RAND ARROYO CENTER

CHILDREN AND FAMILIES
EDUCATION AND THE ARTS
ENERGY AND ENVIRONMENT
HEALTH AND HEALTH CARE
INFRASTRUCTURE AND TRANSPORTATION
INTERNATIONAL AFFAIRS
LAW AND BUSINESS
NATIONAL SECURITY
POPULATION AND AGING
PUBLIC SAFETY
SCIENCE AND TECHNOLOGY
TERRORISM AND HOMELAND SECURITY

The RAND Corporation is a nonprofit institution that helps improve policy and decisionmaking through research and analysis.

This electronic document was made available from www.rand.org as a public service of the RAND Corporation.

Skip all front matter: Jump to Page 1 ▼

Support RAND

Purchase this document

Browse Reports & Bookstore

Make a charitable contribution

For More Information

Visit RAND at www.rand.org

Explore the RAND Arroyo Center

View document details

Limited Electronic Distribution Rights

This document and trademark(s) contained herein are protected by law as indicated in a notice appearing later in this work. This electronic representation of RAND intellectual property is provided for non-commercial use only. Unauthorized posting of RAND electronic documents to a non-RAND website is prohibited. RAND electronic documents are protected under copyright law. Permission is required from RAND to reproduce, or reuse in another form, any of our research documents for commercial use. For information on reprint and linking permissions, please see RAND Permissions.

This product is part of the RAND Corporation technical report series. Reports may include research findings on a specific topic that is limited in scope; present discussions of the methodology employed in research; provide literature reviews, survey instruments, modeling exercises, guidelines for practitioners and research professionals, and supporting documentation; or deliver preliminary findings. All RAND reports undergo rigorous peer review to ensure that they meet high standards for research quality and objectivity.

TECHNICAL REPORT

Lightening Body Armor

Arroyo Support to the Army Response to Section 125 of the National Defense Authorization Act for Fiscal Year 2011

Kenneth Horn • Kimberlie Biever • Kenneth Burkman • Paul DeLuca
Lewis Jamison • Michael Kolb • Aatif Sheikh



ARROYO CENTER

The research described in this report was sponsored by the United States Army under Contract No. W74V8H-06-C-0001.

Library of Congress Cataloging-in-Publication Data

Lightening body armor : Arroyo support to the Army response to Section 125 of the National Defense Authorization Act for Fiscal Year 2011 / Kenneth Horn ... [et al.].
p. cm.
Includes bibliographical references.
ISBN 978-0-8330-5844-7 (pbk. : alk. paper)
1. Body armor—Standards—United States. 2. Body armor—United States—Testing. 3. United States. Dept. of Defense—Appropriations and expenditures. I. Horn, Kenneth P., 1937- II. Rand Corporation. III. Arroyo Center.

U825.L54 2012
623.4'41—dc23

2012003923

The RAND Corporation is a nonprofit research organization providing objective analysis and effective solutions that address the challenges facing the public and private sectors around the world. RAND's publications do not necessarily reflect the opinions of its research clients and sponsors.

RAND® is a registered trademark.

© Copyright 2012 RAND Corporation

Permission is given to duplicate this document for personal use only, as long as it is unaltered and complete. Copies may not be duplicated for commercial purposes. Unauthorized posting of RAND documents to a non-RAND Web site is prohibited. RAND documents are protected under copyright law. For information on reprint and linking permissions, please visit the RAND permissions page (http://www.rand.org/publications/permissions.html).

Published 2012 by the RAND Corporation
1776 Main Street, P.O. Box 2138, Santa Monica, CA 90407-2138
1200 South Hayes Street, Arlington, VA 22202-5050
4570 Fifth Avenue, Suite 600, Pittsburgh, PA 15213-2665
RAND URL: http://www.rand.org
To order RAND documents or to obtain additional information, contact
Distribution Services: Telephone: (310) 451-7002;
Fax: (310) 451-6915; Email: order@rand.org

Preface

The body armor that U.S. forces wear in Afghanistan is effective against ballistic threats: There have not been any known penetrations of the body armor or fatalities when the currently issued body armor was struck by projectiles it was designed to stop. However, the combat loads that dismounted soldiers and marines carry on patrol are very heavy, and a large portion of this load is due to body armor.

Congress asked the question, How can body armor weight be reduced? Congress's perception is that the Department of Defense has been slow in developing and deploying lighter-weight body armor. In Section 125 of the National Defense Authorization Act for Fiscal Year 2011, Congress requested that a federally funded research and development center conduct a study of lightening body armor. RAND Arroyo Center was selected to perform this study and was sponsored by Dr. Scott Fish, Army Chief Scientist, Assistant Secretary of the Army for Acquisition, Logistics and Technology.

This document should interest those involved with lightening body armor and the combat loads of dismounted soldiers and marines.

The research was conducted in RAND Arroyo Center's Force Development and Technology Program. RAND Arroyo Center, part of the RAND Corporation, is a federally funded research and development center sponsored by the United States Army.

The Project Unique Identification Code (PUIC) for the project that produced this document is HQD116049.

For more information on RAND Arroyo Center, contact the Director of Operations (telephone 310-393-0411, extension 6419; FAX 310-451-6952; email Marcy_Agmon@rand.org) or visit the Arroyo Center's website at http://www.rand.org/ard/.

Contents

Preface iii
Figures and Tables vii
Summary ix
Acknowledgments xiii
Abbreviations xv

CHAPTER ONE
Introduction 1
Purpose of the Study 1
Study Caveats 2
Research Approach 3
Literature Review 3
Interviews 3
Independent Analyses 3
Organization of This Document 3

CHAPTER TWO
Background 5
Soldier Combat Load Is Daunting 5
Average Combat Loads for Soldiers and Marines 5
Load Impacts Performance 6
Body Armor Weight Contributes to the Overall Load 9
Current Body Armor Is Effective 10
Body Armor Must Be Capable of Handling Multiple Ballistic Round Penetrations and Limiting Backface Deformation 11
Basis for the Two Requirements 11
Summary 12

CHAPTER THREE
Four Approaches to Lightening Body Armor 15
Refining Requirements 15
Assessing Threats 15
Tailoring Body Armor as a Means to Lighten Body Armor 17
Using Modular Configurations 17
Examples of Modular Configurations 18
Coverage Versus Weight 18

Body Armor Protection Levels 20
Using Modular Configurations as a Means to Lighten Body Armor 21
Improving Testing 22
Literature Review 22
Our Findings Regarding Current Testing 23
Our Findings Regarding Future Testing 24
Testing as a Means to Lighten Body Armor 25
Improving Materials 25
Materials Used in Today's Body Armor 25
Potential Future Body Armor Materials 26
Improving Hard Armor Materials 27
Improving Soft Armor Materials 28
How to Best Develop the Next Generation of Body Armor: Acquisition Program of Record Versus Commodity Procurement 29
Developing and Fielding Lighter Body Armor Would Require a Comprehensive R&D Strategy 31
Using the Procurement Process/R&D Funding as a Means to Lighten Body Armor 33

CHAPTER FOUR
Conclusions 35
Comparison of the Four Approaches 35
General Conclusions 37
Specific Issues Raised in Section 125 of P.L. 111-383 37

CHAPTER FIVE
Recommendations 39
Top-Level Recommendations 39
Specific Recommendations 39

APPENDIX
Army, Marine Corps, and SOCOM Processes for Procuring Body Armor 41

Bibliography 45

Figures and Tables

Figures

S.1. Comparison of the Four Approaches to Reducing Body Armor Weight x
2.1. An Army Soldier Carrying a Full Combat Load 6
2.2. Individual Combat Loads for Marines, by Position 7
2.3. Performance Decreases as Combat Load Increases 8
2.4. Probability of Lethality as a Function of Backface Deformation 13
3.1. Effectiveness of Body Armor Against Different Threat Types 16
3.2. An Example of a Suite of Body Armor Plates 19
3.3. Example Components for Modular Body Armor Configurations 19
3.4. Body Armor Weight Increases as Coverage Increases 20
3.5. Stiffness of Current and Potential Hard Plate Materials as a Function of Density 27
4.1. Comparison of the Four Approaches to Reducing Body Armor Weight 35

Tables

2.1. Average Combat Loads for Army Soldiers in Afghanistan, 2003 5
3.1. Body Armor Protection Levels 21
3.2. Comparison of Commodity Procurement Versus Hypothetical Program of Record Acquisition 30
A.1. Summary of Army, Marine Corps, and SOCOM Processes for Procuring Body Armor 42
A.2. Summary of Army Body Armor RDT&E Funding 43

Summary

The body armor that U.S. forces wear in Afghanistan is effective against ballistic threats: There have not been any known penetrations of the body armor or fatalities associated with the threat of projectiles that the currently issued body armor is designed to stop. The body armor is heavy, however, constituting approximately 30 percent of the total load that is carried into combat by a dismounted soldier or marine.

