Health Hazard Assessor's Guide

Technical Guide 351C

Hazards Related to Musculoskeletal Trauma, Vibration, Shock, and Thermal Stress

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PREFACE

TG 351C, *Hazards Related to Musculoskeletal Trauma, Vibration, Shock, and Thermal Stress,* is the third volume of the *Health Hazard Assessor's Guide.* This volume includes an introductory chapter followed by eight chapters presenting guidance for conducting health hazard assessments of exposure to lift and carry, load carriage, head-supported mass, whole-body vibration, hand-arm vibration, mechanical shock, recoil, and thermal stress.

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CHAPTER 1. INTRODUCTION TO THE HEALTH HAZARD ASSESSOR'S GUIDE

Source: Defense Visual Information Distribution Service (DVIDS)

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1–1. Purpose

The Health Hazard Assessor's Guide consists of a series of chapters, each focusing on a health hazard category addressed in the current version of Army Regulation (AR) 40–10, *Health Hazard Assessment Program in Support of the Army Acquisition Process*. The purpose of this technical guide (TG) is to—

(1) Characterize health hazard categories and expand upon the Health Hazard Assessment (HHA) Program process as established in AR 40–10*.*

(2) Provide guidance on the process of conducting an HHA for each unique health hazard category in order to assign consistent risk assessment codes (RACs) and effectively communicate recommendations to the materiel developer (MATDEV) responsible for hazard mitigation. (Note: A category may comprise multiple sub-categories.)

(3) Provide a technical resource for U.S. Army Public Health Center (APHC) independent medical assessors (IMAs) and other personnel who identify and assess potential materiel system health hazards in support of the Army Acquisition Process. Chapter 1 serves as the reference for the remaining chapters as it contains key relevant definitions and general risk assessment processes that appear throughout the Guide.

1–2. Definitions of Key Terms

Capability developer (CAPDEV): A command or agency that formulates doctrine, concepts, organization, training, materiel requirements, and objectives. The CAPDEV represents the user community over the life cycle of the system.

Hazard probability (HP): An expression of the degree of likelihood that an exposure to a hazard/hazardous condition (physical, chemical, or biological) will produce an adverse health outcome to a materiel system user or maintainer. HP is based on an assessment of factors such as the affected population, the user scenario, and the duration and frequency of the exposure. See Table 1–1 for the HP levels.

Hazard severity (HS): An expression of magnitude of an adverse health outcome (occupational injury/illness) to a materiel system user or maintainer that will occur from exposure to a hazard/hazardous condition (physical, chemical, or biological) during normal use or maintenance of the materiel system. See Table 1–2 for the HS categories.

Health hazard: An existing or likely condition, inherent to the operation or use of materiel, that can cause personnel death, injury, illness, disability, and/or reduced job performance. It is important to distinguish between hazards inherent in the normal use and maintenance tasks and those hazards related to equipment failures, mishaps, or human errors. The scope of the HHA process includes assessment of inherent hazards during normal use and maintenance while the hazards related to failures, mishaps, or human errors fall within the scope of the system's safety program.

Health Hazard Assessment (HHA): The application of biomedical knowledge and principles to document and quantitatively determine the health hazards of Army systems during normal system operation and maintenance. This assessment identifies, evaluates, and recommends controls to reduce risks to the health and effectiveness of personnel who test, use, or service Army systems. This assessment includes—

- The evaluation of HS, HP, risk assessment, consequences, and operational constraints.
- The identification of required precautions and protective devices.
- Training requirements.

Health protection criteria: Include applicable criteria and standards that have been adopted for use in assessing potential adverse effects associated with exposure to the identified hazards. The Department of Defense (DOD), Department of the Army (DA), and other governmental (Federal, state, and local) criteria and standards should be used as deemed practical. Other scientific and professional criteria and standards may be developed, and the HHA Program may adopt these consensus standards to be applicable to military-unique requirements. The type of criteria may differ depending on the specific hazard and available research (e.g., medical criteria, injury criteria, damage risk criteria, design criteria). When military design, specification, or deployment requirements render compliance with existing occupational health standards infeasible or inappropriate, or when no standard exists for military-unique applications, the Army will apply standards appropriate for the exposure scenario or use the health risk management process to develop military-unique occupational health standards.

