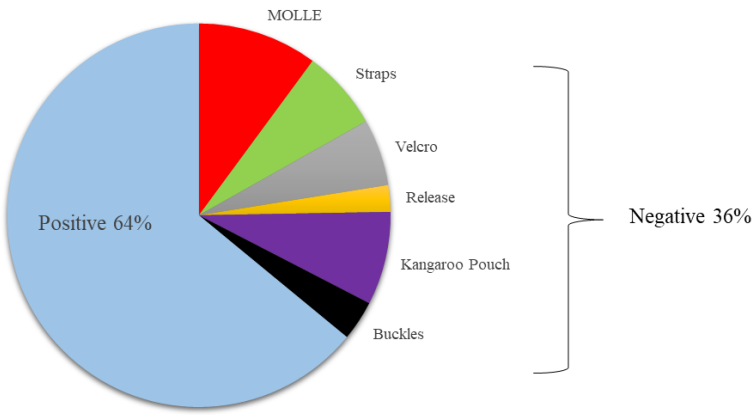



Figure 6. Breakdown of the positive and negative comments of the third generation plate carrier and low intensity threat environment armor plate personal protective equipment configuration. MOLLE = modular lightweight load carrying equipment.

**RECOMMENDATIONS:**

Following the evaluation of the two plate carrying systems, transitioning to the PC GEN III+LW is warranted. The data suggest significant benefits exist in adopting the PC GEN III+LW in comparison to the Legacy+ESAPI system. Utilizing the PC GEN III+LW PPE configuration resulted in a ~2.6% reduction to the relative body weight carried and a ~3.9% decline to the absolute load placed on the Marine. Thus, adopting the new PC GEN III+LW PPE may act as a way to help address the load constraints the Marines often face.

Beyond lightening the load to help reduce the Marine's risk of injury, the PC GEN III+LW armor system resulted in a lower perception of fatigue following each activity, which is supported by the heightened increase in low-body explosiveness metrics. Interestingly, greater differences were noted following the longest hike, suggesting there may be a cumulative advantage of wearing the PC GEN III+LW as time of activity persists. Despite the total load differences in weight between the two systems, there were no differences in heart rate or estimated caloric expenditure between the PPE systems.