Congress has asked the question, How can body armor weight be reduced? Congress's perception is that Department of Defense (DoD) has been slow in developing and deploying lighter-weight body armor. In Section 125 of the National Defense Authorization Act for Fiscal Year 2011, Congress requested that a federally funded research and development center conduct a study of lightening body armor. The RAND Arroyo Center was selected to perform this study.

The study focus is on soldier protection from ballistic threats—both small arms fire and fragmenting munitions. The study concentrates on reducing the weight of the torso armor, since most of the body armor weight is in protecting the torso area of the body. Protection of the torso area is provided using soft body armor vests with ceramic plate inserts, and the ceramic plates are heavy. The weight range of a full-up torso body armor set is 27 to 38 pounds for small to extra-large sizes.

Body armor must be capable of meeting two requirements. First, the ceramic plates cannot be penetrated when struck by multiple ballistic rounds in a well-defined shot pattern. Second, the backface deformation (a surrogate measure of blunt force trauma) that occurs when the bullet impacts the ceramic plate must be no greater than 44 mm, as measured by indentation depth in the test material backing the plate. This depth is based on limited 1977 research using anesthetized animals. Additional mathematical modeling predicted that a backface deformation of 44 mm or less would result in a maximum 10 percent probability of lethality.

Comparison of Approaches

The four approaches to lighten body armor—refining requirements, using modular configurations, improving testing, and improving materials—are compared in Figure S.1. In some respects, refining requirements is the most difficult approach to implement: Changing the processes necessary to meet requirements is not very difficult, but the decision to change requirements in the first place is. A change from the currently accepted threat round that the body armor must be capable of stopping to a less capable round (in terms of muzzle velocity, bullet type, or caliber) would have serious consequences if the change were later shown to be unwarranted and additional lethal casualties result.

Figure S.1
Comparison of the Four Approaches to Reducing Body Armor Weight

Approach	Ease in Executing Change	Required Army Coordination	Estimated Weight Reduction	Comment
Refine requirements	Moderately difficult	DCS G-3, TRADOC	Small to moderate (~10–20%)	Consequence great if wrong
Use modular body armor configurations	Easy in principle	Field commanders, TRADOC	Moderate to large (~20–45%)	Questions remain about risks
Improve testing	Moderate	PEO Soldier, ATC	Small (~5–10%)	Requires coordination with other services, DLA, and SOCOM and DOT&E approval
Improve materials (R&D, procurement process)	Moderate (funding)	ASA(ALT), DCS G-8	Unknown at present	Long-term solution; appropriate procurement process depends on technological challenge

NOTES: TRADOC = U.S. Army Training and Doctrine Command; PEO = Program Executive Office; ATC = Aberdeen Test Center; DLA = Defense Logistics Agency; SOCOM = U.S. Special Operations Command; DOT&E = Office of the Director, Operational Test and Evaluation; R&D = research and development; ASA(ALT) = Assistant Secretary of the Army (Acquisition, Logistics and Technology); DCS = Army Deputy Chief of Staff.

RAND TR1120-S.1

The least difficult approach is the use of modular body armor configurations, simply because the decision to use modular body armor has already been made. However, this approach carries the largest risk. If a commander decides to use a less effective body armor configuration (i.e., a lower level Body Army Protect Level [BAPL]) and his choice proves to be incorrect, avoidable casualties could result. The other two approaches we considered—improving testing and improving materials—involve some difficult choices but should not lead to catastrophic outcomes.

Each of the approaches requires Army and broader DoD coordination before it can be implemented. Both refining of requirements and using the modular body armor approach require high-level coordination because of the potential risk. Improving testing requires approval from the Office of the Director, Operational Test and Evaluation (DOT&E), and developing better materials requires funding and time.

With regard to estimated weight reductions, greater increases in reduction may be possible if some of the approaches are considered synergistically. For example, a larger weight loss should be achieved if the benefits derived from reduced requirements are combined with the benefits gained from improved testing coupled with modular configurations.

Conclusions

The conclusions of this study are as follows:

- Today, no "silver bullet" material solution exists that will greatly reduce body armor weight.
- Some means (mainly nonmaterial) are available that can reduce body armor weight.
- A combination of material and nonmaterial approaches to lighten body armor will result in greater weight reductions.
- Synergy of modular concepts may lead to greater weight reduction (e.g., integration of hard and soft body armor designs).
- Further reductions in weight will require a significant investment of money and time.

A 10 percent reduction in weight appears to be about the most that is realistic in the short term if overall protection is to remain constant. Even this small increment will be quite difficult to achieve, however. A longer-term solution to reducing body armor weight likely involves the development and integration of new materials. However, the technology is currently too immature to make reliable estimates about the weight and protective effectiveness of new materials.

There are some nonmaterial solutions available that can result in a greater than 20 percent weight reduction. For example, with modular body armor configurations, a 45 percent reduction results when BAPL 2 is selected instead of BAPL 5.[1] The problem is that the choice of the appropriate BAPL is a difficult decision. Also, a large inventory of body armor vests and plates must always be available to provide the various plates and vests in all sizes to forward to combat areas.

A combination of material and nonmaterial approaches should result in greater weight reduction. For example, if the plates are over-designed for the threat, then the requirements and testing procedures could be changed, resulting in thinner and lighter-weight plates.

A synergy of modular concepts may also lead to greater weight reduction. Soft and hard body armor should be developed and procured as one item. Today's practice is to simply add hard plate inserts to a soft vest, but a systems approach would design a single body armor concept that optimized the characteristics of the two components.

Further reductions in weight will require a significant investment of money and time. Changes to the plate design could reduce the plate weight. For example, variable-thickness plates could be constructed that provide greater protection over the chest portion of the torso than over the abdomen portion. However, variable-thickness plates would involve changing the manufacturing process and the testing procedures.

Answers to the eight issues specifically raised by Section 125 are presented in the main body of the document.

Recommendations

As a result of our examination of the issues associated with reducing the weight of body armor, we propose four top-level recommendations:

---

[1] BAPL 5 includes an improved outer tactical vest with front, back, and side plates, while BAPL 2 uses a plate carrier without the side plates.

- First, development of significantly lighter, next-generation body armor using advanced technology materials will require more research, development, test, and evaluation (RDT&E) funding, though we have not attempted to quantify that requirement. The various RDT&E program elements also need to be better coordinated, and the various service efforts should be mutually supporting.
- Second, the threat level requirement should be consistent with the threat environment being encountered today and anticipated in the future.
- Third, the requirements-development process needs to be reviewed to ensure that coordination among the relevant stakeholder offices is continuous as requirements are developed. Making optimal trade-offs between protection, weight, ergonomic impact, and cost requires ongoing interaction among the user representative, the technical community, and the resource providers, from the start of requirements assessment to the publication of the requirements document.
- Fourth, performance—including weight—should be included as a contract award selection criterion when awarding production contracts for body armor. Currently, products that meet the threshold criteria are selected solely on a cost basis by the Defense Logistics Agency, so prospective producers have no incentive to improve body armor performance beyond the threshold.

We also propose five specific recommendations:

- Exceptions should be made to the Berry and Kissell Amendments, which limit the design and manufacturing of soft body armor intended for U.S. service members to American and Canadian producers. If offshore sources offer improved body armor solutions, they should not be denied to our service members.
- The 1977 Prather study that provided a preliminary correlation of mortality and backface deformation on soft body armor should be updated by conducting new research using today's body armor (soft and hard). New data will help improve requirements generation and make testing more realistic.
- Field commanders may be reluctant to utilize a BAPL lower than the maximum without some sort of decision aid tool to back up their assessment. The development of the Operational Requirements-based Casualty Assessment (ORCA)/Modular UNIX-based Vulnerability Estimation (MUVES) model should be continued and used to help develop a decision aid that field commanders can use to make BAPL decisions.
- A comprehensive trauma data collection and analysis process should be established to better inform researchers, developers and decisionmakers.
- Finally, research should be conducted to better understand how body armor weight degrades soldier combat performance. There is a trade between individual protection and individual—and unit—effectiveness. That trade space is not well understood today, so making assessments concerning developmental requirements and about BAPL during operations is currently difficult.