Independent Medical Assessor (IMA): Personnel, independent of materiel and combat developers, who are tasked by the Army Medical Department (AMEDD) to provide the appropriate HHA support to Army materiel systems.

Initial risk: The first assessment of the potential risk of an identified hazard. Initial risk establishes a fixed baseline for the health hazard.

Life cycle: The life of a system from conception to disposal.

Materiel developer (MATDEV): The research, development, and acquisition command agency or office assigned responsibility for the system under development or being acquired. This term may be used generically to refer to the research, development, and acquisition community in the materiel acquisition process (counterpart to the generic use of combat developer).

Military-unique operations, equipment, or systems: Operations, equipment, or systems that are unique to the national defense, including combat and operation testing and maintenance of military-unique weapons, aircraft, ships, missiles, early warning systems, ordnance, and tactical vehicles. Nonmilitary-unique operations are those Army operations that are generally comparable to those of the private sector (for example, repair and overhaul of weapons, vessels, aircraft, or vehicles).

Program, project, and product managers: Individuals who are chartered to conduct business on behalf of the Army. These managers report to and receive direction from either a program executive officer, the Army Acquisition Executive, or other MATDEV and are responsible for the centralized management of a specified acquisition program.

Residual risk: The risk remaining after hazard mitigation strategies and control measures have been implemented.

Risk: An expression of possible injury or illness in terms of HS and HP.

Risk assessment: A structured process for identifying and assessing health hazards in terms of HS and HP. A risk assessment also provides recommendations for eliminating or controlling hazards.

Risk assessment code (RAC): A unique combination of HS and HP alphanumeric values (e.g., 1A, 2B, 3B) that describe risk and correspond to a risk level. The use of RACs is a standard way of portraying risk by the two individual HS and HP components rather than by a single risk level. Because a single risk level may be correlated with several different RACs, expressing risk in terms of an alphanumeric combination provides more information about the nature of the risk. See the risk matrix in Table 1–3 for the corresponding risk levels of each RAC.

Risk level: The characterization of risk as either High, Serious, Medium, or Low. See the risk matrix in Table 1–3 for the corresponding risk levels of each RAC.

Subject matter expert/evaluator (SME): A person who has the knowledge, skills, abilities, and other characteristics required to perform a specific job and who maintains competency by taking continuing education classes, writing articles, or producing other products associated with the subject area of expertise. Based on their experience and knowledge, SMEs use their professional judgment to make decisions logically and appropriately.

System: A composite, at any level of complexity, of trained personnel, procedures, materials, tools, equipment, facilities, and software. The elements of this composite entity are used together in the intended operational or support environment to perform a given task or achieve a specific production, support, or mission requirement.

Test condition: A set of unique parameters established for testing a materiel system. Such parameters may include, but are not limited to, location of materiel; location and/or position of personnel; temperature (atmospheric and/or materiel); atmospheric pressure; wind direction and speed; number and type(s) of propellant, charges, and/or weapons fired; quadrant elevation; azimuth; and/or materiel configuration changes (e.g., open/closed hatches).

1–3. Applicable References/Health Protection Criteria

Appendix 1A lists the references applicable to this Guide.

1–4. Objectives

As part of the overall HHA Program Strategy, the primary objectives of this Guide are to—

(1) Review and improve the process for assessing specific health hazards and interpreting their health and/or performance risks.

(2) Provide a consistent approach to estimate HS and HP.

(3) Document and improve current risk calculation methodologies.

(4) Instruct in the use of biomedical data to consistently assess identified health hazards against established health protection criteria and standards, and to identify HHA capability gaps and recommend system-specific medical research requirements.

(5) Improve HHA Program support to the Army Acquisition Community, including Army CAPDEVs, MATDEVs, and, ultimately, the Soldier.

1–5. Scope

(1) This Guide describes the processes for conducting HHAs for each unique health hazard category; therefore, this Guide falls within the scope of the HHA Process (detailed in section 1–7A).

(2) The target audience for this Guide comprises all personnel who support the completion of an HHA, including IMAs, SMEs, HHA project managers, and MATDEVs; as well as the HHA Report (HHAR) recipients. By explaining assessment processes and the derivation of RACs, this Guide enables those who support HHA completion to better interface with HHAR recipients.