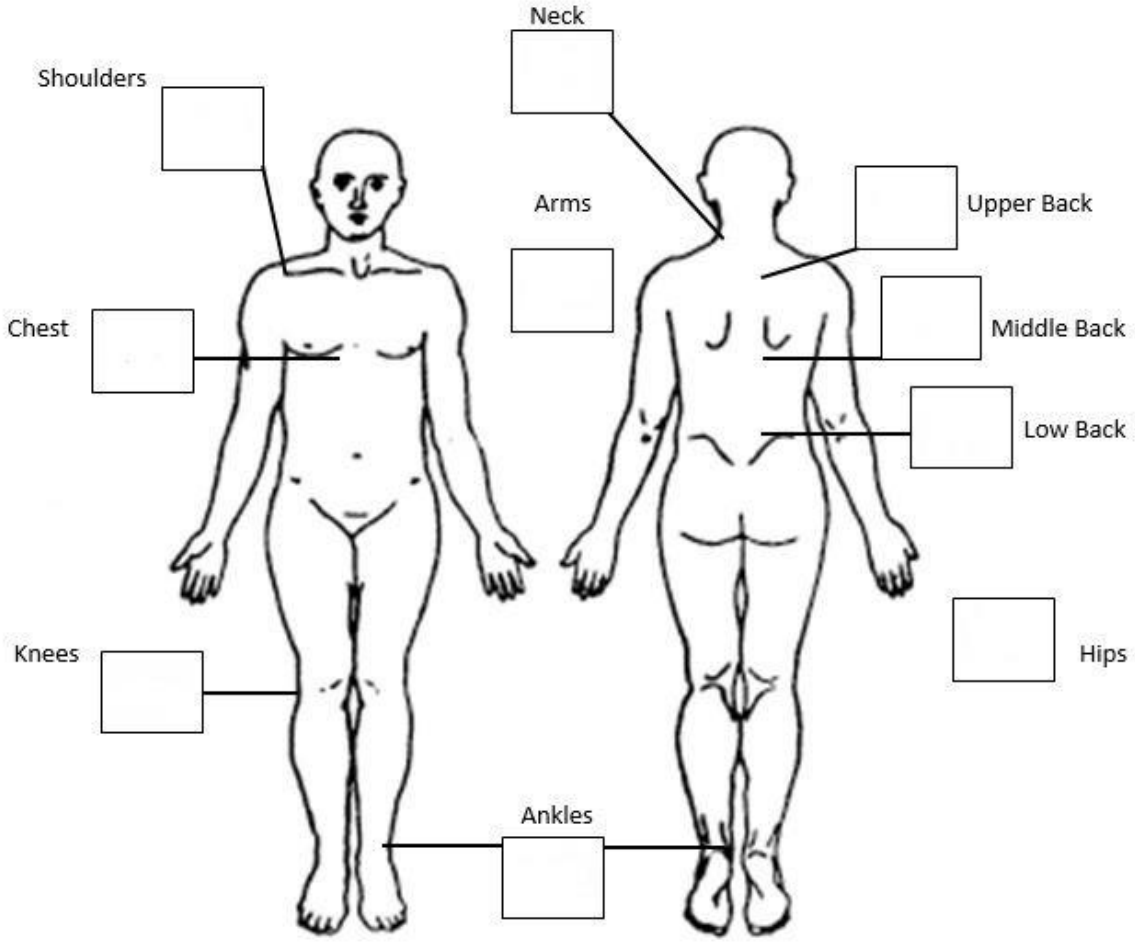
Subjective ratings from Marines showed the PC GEN III+LW body armor system is favored over the Legacy+ESAPI system. Marines wearing the PC GEN III+LW body armor reported less subjective fatigue, enhanced comfort, and increased maneuverability following activities. Moreover, the PC GEN III+LW configuration resulted in a diminished perception of muscle soreness to the neck, shoulders, upper back, middle back, and chest regions following all activities. This finding may be attributed to the reduced overall weight of the PC GEN III+LW body armor system and/or the fact that the Marines knew they were testing a potentially new lighter system which may have skewed the ratings.

Finally, aggregation of general comments about the PC GEN III+LW body armor showed that the majority of Marines (~64%) exhibited positive feedback on the system. Negative comments and feedback were primarily related to the modular lightweight load carrying equipment, straps, and buckles. Specifically, multiple Marines expressed concern about the potential of the plastic buckle system failing and their distaste for the Velcro system. Additionally, a common request was for a kangaroo pouch to be added. While the PC GEN III+LW has many advantages over the Legacy+ESAPI body armor system related to weight and comfort, it is our recommendation to update the body armor system further to address the reoccurring comments from the Marines.