Acknowledgments

We are grateful to Scott Fish, Army Chief Scientist, and Carolyn Nash, Office of the Assistant Secretary of the Army for Acquisition, Logistics and Technology, for their guidance and interest in the study. We also wish to thank the following Army personnel for providing important information on body armor: Gary Pesano and Chris Perritt, PM Soldier Protection and Individual Equipment; James Zheng and Karl Masters, PEO Soldier; Michael Codega, Natick Soldier Research, Development, and Engineering Center; John Beatty, Patrick Gillich, Lisa Roach, and Steve Taulbee, Army Research Laboratory; and COL Jeff Holt and Lindsey Yowell, Aberdeen Test Center. Thanks also go to Judah Goldwasser, Defense Advanced Research Projects Agency; Christopher Moosmann, Office of the Director, Operational Test and Evaluation; Lt Col Kevin Reilly and Major Billy Short, U.S. Marine Corps; and Col Richard Converse, James Boisselle, and Richard Dunnigan, U.S. Special Operations Command. We thank the following body armor vendors for providing valuable technical information: Mack Thorn, BAE Systems; Marc King, Ceradyne; Tim Haen, Coorstek; Ron Egres, DuPont; and Lori Wagner, Honeywell.

We benefited greatly from the insightful technical reviews provided by Ronald Fricker, Jr., Naval Postgraduate School, and Richard Silberglitt, RAND.

At RAND, we thank Bruce Held for providing guidance and support of the research, Karin Suede for her dedicated work in preparing the numerous drafts and final manuscript, and James Torr for his editorial review of the manuscript.

Abbreviations

AEI	Armament Enhancement Initiative
AoA	Analysis of Alternatives
ARL/SLAD	Army Research Laboratory, Survivability and Lethality Analysis Directorate
ATC	Aberdeen Test Center
ATM	Anthropomorphic Test Module
BAA	Broad Agency Announcement
BAPL	Body Armor Protection Level
BAST	Board on Army Science and Technology
BFD	backface deformation
CBA	Capabilities Base Assessment
CBRN	chemical, biological, radiological, nuclear
CDD	Capability Development Document
CNT	carbon nanotube
CSS VSAT	Combat Service Support Very Small Aperture Transmission
DARPA	Defense Advanced Research Projects Agency
DAS	Defense Acquisition System
DLA	Defense Logistics Agency
DoD	Department of Defense
DOT&E	Office of the Director, Operational Test and Evaluation
ESAPI	enhanced small arms protection insert
ESBI	enhanced side body insert
FAT	first article test
ICD	Initial Capabilities Document
IED	improvised explosive device

IOTV	improved outer tactical vest
JCIDS	Joint Capabilities Integration Development System
JROC	Joint Requirements Oversight Council
JTAPIC	Joint Trauma Analysis and Prevention of Injury in Combat program
LAT	lot acceptance test
LSAPI	light small arms protection insert
MAIS	Maximum Abbreviated Injury Scale
MDO	Materiel Development Decision
METT-C	Mission, Enemy, Time, Terrain, Civilians
MOPP	Mission Oriented Protective Posture
MUVES	Modular UNIX-based Vulnerability Estimation Suite
NRAC	Naval Research Advisory Committee
O&M	operations and maintenance
ORCA	Operational Requirements-based Casualty Assessment
PEO	program executive office, program executive officer
PM	program manager
POR	program of record
PPBES	Planning, Programming, Budgeting, and Execution System
PPE	personal protective equipment
R&D	research and development
RDECOM	U.S. Army Research, Development and Engineering Command
RDT&E	research, development, test, and evaluation
SAPI	small arms protection insert
SOCOM	U.S. Special Operations Command
SOFSA	Special Operations Forces Support Activity
STF	shear thickening fluid
TRADOC	U.S. Army Training and Doctrine Command
UHMWPE	ultra-high-molecular-weight polyethylene
XSAPI	X-small arms protection insert

CHAPTER ONE

Introduction

This report documents RAND Arroyo Center support to the U.S. Army in responding to Section 125 of the National Defense Authorization Act for Fiscal Year 2011 (P.L. 111-383). The research on lightening body armor was performed over a two-and-a-half-month period. The cutoff date of the research phase was mid-June 2011. The research consisted of literature reviews, interviews, independent analyses, and a synthesis of the study findings. Besides providing general conclusions, the specific questions that are raised in Section 125 are addressed. Both top-level and specific recommendations are made regarding lightening body armor.

Purpose of the Study

Congressional concerns about efforts across the department of Defense (DoD) to develop lighter-weight body armor resulted in Section 125 of the National Defense Authorization Act for Fiscal Year 2011. Section 125 directs DoD to contract with a federally funded research and development center to study how the DoD effort to lighten body armor could be improved. Congress directed that the study be performed by an independent, objective analysis team composed of analysts that understood both advanced material technologies and combat operations. The RAND Arroyo Center was selected by the U.S. Army to perform this study.

The basis of congressional concern is a perception by some in Congress that DoD has been slow in developing and deploying lighter-weight body armor. Congress believes that this may be due to the research and development (R&D)/procurement approach that the Army currently has in place to develop and introduce lighter-weight body armor.

The body armor study requirements listed in Section 125 are as follows:

1. Assess the effectiveness of the process used by the Secretary [of Defense] to identify and examine the requirements for lighter-weight body armor systems.
2. Determine ways in which the Secretary may more effectively address the research, development, and procurement requirements regarding reducing the weight of body armor.

The research reported in this document addresses these two study requirements.

Section 125 also states that the study must address the following issues:

1. the requirement for lighter weight body armor and personal protective equipment and the ability of the Secretary [of Defense] to meet such requirements
2. innovative design ideas for more modular body armor that allow for scalable protective levels for various missions and threats

3. the need for research, development, and acquisition funding dedicated specifically for reducing the weight of body armor
4. the efficiency and effectiveness of current body armor funding procedures and processes
5. industry concerns, capabilities, and willingness to invest in the development and production of lightweight body armor initiatives
6. barriers preventing the development of lighter weight body armor (including such barriers with respect to technical, institutional, or financial problems)
7. changes to procedures or policy with respect to lightweight body armor
8. other areas of concern not previously addressed by equipping boards, body armor producers, or program managers.

These issues fall under four general areas:

- requirements for lighter-weight body armor and the ability to meet them
- innovative design ideas and required funding for reducing body armor weight
- barriers/concerns that prevent the development of lighter-weight body armor
- efficiency/effectiveness in current funding procedures and processes and required changes to procedures and policy.

To perform the required analyses in the allotted time period, the study focused on the most important aspects of body armor protection—ballistic threats and torso protection.

Study Caveats

The study has two major caveats. First, the study's focus is on soldier protection from ballistic threats; nonballistic threats are only indirectly considered. Ballistic threats include small arms fire and fragmenting munitions from improvised explosive devices (IEDs), land mines, and indirect fires. IEDs are very effective fragmenting munitions. They have killed more troops in Afghanistan than any other weapon type. Soft body armor is designed to protect against shrapnel from fragmenting munitions.[1]

Second, our research focus is limited to torso armor, since most of the body armor weight is in protecting the torso area of the body. Since technological advances are being made in other soldier personal protective equipment areas, there was less need to investigate them. For example, the advanced technology helmet currently being developed is made from ultra-high-molecular-weight polyethylene and weighs slightly less than the current Kevlar helmet. Face protection masks and groin protection are also being developed. In contrast to these lighter-weight components, protection of the torso area is provided using soft body armor vests with ceramic plate inserts, which are effective but heavy.

---

[1] Soft armor was designed to provide fragmentation protection and was based on an early study of land mines and grenades. Although soft and hard armor were not designed to protect against the IED threat, they do have a certain protection level against shrapnel from IEDs or other threats. Hard armor provides much higher fragmentation (shrapnel) protection than soft armor. However, the overpressure from an IED blast is a different story. Recent research shows that soft armor has almost no effect on overpressure, but hard armor has some level of overpressure reduction, i.e., provides some degree of protection if the overpressure is the cause of the injury. The primary concern for torso protection against a blast has been lung injury. However, it appears that lung injury caused by blast overpressure is rare in the field, according to the medical community's injury analysis. (Dr. James Q. Zheng, PEO Soldier, private communication, June 29, 2011.)

Research Approach

The analysis was performed following a three-prong research approach that consisted of literature reviews, interviews, and independent analyses.

Literature Review

The literature reviews consist of assessments by the Army Audit Agency, the Government Accountability Office (GAO), the DoD Inspector General (DoD IG), and the Board on Army Science and Technology (BAST) of the National Academies. These assessments concentrated on testing issues.