1–6. Objectives of the Health Hazard Assessment Program

The primary objective of the HHA Program is to identify and assess health hazards associated with materiel system life cycle management and provide recommendations to CAPDEVs, MATDEVs, and training developers to eliminate or control the health hazards inherent in weapon platforms, munitions, equipment, clothing, training devices, and other materiel systems. The Army's effort to eliminate health hazards from materiel systems links the HHA Program with Army warfighting capabilities and performance.

(1) Specific HHA Program objectives include—

(a) Preserving and protecting the health of individual Soldiers.

(b) Reducing degradation of Soldier performance and enhancing system effectiveness.

(c) Removing health hazards from systems by design to eliminate the need for health hazard-based retrofits.

(d) Reducing the number of readiness deficiencies attributable to health hazards, thus reducing training or operational restrictions.

(e) Reducing personnel compensation claims by eliminating or reducing injury or illness caused by health hazards associated with the use and maintenance of Army systems.

(f) Reducing or eliminating occupational health hazards attributable to Army systems.

(g) Estimating costs avoided as a result of implementing HHA Program recommendations.

(2) The focus of the HHA is on potential health hazards resulting from training and combat scenarios; however, health hazard issues in any phase of the life cycle may be addressed. The HHAR documents the results of the evaluation of these issues. The HHAR provides developers, testers, evaluators, and users of new materiel with assessments and recommendations for controlling identified health hazards.

(3) The Army's HHA Program is continuously adapting to new dimensions of its mission and focusing on initiatives to protect and preserve the health of the Soldier and enhance the military mission. Since the inception of the *Health Hazard Assessment (HHA) Program Strategy and Action Plan* approved by Army Leadership in 1995, the HHA Program has continued to improve its structure and framework to support the Army in assessing evolving health hazard challenges.

1–7. Overview of the Health Hazard Assessment Process

A. Scope. Ensure the HHA is performed within the limits of normal use and maintenance of the system. The HHA and RACs describe the inherent hazards to which Soldiers who operate and maintain materiel may be exposed during normal use and maintenance. The maintenance assessment is limited in scope to operator-, crew-, and unit-level maintenance. Those individuals who are downrange are out of scope. Testing personnel are out of scope. Mishaps, accidents, equipment failures, and human error fall within the scope of the system's safety program and are not included in the HHA. Survivability, environmental, and human factor issues are also out of scope.

B. Health Hazard Identification and Categories. The first step in the HHA process is identifying potential health hazards. Hazard identification consists of analyzing specific hazardous conditions (chemical, physical, or biological) associated with the operation, maintenance, and operating environment of a system. The specific health hazard categories assessed include, but are not limited to, the following:

- Acoustic Energy
    - Steady-state Noise
    - Impulse Noise
    - Blast Overpressure
    - Ultrasonic Noise
- Biological Substances
    - Sanitation
    - Pathogenic Microorganisms
- Chemical Substances
    - Weapon Combustion Products
    - Fuel Combustion Products
    - Toxic Materials
- Radiation Energy
    - Ionizing Radiation
    - Nonionizing Radiation
        - Lasers
        - Radiofrequency Radiation
        - Optical Radiation
- Shock
    - Acceleration and Deceleration
    - Recoil
- Temperature Extremes
    - Heat Stress
    - Cold Stress
- Trauma
    - Blunt Trauma
    - Sharp Trauma
    - Musculoskeletal Trauma
- Vibration
    - Whole-body
    - Hand-arm
    - Multiple Shock (Jolt)
- Oxygen Deficiency
    - Crew/Confined Spaces
    - High Altitude
    - Ventilation

To aid in the identification of health hazards, data are obtained from sources such as—

- Previous systems.
- Safety assessments.
- Human factor assessments.
- Capability documents.
- Management documents.
- Test documents.
- User manuals.
- Field observations.

C. Exposure and Dose-Response Assessments. The exposure assessment is fundamental to the HHA process. The IMA reviews the available qualitative and quantitative information on the presence and magnitude of the health hazards, routes of exposure, duration of exposure, frequency of exposure, and population at risk. When available, quantitative data is preferred over qualitative data. Based on the exposure dose information, the physiological response and potential adverse health effects may be assessed.

