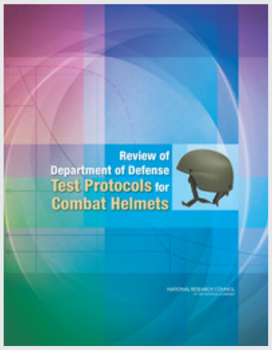

Review of Department of Defense Test Protocols for Combat Helmets

DETAILS

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Introduction

This chapter provides the study context and statement of task. It also describes the scope of the study and includes summaries of the various chapters in the report.

In June 2012, Rep. Louise Slaughter (D-NY) sent a letter (Slaughter, 2012)[1] to Secretary of Defense Leon Panetta expressing concerns that a recent modification to the standard for ballistic testing for the Advanced Combat Helmet (ACH) posed "an unacceptably high risk" for such protective equipment. She urged that ballistics testing procedures be modified.

The July 13, 2012, response to Rep. Slaughter (Gilmore, 2012)[2] was made by J. Michael Gilmore, Director of Operational Test and Evaluation (DOT&E), the principal staff assistant and advisor to the Secretary and Deputy Secretary of Defense for operational test and evaluation and live-fire test and evaluation matters. He expressed the view that the revised test protocol for the ACH is "better in several ways that the previously used protocol while being designed to demonstrate the same level of protection (probability of perforation) and also the same level of certainty of our knowledge of the level of protection." However, he also noted that DOT&E was requesting that the National Research Council conduct a study to review the revised protocol for testing military combat helmets. This report is the result of that request. Following is the statement of task.

> The National Research Council will establish an ad hoc committee to consider the technical issues relating to test protocols for military combat helmets and prepare a report. The committee will examine the testing protocols along the following lines:
>
> - Evaluate the adequacy of the Advanced Combat Helmet test protocol for both first article testing and lot acceptance testing, including its use of the metrics of probability of no penetration and the upper tolerance limit (used to evaluate backface deformation).
> - Evaluate the appropriate use of statistical techniques (e.g., rounding numbers, choosing sample sizes, or test designs) in gathering the data.
> - Evaluate the adequacy of the current helmet testing procedure to determine the level of protection provided by current helmet performance specifications.
> - Evaluate procedures for the conduct of additional analysis of penetration and backface deformation data to determine whether differences in performance exist.
> - Evaluate the scope of characterization testing relative to the benefit of the information obtained.

[1]The text of Rep. Slaughter's letter to Secretary Panetta is found in Appendix A.

[2]The text of Director Gilmore's letter to Rep. Slaughter is found in Appendix A.

1.0 INFORMATION GATHERING

The committee held six meetings. The first was held in Aberdeen, Maryland, and included a site visit to the combat helmet test range at the Aberdeen Test Center. The second through sixth meetings were held at the Academies' facilities in Washington, D.C., and Woods Hole, Massachusetts. A total of 18 presentations were received from the following entities:

- Offices within the United States Army, the Marine Corps, and the Special Operations Forces
- Manufacturers of combat helmets
- Office of the Department of Defense (DoD) Inspector General

The titles of the presentations are listed in Appendix C.

1.1 SUMMARY OF THE REPORT

The report contains 10 chapters and several appendices. This is an introductory chapter. Summaries of the remaining chapters are given below.

Chapter 2: Evolution of Combat Helmets

Chapter 2 describes the changes in design and materials, from those used in World War I to today's ACH. One of the key advances was the development of aramid fibers in the 1960s, which led to today's Kevlar-based helmets. The DoD is continuing to invest in research to improve helmet performance, through better design and materials as well as better manufacturing processes.

Chapter 3: Threats, Head Injuries, and Test Methodologies

A variety of threats lead to head injuries in the battlefield. Since World War II, the predominant threats have been from the following: *fragmentation and ballistic* threats from explosions, artillery, and small arms fire; *blunt trauma* caused by translation from blast, falls, vehicle crashes, and impact with vehicle interiors and from parachute drops; and exposure to *primary blasts*. Key findings in this chapter indicate the following:

- Wounding from an explosive source (e.g., fragmentation from bombs, mines, and artillery) dominates all wounding, including bullets.
- Nonbattle causes, including blunt traumatic injuries, produced nearly 50 percent of the hospitalizations for traumatic brain injury in Iraq/Afghanistan.
- There is no biomechanical link in the current test methodology between the backface deformation (BFD) assessment and head injuries from behind-helmet deformation.