Interviews

Both on-site and telephone interviews were conducted with 18 organizations that are involved with body armor development and procurement. These included eight separate Army organizations: Program Executive Office (PEO) Soldier (Haymarket), PEO Soldier/Program Management (PM) Soldier Protection and Individual Equipment, PEO Contracting Office, the U.S. Army Training and Doctrine Command (TRADOC) Maneuver Center of Excellence, the Army Research Laboratory (ARL), the Natick Soldier Research, Development, and Engineering (RD&E) Center, the ARL Survivability/Lethality Analysis Directorate, and the Aberdeen Test Center (ATC). In addition, we interviewed two Navy/Marine Corps organizations, the Office of Naval Research (ONR) and Marine Corps Systems Command (MCSC) (Infantry Combat Equipment, Armor and Load Bearing Team [PM-ICE]); U.S. Special Operations Command (SOCOM) and the Defense Advanced Research Projects Agency (DARPA); the Office of the Director, Operational Test and Evaluation (DOT&E); two civilian testing facilities, Chesapeake testing and HP White; and five body armor vendors (Ceradyne, Coorstek, BAE Systems, Honeywell, and DuPont). The vendors represent two plate manufacturers, two soft armor providers, and one integrator.

Independent Analyses

Our independent analyses concentrated on future materials for soft and hard body armor. Performance potential and cost were investigated.

Organization of This Document

The organization of this report is as follows. In Chapter Two, we present background on some issues associated with body armor operations, effectiveness, and requirements. In Chapter Three, we describe four approaches to lightening body armor and assess each. In Chapter Four, we provide an overall comparison of the four approaches, present our general conclusions, and specifically address each of the eight congressionally raised issues. Finally, in Chapter Five we provide both top-level and specific recommendations.

CHAPTER TWO

Background

The purpose of this chapter is to set the stage for our analysis, in Chapter Three, of four approaches to lightening body armor. In this chapter we discuss three related points, each of which highlights an issue that affects body armor.

Soldier Combat Load Is Daunting

The first point is that soldier combat load is very heavy and detrimental to combat performance. Body armor is a significant contributor to this overall load.

Average Combat Loads for Soldiers and Marines

Dismounted soldiers fighting in Afghanistan carry very heavy loads relative to their body weight. Figure 2.1 shows such a soldier, carrying a full combat load. Table 2.1 shows the combat loads for three duty positions under three operational load conditions—average fighting load, average approach march load, and average emergency approach load.

The average fighting load includes the following items: bayonet, weapon, clothing, helmet, body armor, load-bearing equipment, and a reduced load of ammunition. The average approach march load includes the fighting load items and, in addition, a basic load of ammunition, a small assault pack, and a lightly loaded rucksack or poncho roll. The average emergency approach march load includes the approach march load and, in addition, a much larger

Table 2.1
Average Combat Loads for Army Soldiers in Afghanistan, 2003

	Average Fighting Load		Average Approach March Load		Average Emergency Approach Load	
Duty Position	Weight (pounds)	Percentage of Body Weight	Weight (pounds)	Percentage of Body Weight	Weight (pounds)	Percentage of Body Weight
Rifleman	63	36	96	55	127	71
Squad automatic rifleman	79	45	111	63	140	80
60mm mortar gunner	64	38	108	64	143	87

SOURCE: Task Force Devil Combined Arms Assessment Team (Devil CAAT), "The Modern Warrior's Combat Load: Dismounted Operations in Afghanistan, April–May 2003," Ft. Leavenworth, Kan.: U.S. Army Center for Army Lessons Learned, 2003.

NOTES: 48–72-hour average mission duration. Load includes body armor with two small arms protection insert (SAPI) plates and no neck or crotch guards (17.5 lb).

Figure 2.1
An Army Soldier Carrying a Full Combat Load



SOURCE: Task Force Devil Combined Arms Assessment Team (Devil CAAT), "The Modern Warrior's Combat Load: Dismounted Operations in Afghanistan, April–May 2003," Ft. Leavenworth, Kan.: U.S. Army Center for Army Lessons Learned, 2003.
RAND TR1136-2.1

rucksack. All three combat loads include a body-worn hydration system that can contain up to three liters of water and weigh up to nine pounds full.

Soldiers in Afghanistan in 2003 wore lighter-weight body armor. Their protection consisted of a vest with two small arms protective insert (SAPI) plates. Today, Army body armor is generally heavier, as much as twice that worn in 2003.

It has, of course, been long recognized that too-heavy combat loads can reduce soldier effectiveness. In 2001, GEN Eric Shinseki, Army Chief of Staff, expressed a goal that the combat load of the individual soldier serving in the Future Force was not to exceed 50 pounds. This goal was to be reached by 2010, but that has not been realized.

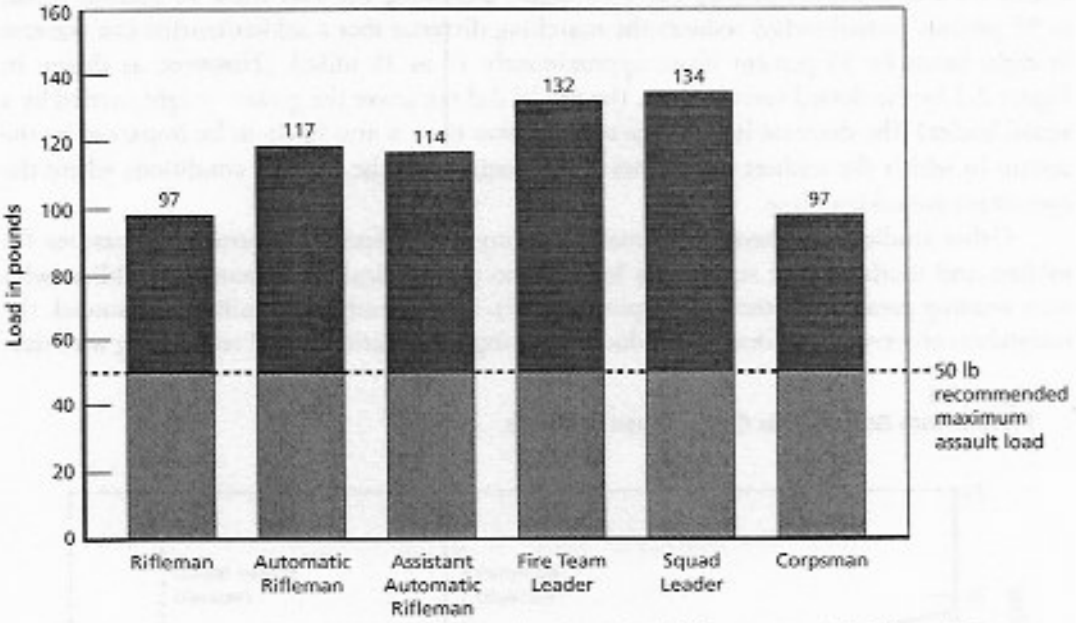
Marines carry combat loads that are similar in weight to what Army soldiers carry. Figure 2.2 shows the actual assault loads for six Marine Corps duty positions on combat patrols. The data are from a 2007 Naval Research Advisory Committee (NRAC) panel study that addressed the issue of lightening the combat load.[1] The NRAC study also recommended a maximum assault load of 50 pounds.

Load Impacts Performance

The U.S. Marine Corps is adamant that heavy loads are detrimental to combat performance. Numerous anecdotes abound that comment on the consequences of carrying heavy loads. As a Marine Corps officer put it in November 2006, "We were ordered to wear everything everywhere in the mountains all the time . . . even if you were in great shape, you couldn't keep up

[1] Naval Research Advisory Committee, "Lightening the Load," briefing to Honorable Delores M. Etter, Assistant Secretary of the Navy for Research, Development and Acquisition, September 2007.

Figure 2.2
Individual Combat Loads for Marines, by Position



SOURCE: Naval Research Advisory Committee, "Lightening the Load," briefing to Honorable Delores M. Etter, Assistant Secretary of the Navy for Research, Development and Acquisition, September 2007.
RAND TR1136-2.2

with the enemy."[2] Or, as it was phrased at the August 2005 Marine Corps Noncommissioned Officer Lessons Learned Conference, "Ounces equal pounds and pounds equal pain."

The NRAC study proposed several material solutions to help reduce the load. They include lighter body armor, caseless ammunition, lightweight weapons, integrated optics, advanced batteries, and overall systems integration. Of all of the material solutions, the NRAC felt that the biggest savings could be gained from lightening body armor. The NRAC also investigated other means of lightening a squad's load. They included offloading certain items and transferring the load via manned/unmanned ground and aviation vehicles, enhancing human performance through tactics and training, and using a systems engineering approach to reducing weight.

It is interesting to note that the loads carried by various infantry units through history experienced a sharp increase starting in World War I. Up until then (from the Greek Hoplites and Roman Legions through the Civil War), the loads were in the 40-pound range.[3] By the time World War II started, the combat loads had increased to 85 pounds and have remained at this level or higher ever since.