(1) Exposure levels can be determined by taking direct readings of actual conditions during testing, training, or simulated combat situations. This data collection is not the responsibility of the HHA Program and is preferably conducted by the U.S. Army

Test and Evaluation Command (ATEC) in accordance with the applicable Military Standard (MIL–STD) and Test Operations Procedure (TOP). For some applications, modeling techniques can yield useful potential exposure data at less cost and in less time than actual testing and sampling. By applying experience and professional knowledge, as logical and appropriate, it is also possible to estimate the significance of the health hazard based on analogy with previous assessments.

(2) The way in which a hazard impacts human health depends on the route of the exposure. The routes of exposure for the chemical and biological health hazard categories include inhalation, dermal absorption, and ingestion. Routes of exposure for physical health hazards depend on the characteristics of the specific energy. The populations at risk are the Soldiers operating or maintaining Army materiel, including Soldiers in close proximity to the hazardous condition.

(3) The hazard's frequency and duration of exposure are determined based on the system's intended normal use during both training and combat scenarios. Combat scenarios are inherently risky and produce situations in which health hazards cannot be avoided. Health hazards related to training are, in most cases, easier to control.

D. Risk Assessment. Risk assessment of the health hazards combines the hazard identification information, exposure assessment, and health protection criteria to express the risk of possible death, injury, or illness in terms of HS and HP (within the scope). The estimated exposure to the identified hazard is compared with established health protection criteria, and a health hazard is assumed for any exposure at or above the criteria. Exposure that remains within the established criteria does not necessarily mean there is no hazard present but represents a permissible level for the specific hazard type. Therefore, this type of exposure is typically assigned either no risk level or a low risk level.

Note individual IMAs may conduct a specific health hazard risk assessment by using many different resources, ranging from gathering SME input, or using mathematical modeling, to conducting field evaluations. In those cases when critical data are incomplete or not available, a professional judgment or inference based on the assessor's experience and the system-specific situation may be necessary to complete the risk assessment.

The goal of the HHA Program is to identify potential hazards early in the life cycle and make recommendations to eliminate or control hazards. When health hazards cannot be eliminated, the HHA Program provides RACs (made up of HP and HS coordinates) to characterize the health risk and recommendations to control the hazard. MIL–STD–882E provides a standard practice to aid MATDEVs in the management of environmental, safety, and health risks encountered in the development, test, production, maintenance, use, and disposal of DOD systems. This standard practice includes a risk assessment matrix used in the HHA process to characterize assessed health hazards in terms that decision makers can prioritize and use in their overall risk management strategy.

(1) The HP is an expression of the degree of likelihood that an exposure to a hazard/hazardous condition (physical, chemical, or biological) will produce an adverse health outcome to a materiel system user or maintainer based on an assessment of factors such as affected population, user scenario, and exposure duration and frequency. Probability level F is used to document cases where the hazard is no longer present. No amount of doctrine, training, warning, caution, or personal protective equipment (PPE) can move an HP from levels A through E to level F.

Note that although the HP levels are derived from MIL–STD–882E, the HHA definition of HP varies from the MIL–STD–882E definition. The MIL–STD–882E focuses on system safety and the probability of occurrence of a mishap, whereas the HHA Program assesses the probability of an exposure producing an adverse health outcome. The HP levels assigned by system safety representatives and the HHA Program may differ.

Table 1–1. Hazard Probability Levels[1]

Description	Level	Likelihood of Occurrence
Frequent	A	Likely to occur often.
Probable	B	Will occur several times.
Occasional	C	Likely to occur sometime.
Remote	D	Unlikely, but possible to occur.
Improbable	E	So unlikely it can be assumed occurrence may not be experienced.
Eliminated	F	Incapable of occurring. This level is used when potential hazards are identified and later eliminated.

Source: Adapted from MIL–STD–882E
Note:
[1] Degree of likelihood that an exposure will produce an adverse health outcome as a consequence of a Soldier’s normal use of an item.

(2) The HS is an expression of magnitude of the adverse health outcome (occupational injury/illness) to a materiel system user or maintainer that will occur from exposure to a hazardous condition (physical, chemical, or biological) during normal use of the materiel system.