There is a need to revise test methodologies to focus on the dominant threats. The current protocol addresses primarily rounds from 9-mm pistol fire, which is a relatively small contributor to soldier injuries. It is also important to develop better understanding of the scientific connection between head injuries and the performance metrics used in current test methodology.

Chapter 4: Combat Helmet Testing

Chapter 4 describes how combat helmets are tested. It includes a brief summary of the testing process, a description of the test threats, and a discussion of the various sources of variation in the testing process.

Chapter 5: Helmet Performance Measures and Trends in Test Data

A helmet's protective capabilities are evaluated on the basis of two primary test measures: resistance to penetration (RTP) and BFD. These are formally defined, and their limitations are discussed in this chapter. RTP data available to the committee indicate that the probability of penetration of a helmet shell by a 9-mm bullet, fired under specified conditions, is on the order of 0.005 or less. Available BFD data show that the probability of exceeding the BFD thresholds is also around 0.005 or less. The distributions of the BFD data also demonstrate significant differences among helmet sizes and shot locations. Some of the performance differences among helmet sizes may be attributed to the test process, such as headforms and standoffs. Many others are likely to be due to the differences in the geometry of helmet shells, molds, manufacturing processes, and other factors. In fact, helmets of different sizes are intrinsically different products. Based on this, Recommendation 5-5 proposes changes to DoD's test protocols. This is one of the major recommendations in the report.

Chapter 6: FAT Protocols for Resistance to Penetration: Statistical Considerations and Evaluation of DOD Test Plans

The test protocols for Army helmets were originally based on a requirement of zero penetrations in 20 shots (5 shots on 4 helmets). The DOT&E protocol replaced this legacy plan with a requirement of 17 or fewer penetrations in 240 shots (5 shots on each of 48 helmets). The helmets spanned four sizes and were tested in four different environments. The 0-out-of-20 (0, 20) plan and DOT&E's 17-out-of-240 (17, 240) plan have comparable performance if the probability of penetrating a helmet shell on a single shot is around 0.10. As noted in the Chapter 5, available data indicate that these penetration probabilities are around 0.005 or less. Near this value of penetration probability, both plans have a 90 percent or higher chance of passing the test, so the manufacturer's risk is small, as it should be. However, if there is a 10-fold increase in the penetration probability from the current level of 0.005 to 0.05, DOT&E's (17, 240) plan still has a 95 percent chance of acceptance. This provides little incentive for the manufacturer to sustain current penetration levels. The (0, 20) plan, on the other hand, has only a 38 percent chance of acceptance. Thus, the (17, 240) plan may have the unintended effect of leading to a reduction in helmet penetration resistance. In the absence of a link between penetration probability and human injury, there is no scientific basis for setting a limit on the penetration probability. In such a circumstance, the committee's view is that the objective of a new test plan should be to provide assurance that newly submitted helmets are at least as penetration resistant as current helmets. Chapter 6 also proposes appropriate criteria for selecting test protocols and illustrates their use through several plans.

Chapter 7: Test Protocols for Backface Deformation: Statistical Considerations and Assessment

The original Army protocols for BFD were based on binary (0-1) data. The BFD measurement at each location was compared against its specified threshold, and the outcome was scored as a "1" (failure) if it exceeded its threshold. This original plan was based on 20 shots; if no BFD measurements exceeded their limit, the demonstration was successful. In this sense, it was similar to Army's legacy protocol for RTP. The DOT&E protocol expanded the number of shots to 240 and used the continuous measurements together with an assumption that the data are normally distributed. Specifically, the plan compared the 90 percent "upper-tolerance limits" computed at 90 percent confidence level (90/90 rule) with their thresholds for the corresponding location on the helmet. As noted in Chapter 5, available BFD test data show that the probability of BFD exceeding its limits is quite small—on the order of 0.005. As this chapter observes, DOT&E's BFD protocol has about a 90 percent chance of accepting the helmet design, even if there is an order of magnitude increase in the exceedance probability (from 0.005 to 0.05). This weakens the incentive for manufacturers to produce helmets that are at least as good as current helmets with respect to BFD. In addition, the DOT&E protocols are based on an (a priori untestable) assumption of normality and the complex notion of an upper tolerance limit. Recommendation 7-1 proposes that DOT&E's protocol for BDF data be changed. This change has the added advantage that the BFD protocol would exactly parallel the RTP protocol and would be easy for designers and manufacturers to understand and interpret. However, it is important that, after testing, the continuous BFD measurements be analyzed to assess the actual BFD levels and monitor them for changes over time.