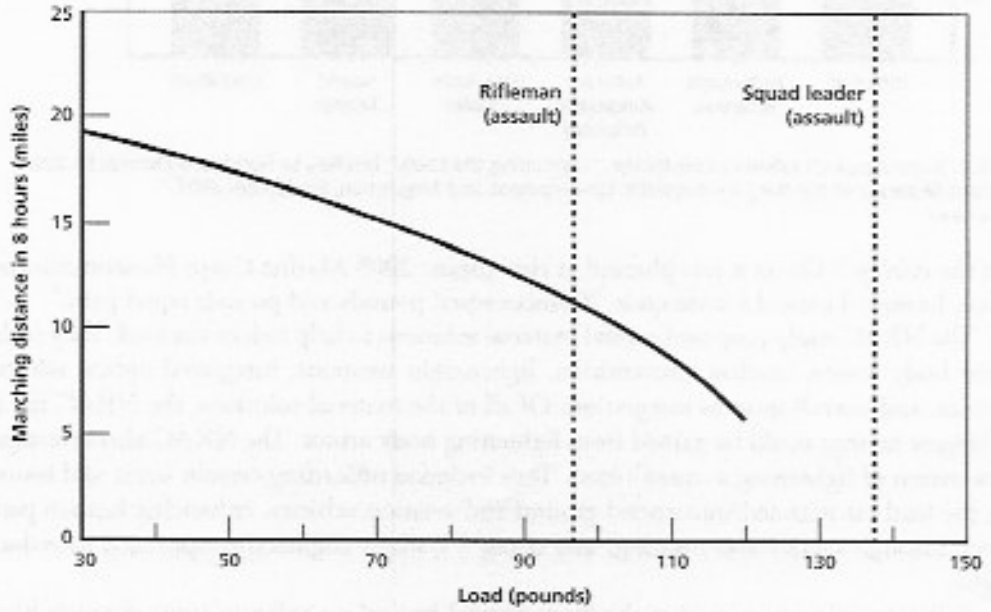
[2] Naval Research Advisory Committee, 2007, p. 43.

[3] Joseph Knapik, "Physiological, Biomechanical and Medical Aspects of Soldier Load Carriage," meeting on Soldier Mobility, Kingston, Canada, RTO MP-056, June 2000.

Heavy loads can severely impact a soldier or marine's combat performance.[4] Figure 2.3 illustrates the effect of combat load on a marine's performance.[5] (Similar results apply to a soldier on a dismounted patrol.) For a rifleman, increasing his load from 50 pounds (goal) to 95 pounds (actual today) reduces the marching distance that a soldier/marine can traverse in eight hours by 35 percent (from approximately 17 to 11 miles). (However, as shown in Figure 2.3 by the dotted vertical lines, the model did not cover the greater weight carried by a squad leader.) The decrease in distance covered over time is also likely to be impacted by the terrain in which the soldiers or marines are operating and the weather conditions where the operations are taking place.

Other studies have been performed that consider different performance measures for soldiers and marines. One such study looked into the physical performance of soldiers who were wearing personal protective equipment (PPE). In this study of 21 military personnel, the researchers observed a performance reduction during the functional field tests, along with dec-

Figure 2.3
Performance Decreases as Combat Load Increases



SOURCE: Unpublished findings from a 1988 Army study by R. F. Goldman.
NOTE: The conditions are for a weight of 171 pounds, a walking surface composed of dirt, a 1 percent grade, and a work level of 350 Kcal/hour.
RAND TR1136-2.3

[4] Long-term injuries are also being blamed on excessive combat loads. A newspaper report found that the number of soldiers medically retired from the Army with at least one musculoskeletal condition increased nearly tenfold from 2003 to 2009, according to Army statistics. The heavy combat loads contributed to a rising number of Afghanistan and Iraq war veterans retiring with degenerative arthritis, cervical strains, spinal injuries, and other musculoskeletal injuries. (Associated Press, "Combat Soldiers Are Carrying Too Much Weight," *Seattle Times*, February 13, 2011.)

[5] The curve shown in this figure is based on an Army study developed using R. F. Goldman's unpublished findings on metabolic energy cost modeling. A current review of metabolic cost models is summarized by Albert Adams III, "Effects of Extremity Armor on Metabolic Cost and Gait Biomechanics," thesis, Worchester Polytechnic Institute and U.S. Army Natick Soldier Research, Development and Engineering Center, 2010.

rements in cardiovascular performance, balance, and strength when wearing PPE (a system of Kevlar front and back plates and an unlined combat helmet).[6]

In another study the physical work performance, energy cost, and physiological fatigue experienced by military personnel were examined when wearing body armor. In this study of 34 military personnel, the findings indicate a significant metabolic cost with increased exercise while wearing body armor.[7]

In a third study, the physiological, biomechanical, and performance of 11 enlisted Army men not wearing armor, an armor vest, or a vest plus extremity armor were tested on separate days in walking, running, and three maximal-effort tasks. The maximal-effort tasks were five continuous 30-m rushes, five minutes of repetitive lifting of a 20.5-kg box, and an obstacle course run. The study demonstrated that performance on maximal efforts was poorer when extremity armor was worn than when armor was not used or only the armor vest was worn; that the use of extremity armor increases the users' metabolic cost while performing soldier tasks and alters gait biomechanics compared with no armor or an armor vest alone; and that there were significant changes in walking and running biomechanics when extremity armor was worn compared with not wearing armor.[8]

Body Armor Weight Contributes to the Overall Load

Today's body armor is heavy and represents a large amount of the combat load that a soldier carries. The weight of a full-up torso body armor set ranges from approximately 27 to 38 pounds, for small to extra-large sizes, respectively.[9] (In our analysis, we have used a medium size body armor set [32 pounds] in our weight comparisons, realizing that the conclusions based on it also effectively apply to the other sizes.)

A 10 percent reduction in body armor weight is not that easy to achieve.[10] Moreover, as we discuss below, a 10 percent reduction lessens the soldier's total combat load by only a few pounds. While every pound that is shaved off the soldier's load is important, three to four pounds only make a small dent in the effort to reach the 50-pound goal.[11]

The challenge is what material and nonmaterial solutions are available to achieve larger weight reductions.

---

[6] M. DeMaio, J. Onate, D. Swain, S. Ringleb, S. Morrison, and D. Naiak, "Physical Performance Decrements in Military Personnel Wearing Personal Protective Equipment (PPE)," poster presentation at the Symposium on Human Performance Enhancement for NATO Military Operations in Sofia, Bulgaria, October 5–7, 2009.

[7] Richard Ricciardi, Patricia A. Deuster, and Laura A. Talbot, "Metabolic Demands of Body Armor on Physical Performance in Simulated Conditions," *Military Medicine*, September 1, 2008, pp. 817–824.

[8] Leif Hasselquist, Carolyn K. Bensel, Brian Corner, Karen N. Gregorczyk, and Jeffrey M. Schiffman, "Understanding the Physiological, Biomechanical, and Performance Effects of Body Armor Use," *26th Army Science Conference Proceedings*, Orlando, Fla.: Natick Soldier Research, Development and Engineering Center, December 2008.

[9] Weights are for a torso set consisting of an improved outer tactical vest (IOTV) with deltoid protector and enhanced small arms protection insert/enhanced side body insert (ESAPI/ESBI) ceramic plates.

[10] "For plates, a 10 percent weight reduction for ESAPI continues to challenge industry" (Natick Soldier RD&E Center body armor overview briefing, March 31, 2011).

[11] The doctrinal fighting load is actually 48 pounds, not 50 (BG[P] Peter Fuller, Program Executive Officer Soldier, testimony before the House Armed Services Committee, March 17, 2011).

Current Body Armor Is Effective

The second point is that today's body armor appears to be effective. U.S. Rep. Roscoe Bartlett (R-MD) has stated:

> Our troops and their families should be reassured to know that to date there hasn't been a single fatality from a failure of currently issued body armor. Specifically, the Army and officials from the Joint Trauma Analysis and Prevention of Injury in Combat (JTAPIC) program found that there hasn't been any penetrations of body armor or a fatality associated with what the currently issued body armor was designed to stop.[12]

Statements like this suggest that there have not been any penetrations of body armor or fatalities associated with the threat that currently issued body armor was designed to stop. Indeed, we were not able to uncover any evidence that current body armor is not effective against the threat for which it is designed. However, while data are routinely collected on soldier injuries and deaths, there may be missing information. For instance, plates are often not returned or associated with the stricken soldiers or bodies. This means that the database may be missing critical information.

In 2004, a theater trauma system was in place for collecting data on trauma patients and implementation of a performance improvement program. Data collected on trauma patients included demographics, mechanism of injury, physiology, diagnostics, treatments, and outcomes, and this information was placed into the Joint Theater Trauma Registry (JTTR). Data collection in the trauma registry continues today, as does the performance improvement for trauma care across the continuum. The injury data collected along with body armor worn is given to the Joint Trauma Analysis and Prevention of Injury in Combat (JTAPIC) program for analysis. If adequate data have been collected, the effectiveness of today's body armor could be quantified. However, we were unsuccessful in obtaining casualty data from the JTAPIC program.