**APPENDIX A: Pre-Activity Questionnaire**

Subject ID number: _____ Date: _____

**Please fill in the box with the corresponding number for area**

**APPENDIX B: Post-Activity Questionnaire**

**Rating of Perceived Exertion Questionnaire**

Subject ID number: _____ Date: _____

Configuration (circle): PC GEN III+LW LEGACY+ESAPI

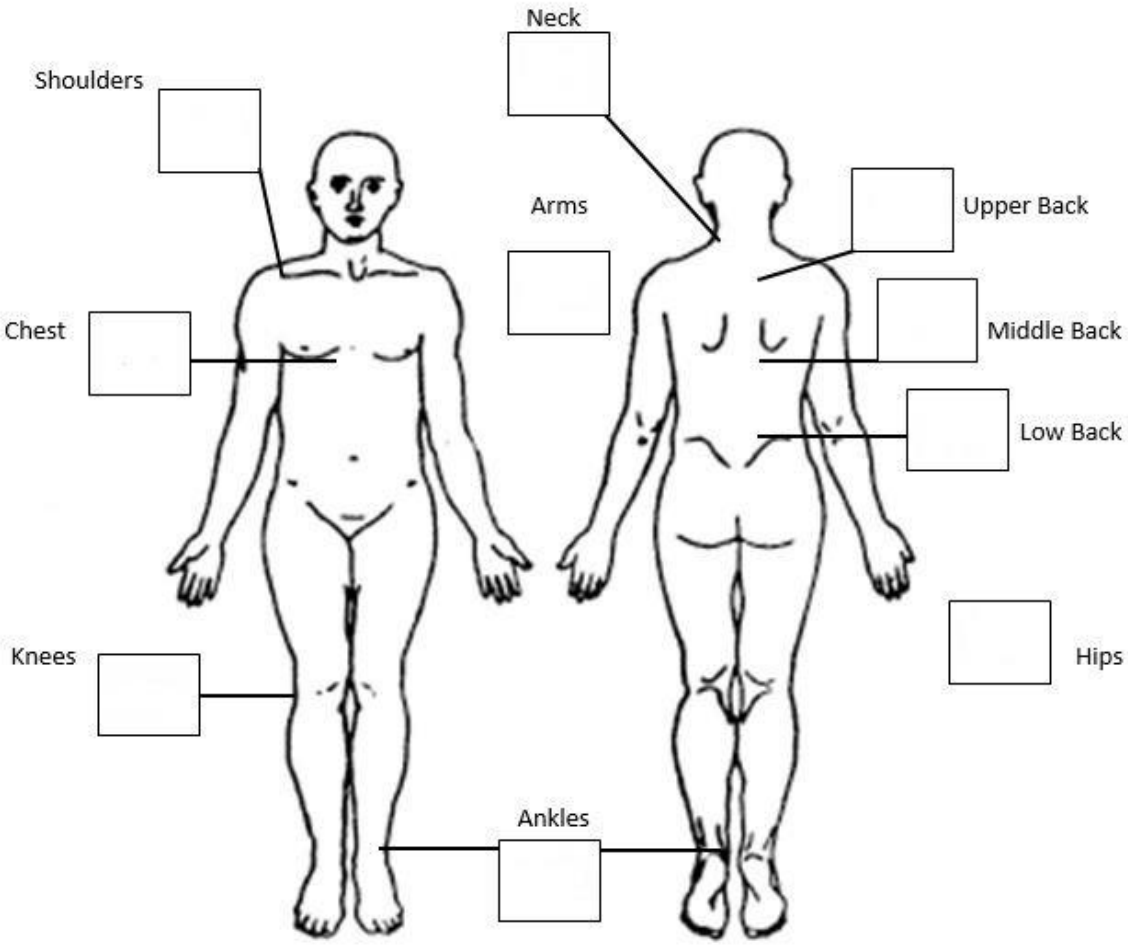
Rate your overall feeling of PHYSICAL **EXERTION (Circle)**

1 2 3 4 5 6 7 8 9 10

| Rating of Perceived Exertion (RPE Scale) | |
|---|---|
| 10 | Maximal |
| 9 | Really, Really, Hard |
| 8 | Really Hard |
| 7 | Harder |
| 6 | Hard |
| 5 | Challenging |
| 4 | Moderate |
| 3 | Easy |
| 2 | Really Easy |
| 1 | Rest |

Subject ID number: _____ Date: _____

**Please fill in the box with the corresponding number for area**

1. Rate your overall comfort of the PPE

1 2 3 4 5 6 7

Extremely Comfortable Moderately Extremely Uncomfortable

2. Rate how the PPE affected your ability to maneuver into position

1 2 3 4 5 6 7

Extremely Difficult Moderately Extremely Easy

3. Rate how the PPE affected your overall fatigue factor (how tired are you)

1 2 3 4 5 6 7

Extremely NOT Fatigued Moderately Extremely Fatigued

4. Please list any other items or issues you would like us to know about PPE

| |
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