Chapter 8: Lot Acceptance Testing

Lot acceptance testing (LAT) is used to ensure that manufacturers continue to produce helmets that conform to contract specifications. A random sample of helmets is selected from the production lot, and the helmet shells, as well as hardware, are tested according to the LAT protocol. The number of helmets in the protocols is determined from an American National Standards Institute (ANSI) standard, and they vary by lot size. Chapter 8 examines the operating characteristic (OC) curves for DOT&E's LAT plans and compares them with FAT protocols in the Army's legacy plans and DOT&E's plans. The OC curves for the LAT plans for the different lot sizes can vary a lot, indicating that the manufacturer's and government's risks can be quite different across lot sizes. This is primarily due to the different sample sizes (number of helmets and number of shots) as determined from an ANSI standard. Further, DOT&E's first article testing (FAT) protocols are considerably less stringent (higher probabilities of acceptance for the OC curves) than their corresponding LAT protocols. This is counter to the philosophy that it should be more difficult for manufacturers to pass FAT than LAT. This issue can be addressed if DOT&E makes changes to the (17, 240) FAT protocol as discussed in Chapters 6 and 7. Chapter 8 also proposes using binary data for BFD LAT protocols, to make them consistent with the recommendations for FAT. Finally, the committee examines the properties of LAT protocols based on helmets as the unit of testing.

Chapter 9: Characterization Tests for ACH and Future Helmets

The committee was tasked to "evaluate the scope of characterization testing relative to the benefit of the information obtained." The term "characterization" is broad and is used in different ways in different contexts. However, DOT&E provided additional information to elaborate on this task. Most of the issues raised by DOT&E that relate to this task are addressed in this chapter. Chapter 9 also describes additional characterization tests that are needed. Some of these are intended for future helmet designs. A number of these additional tests have been discussed in earlier chapters and are repeated here because they can be viewed as being related to characterization studies. These include the following: evaluating helmet performance across a more realistic, broader range of threats; assessing the effect of aging; understanding the relationship between helmet offsets and helmet protection; and conducting gauge repeatability and reproducibility studies to understand the different sources of variation in the test process and possibly providing opportunities to reduce some of the variation. Chapter 9 also includes a discussion of current V_{50}—the velocity at which complete penetration and partial penetration are equally likely to occur—testing and an alternative methodology as well as a discussion of industrial practices in characterizing process capability.

Chapter 10: Linking Helmet Protection to Brain Injury

The relationships between helmet deformation and brain injury are not well known. Most of the studies in biomechanical engineering and medicine are related to sports and vehicle collisions, and these investigations are based on a different range of stresses and stress rates from those encountered in the battlefield. The aim of Chapter 10 is to present information on what is known, and the gaps in knowledge, about the linkage between brain injury and current battlefield threats. The major finding is that helmet protection from penetration and BFD greater than a particular value does not protect the brain from occurrence of many categories of tissue injury. This chapter discusses recommendations that can help focus research, including determination of the prevalence of reversible declines in hormonal function years after brain trauma and acceleration of research in computational modeling and simulation that can show shear stress fields associated with the known spectrum of threats and the protective capabilities of helmets.

1.2 REFERENCES

Gilmore, J.M. 2012. Letter from J. Michael Gilmore, Director of Operational Test and Evaluation, to Representative Louise M. Slaughter, July 13.

Slaughter, L.M. 2012. Letter from Representative Louise M. Slaughter to Secretary of Defense Leon Panetta, June 26.