While today's body armor appears to be effective, it may also be that the body armor is over-designed for the threats that our soldiers and marines are facing in Afghanistan. (JTAPIC data should also be able to help answer this question.) While casualty data are reported in specific case studies, further analysis of the complete data is needed to better understand the following:

1. Does body armor protect against ballistic threats?
2. What is killing our soldiers? Concussive blast? Shock? Headshots through the helmet? Headshots in noncovered areas? Neck or throat shots? Torso shots through the soft armor? Torso shots through the plates? Exsanguinations because of a severed limb or artery not covered by body armor? Such information is needed.
3. There should be a report on every penetrating wound. Who has these reports and what is done with the data?

We recommend that JTAPIC identify and analyze casualty trends and circulate its findings among the body armor research community.

---

[12] "Congressman Roscoe Bartlett Reassures Troops and Their Families That They Are Protected by Effective Body Armor in Iraq and Afghanistan," press release, January 6, 2011.

Body Armor Must Be Capable of Handling Multiple Ballistic Round Penetrations and Limiting Backface Deformation

The third point is that today's body armor has two key requirements: It must be capable of handling multiple ballistic round penetrations and limiting backface deformation (BFD). Both requirements are stringent to meet.

The purchase description for personal armor protective inserts states that the ceramic plates must be able to stop three rounds spaced in a well-defined shot pattern.[13] In addition to meeting this penetration requirement against different ballistic rounds, body armor plates must also meet other conditions (temperature extreme, fluid resistance, altitude test, fungus test, etc.). In order to satisfy all of these requirements, the ceramic plates are necessarily heavy.

The ability to limit BFD is another stringent requirement. BFD is a surrogate measure of blunt force trauma. Clay is used as the backing in tests where BFD is measured as the depth of the crater created after bullet impact.[14] Based on 1977 research findings by Prather, Swann and Hawkins, 44 mm indentation has been accepted by the Army as the maximum accepted depth.[15-16]

These test requirements are for the current Army X-small arms protection insert (XSAPI) test procedures. Other test requirements have been used that vary slightly with plate type and time.[17]

Both the multiple ballistic round penetration and the maximum backface deformation requirements force the vendors to produce heavy ceramic plates with adequate backing material.

Basis for the Two Requirements

The requirement that body armor be able to handle multiple ballistic round penetration is based on a conservative decision approach and the desire to protect against this type of attack in-theater.

---

[13] Purchase Description, "Personal Army X Small Arms Protective Insert," FQ/PD 07-03B, August 25, 2010.

[14] Convention dictates that the crater in clay resulting from a ballistic test be called backface deformation (BFD), but it is more accurately described as backface signature (BFS). The degree of plate deformation (BFD) in a ballistic test is actually less than the resulting crater (BFS). (J. P. F. Broos and M. J. van der Jagt-Deutekom, "What Does the Indent in Plastilina Mean?" Personal Armour Systems Symposium (PASS), Quebec City, Canada, September 13–17, 2010.)

[15] R. Prather, C. Swann, and C. Hawkins, *Backface Signatures of Soft Body Armors ad the Associated Trauma Effects*, Aberdeen Proving Ground, Md.: Chemical Systems Laboratory, November 1977.

[16] Current DOT&E requirements state that "60 plates are to be tested in nine environments, under ambient conditions and by shot order" (*Standard for Lot Acceptance Testing of Hard Body Armor*, memorandum 2 July 2010). The 60-plate design is replicated for each threat. The DOT&E standard does not specify the specific threats for testing. For any threat, the following is required to successfully pass the first article test (FAT):

- For the first shot, the 90 percent lower confidence bound for the probability of no complete penetration is greater than or equal to 0.9.
- For the second shot, the 90 percent lower confidence bound for the probability of no complete penetration is greater than or equal to 0.7.
- For the first shot, with 90 percent confidence the 90 percent upper tolerance limit for the BFD is less than 44.0 mm.
- For the second shot, with 90 percent confidence the 80 percent upper tolerance limit for the BFD is less than 44.0 mm.

[17] For example, the March 2010 ESAPI PD used a point system to determine first article test (FAT) failures based on first and second shot penetrations and BFD greater than 44 mm, while the December 2009 XSAPI PD also used a point system but a 43 mm BFD requirement with a pass/fail criteria that differed by threat type.

The BFD requirement is based on 1977 study by Prather, Swann, and Hawkins, commissioned by the National Institute for Law Enforcement and Criminal Justice of the Law Enforcement Assistance Administration. The purpose of the study was to develop a simple, readily available backing material for use in characterizing both the penetration and deformation effects of ballistic impacts on soft body armor and relate this deformation to the injury potential of nonpenetrating ballistic impacts.

Prior to the study, 20 percent gelatin had been used as a backing material for the study of ballistic impacts on soft body armor materials. However, a major limitation of gelatin is the near total recovery of any deformation that may occur. The only way to analyze deformations in gelatin is through the use of high-speed photographic techniques. The Prather study was able to establish that Roma Plastilina 1 clay was a second option that could be used to correlate clay deformation to injury and tissue deformation. Because the clay exhibited very little recovery, a readily available impact cavity could be used for BFD measurements.

To establish the acceptable BFD, a model was formulated using experimental data sets obtained from tests on anesthetized animals, for which physical characteristics of the impacting projectile was known.[18] Based on the model and tests done with the clay, Prather, Swann, and Hawkins concluded that "A depth of deformation greater than 50 mm is associated with the probability of lethality of approximately 15%."[19] This is shown in Figure 2.4. They also wrote, "However, the available data is limited and hence no solid conclusions can be drawn as yet regarding the effect of deformation depth."[20] Regardless, the limited data were used as the basis for mathematical modeling that predicted that a BFD of 44 mm or less would ensure a probability of lethality no greater than 10 percent.

The 44 mm standard should be corrected in three ways. First, this standard was established in tests with soft body armor. Second, the model created to equate clay BFD to tissue deformation and lethality was based on limited data. Third, injury data from human ballistic impacts were not readily available in the past, and the BFD standard that was set has not been validated. The 44 mm standard should be reevaluated using the human ballistic impact and injury data from the conflicts in Afghanistan and Iraq that PEO Soldier and JTTR collect and submit to JTAPIC.

Summary

These three related issues—the goal of reducing average combat loads, the effectiveness of current combat armor, and the requirements that body armor must meet—inform our assessments of the approaches to improving body armor. In Chapter Three, we discuss four such approaches.

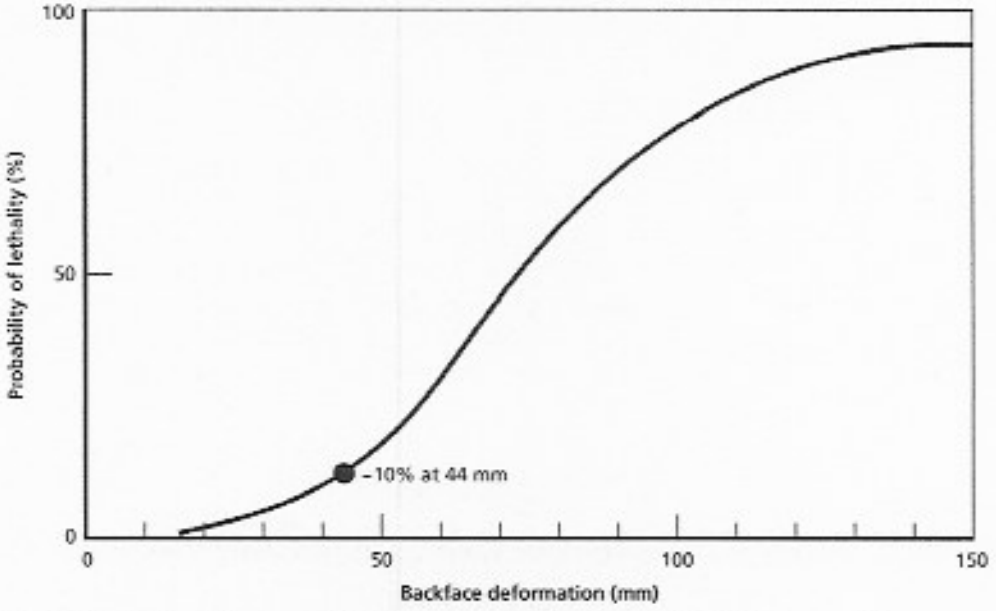
---

[18] Data for three animal species were used in the analysis. The database consisted of 30 live cohorts each, of goats, swine, and dogs (Victor Clare, James Lewis, Alexander Mickiewicz, and Larry Sturdivan, "Blunt Trauma Data Collection," Edgewood Arsenal, Aberdeen Proving Ground, EB-TR-75016, May 1975). In a related study, goats were used that wore lightweight soft body armor (Biophysics Division 1-A, "Backface Signature Study Using Armored Goats," internal report, undated).

[19] Prather, Swann, and Hawkins, 1977, p. 10.

[20] Prather, Swann, and Hawkins, 1977, p. 10.

Figure 2.4
Probability of Lethality as a Function of Backface Deformation



SOURCE: R. Prather, C. Swann, and C. Hawkins, *Backface Signatures of Soft Body Armors and the Associated Trauma Effects*, Aberdeen Proving Ground, Md.: Chemical Systems Laboratory, November 1977.

RAND TR7136-2.4

CHAPTER THREE

Four Approaches to Lightening Body Armor

In this chapter, we discuss four approaches for lightening body armor and assess their potential. Both material and nonmaterial means are considered.

The first candidate approach to lightening body armor is reassessing the threat and refining requirements. As we mentioned in Chapter Two, a big driver in designing body armor that will provide adequate protection is the threat that the body armor will encounter. If the plates are over-designed relative to the threat, then weight can be shaved off the ceramic plates, and this reduction will permit the vendors to introduce more innovation into their plate designs.

A second approach involves using modular body armor configurations to better match the protection to the expected threat. As we will discuss later, this approach is already available but comes with great risks.

A third approach is to improve the Army's testing procedures to eliminate any excess variation in the tests, such as by reformulating the clay so that it can be used at ambient temperatures. Such changes may reduce the need to over-design the plates in order to pass the tests, and thus potentially allow for lighter-weight body armor to be constructed.

A fourth approach is to develop new soft and hard body armor materials that are inherently stronger relative to their weight. This development will most likely require more research, development, test, and evaluation (RDT&E) funding and may require changes in the procurement process that is used today to procure body armor as a commodity item.

Refining Requirements

We start our analysis by looking at refining requirements as an approach to lighten body armor. Because the details of threats that the body armor must be effective against are classified, our discussion of requirements is limited. We use unidentified threats in place of the classified threats; the relationship between threat and requirements can still be explained using the notional threats.

Assessing Threats

Eight threats have been devised that cover a range of calibers and projectile types for ESAPI and XSAPI ceramic inserts. These are labeled as follows:

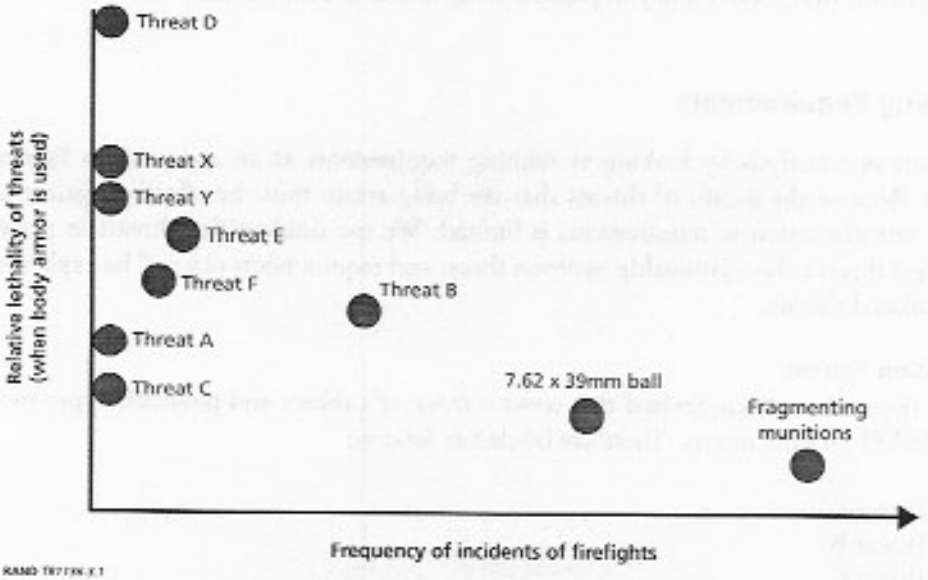
- Threat A
- Threat B
- Threat C

- Threat D—the most stressing type, and the former test standard
- Threat E—less stressing than Threat D, and the current test standard
- Threat F
- Threat X
- Threat Y

The current line of ceramic inserts has been designed to protect against a worst-case scenario—conflict with a nation-state that is well funded and considered a near-peer military competitor to the United States. While it is important to prepare for a large-scale conflict against a sophisticated adversary, current ceramic inserts are over-designed for the threat posed by the Taliban, al Qaeda militants, and other belligerents currently opposing U.S. forces in Afghanistan. Over-design means a heavier plate than necessary to counter the threat. The military, realizing this, has stepped back from using the most stressing round available (Threat D) and is now using Threat E as the primary standard, a move that will likely result in ceramic insert weight reductions.

Figure 3.1 shows the protection level of current body armor against the threats occurring in Afghanistan and Iraq. The x-axis shows the frequency of employment of the threat rounds in the current theater of operations. The y-axis shows the relative lethality of a given threat round against ceramic-plate protected body armor. Soft body armor alone protects against shrapnel from fragmenting munitions, and the addition of SAPI will successfully defend against AK-47 ball ammunition. The ESAPI and XSAPI plates were designed to protect against armor-piercing ammunition, which is rarely employed by our current enemy. The new testing standard, Threat E, is more likely to be encountered in the battlefield (although still rare) than Threat D, which is a test round not available on the world market.

Figure 3.1
Effectiveness of Body Armor Against Different Threat Types



Tailoring Body Armor as a Means to Lighten Body Armor

While a certain amount of armor overmatch is desired, extensive overmatch has operational costs, such as excess weight and bulk that reduces the maneuverability and mobility of the wearer.[1] One relatively simple weight reduction technique is to allow commanders to tailor body armor to match the current threat level in theater. For example, the threat in Afghanistan today is primarily fragmenting munitions, 7.62mm x 39 ball bullets, and 7.62mm x 54R ball bullets. Current body armor provides excessive overmatch against those threats, and its weight could likely be reduced if designed to the threat. If the threat were to increase (to armor-piercing rounds, for example), the level of body armor protection could increase as well.[2]

The military tends to be risk-adverse and requires its plates to withstand trauma in worst-case scenarios (muzzle velocity against armor-piercing bullets) instead of the data-supported threat. And leaders are understandably reluctant to make the decision to scale down threat requirements, lest they be blamed for a soldier death or injury due to projectile-armor overmatch. Yet, due to several large purchases over the past decade, the military now has a wide variety of ceramic plates in inventory (SAPI, ESAPI, XSAPI, and soon light SAPI [LSAPI]) designed to protect against a variety of threats. With this inventory, commanders could tailor body armor levels based on the current threat, without additional cost to the Army.

Using Modular Configurations

Next, we look at modular configurations as an approach to lighten body armor and discuss the merits and risks of this approach.

Combat conditions can vary greatly based on the mission, the threat, and the environmental conditions, such as elevation. Accordingly, field commanders must be able to adjust body armor to minimize the detrimental effects of weight and heat without unduly sacrificing protection. To enable these adjustments, requirements developers have established language to specify how body armor must be configurable for the range of combat conditions.

Requirements developers have parsed the configurability of body armor into three aspects: modularity, tailorability, and scalability. The draft Soldier Protection System Capability Development Document defines these terms as follows:[3]

1. Modular: Made up of separate modules that can be rearranged, replaced, combined, or interchanged easily.

---

[1] There are no data that we could uncover that address how current body armor affects lethality and injury to U.S. forces, despite the decade-long natural experiment in Iraq and Afghanistan. Nor does there seem to be data from operational testing to assess the effects that degraded individual performance due to the weight and bulk of the body has on operational effectiveness. These kinds of data are critical for developing better requirements.

[2] Changing test requirements to meet current battlefield threats would indeed lessen plate weight (SAPI is lighter than ESAPI, which is lighter than XSAPI). However, we must have body armor in the inventory to protect against possible worst-case threats, in the event that our enemies begin to use armor-piercing ammunition. Therefore, we cannot simply lessen the threat requirements. Instead, the recommendations come down on the side of modularity of body armor that can be tailored to protect against the current threat, but could also be modified quickly if the threat increased.

[3] Capability Development Document (CDD) for Soldier Protection System Increment I, ACAT: III, draft version 1.0, 10 December 2010.

2. Tailorable: The ability to adapt body armor to make it suitable for a particular duty position, mission, etc.
3. Scalable: Describes protection levels that can be upgraded or downgraded to meet a specific threat.

An example of modularity is adopting plate carriers in lieu of the improved outer tactical vest (IOTV) for dismounted operations at high elevation. An example of tailorability is allowing a static, relatively vulnerable gate guard to wear groin, throat, and shoulder armor protection but also to remove them when more movement is required. An example of a scalable system is the Body Armor Protection Levels (BAPLs) described later in this chapter.

These aspects of modularity, tailorability, and scalability are somewhat similar in nature; the key takeaway is that they allow a commander to reduce the body armor weight of his soldiers when appropriate for the threat environment.

Examples of Modular Configurations

Like helmets and uniforms, ceramic plates (and the vests that carry them) come in multiple sizes to fit the wearer properly. Different plates are available, as well, to defeat varying levels of threat. The larger the plate, and the more lethal the threat against which the plate is designed to defend, the more the plate weighs. Special Operations Forces use a suite of plates that includes a swimmer plate design that allows greater range of arm motion. Figures 3.2 shows the ECLiPSE Solar family of plates that were designed by the Special Operations Equipment Advanced Requirements (SPEAR) under the Body Armor/Load Carriage System (BALCS) program (BAE Systems, 2012).[4]

Figure 3.3 gives a sense of the variety of configurations and body armor components that are available. When soft armor alternatives, whether vest or plate carrier, are used in conjunction with plates of varying protection level, as well as supplemental protection for the groin, throat, and shoulders, the number of possible configurations becomes quite large. While Figure 3.3 shows a group of armor systems, they are only examples and are not currently used as such by any particular DoD component.

Coverage Versus Weight

While the correlation between body armor weight and the amount of the body covered by soft armor should be intuitive, Figure 3.4 shows the estimated linear relationship between coverage and weight. In this figure, the body armor weight includes the weight of the inserts. What is important is the slope of the curve, which is 1.1 pounds of weight per square foot of soft ballistic coverage. Soft armor protects against small-caliber handgun rounds, shotgun blasts, and fragmenting munitions, such as hand grenades. Covering more of the body with soft armor results in greater protection from these threats, but at the cost of increased weight.

Figure 3.4 does not explicitly portray thermal load, which is also correlated to area coverage and is an increasing concern of requirements developers.

---

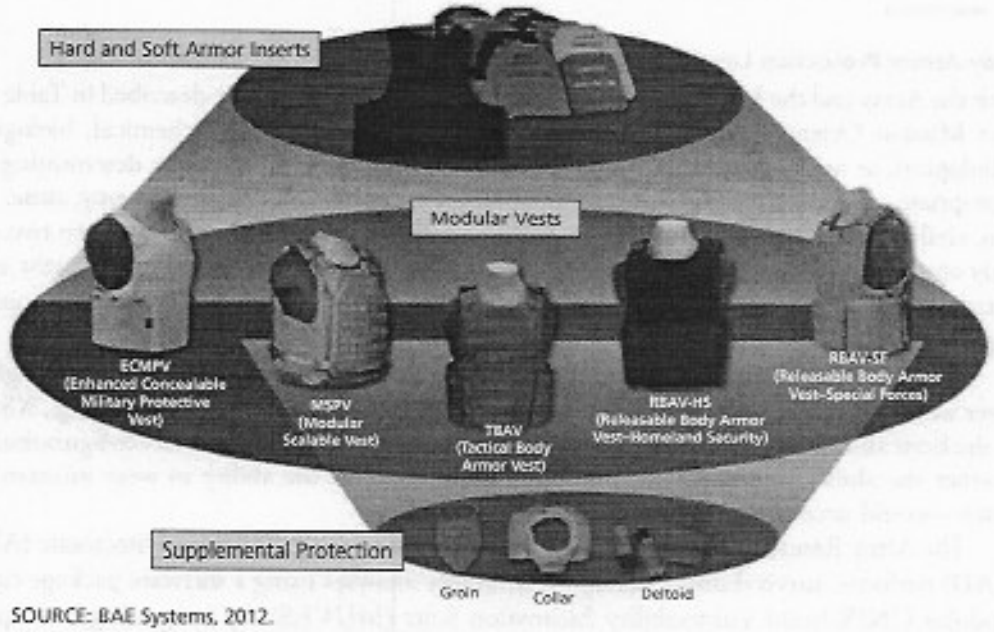
[4] The reason special operations forces are able to operate with more modular designs and mission-specific plates is because established mission profiles allow small unit commanders to accept higher levels of risk. This is different from the Army and Marine Corps forces, who do not have access to the same quality of intelligence for their missions and tend to wear full protection because they must expect the unexpected. (COL [Ret.] Luigi E. Biever, former Director, Joint Staff Support Services and Joint Staff Inspector General, private communication, June 10, 2011.)

Figure 3.2
An Example of a Suite of Body Armor Plates



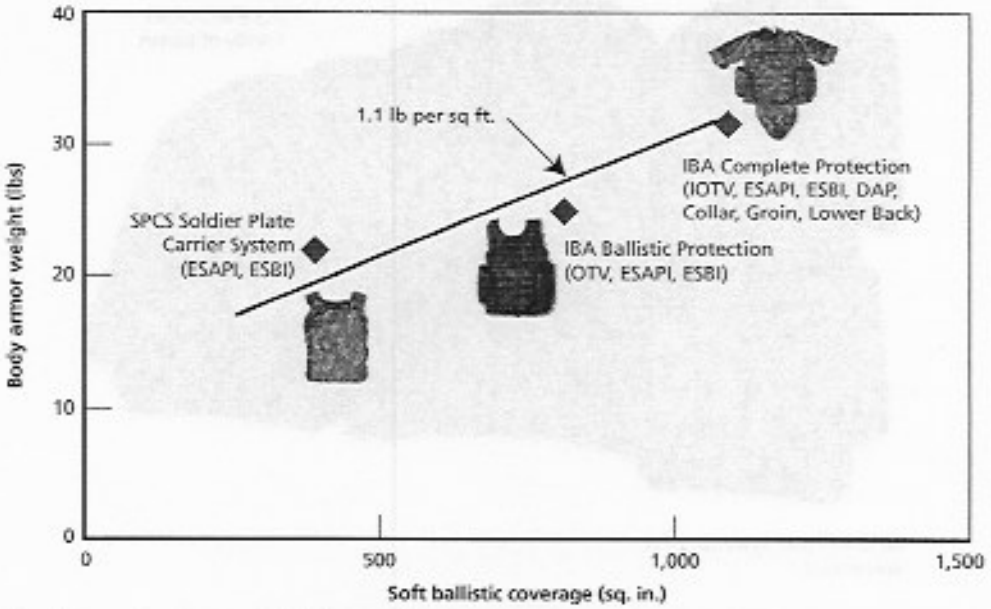
SOURCE: BAE Systems, 2012.
RAND TR1136-3.2

Figure 3.3
Example Components for Modular Body Armor Configurations



SOURCE: BAE Systems, 2012.
RAND TR1136-3.3

Figure 3.4
Body Armor Weight Increases as Coverage Increases



SOURCE: Based on data provided by PM Soldier Protection and Individual Equipment, private communication, April 2011.
NOTES: The figure shows values for size medium body armor with all plates. SPCS = Soldier Plate Carry System; IBA = Interceptor Body Armor; DAP = deltoid and axillary protectors; OTV = outer tactical vest; IOTV = improved outer tactical vest.
RAND TR1126-3.4

Body Armor Protection Levels

Both the Army and the Marine Corps have established BAPLs, which are described in Table 3.1. Like Mission Oriented Protective Posture (MOPP) levels for CBRN (chemical, biological, radiological, or nuclear) threats, BAPLs standardize commanders' options in determining the appropriate amount of protective equipment based on METT-C (mission, enemy, time, terrain, civilians) considerations. While the Army's six BAPL levels distinguish between two soft body options (IOTV and plate carrier) to account for the different protection and weight associated with each, the Marine Corps' four-level system does not direct which soft body option is used in a given BAPL.

Note that the weights shown are for X-threat protection, which is the heaviest. Weight is lower when ESAPI and LSAPI plates are worn. Asymmetric plate configurations, e.g., XSAPI on the front and ESAPI in the rear, could also reduce weight. These additional configurations—whether the ability to adjust both plate protection levels or the ability to wear mismatched plates—would necessitate additional BAPL designations.

The Army Research Laboratory's Survivability and Lethality Analysis Directorate (ARL/SLAD) performs survivability/lethality/vulnerability analyses using a software package called Modular UNIX-based Vulnerability Estimation Suite (MUVES). By integrating the Operational Requirement-based Casualty Assessment (ORCA) into MUVES, the SLAD team has developed a new approach to personnel survivability and casualty assessment.