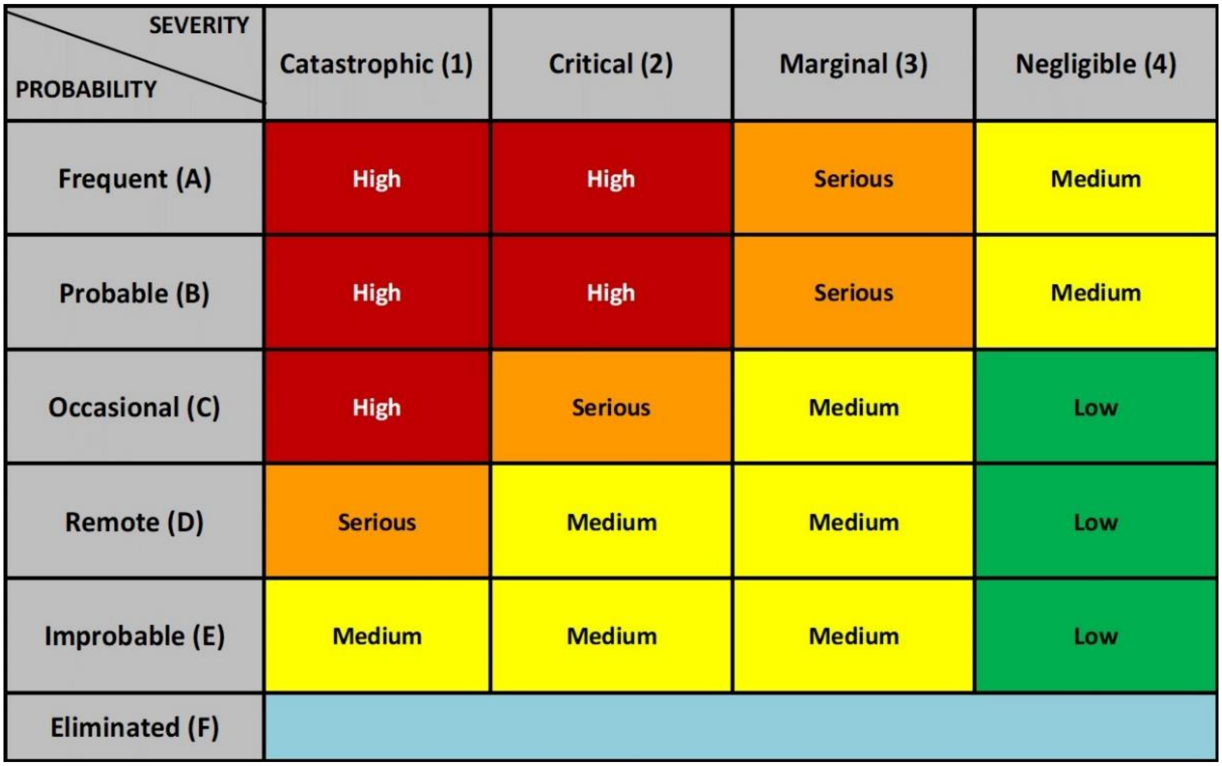
Table 1–2. Hazard Severity Categories

Description	Category	Result Criteria
Catastrophic	1	Could result in death or permanent total disability.
Critical	2	Could result in permanent partial disability, injuries, or occupational illness that may result in hospitalization.
Marginal	3	Could result in injury or occupational illness resulting in one or more lost work days.
Negligible	4	Could result in injury or occupational illness not resulting in a lost work day.

Source: Adapted from MIL–STD–882E

(3) Using the risk assessment matrix derived from MIL–STD–882E (Table 1–3), the assigned HP and HS are combined to determine the RAC and risk level. The RAC is the alphanumeric combination of the HS and HP. The risk level is determined by the intersection of the HS category and HP level, as shown in Table 1–3.

Table 1–3. Risk Assessment Matrix



SEVERITY PROBABILITY	Catastrophic (1)	Critical (2)	Marginal (3)	Negligible (4)
Frequent (A)	High	High	Serious	Medium
Probable (B)	High	High	Serious	Medium
Occasional (C)	High	Serious	Medium	Low
Remote (D)	Serious	Medium	Medium	Low
Improbable (E)	Medium	Medium	Medium	Low
Eliminated (F)				

Source: MIL–STD–882E

E. Recommendations. Recommendations to eliminate or control health hazards are developed using the hierarchy of effectiveness of controls consistent with DOD Instruction (DODI) 6055.01, *DOD Safety and Occupational Health (SOH) Program* (Figure 1–1). The goal of the HHA Program is to identify potential hazards early in the life cycle in order to provide more efficient controls. An assessment may result in multiple recommendations, each with its own residual risk and RAC. The approving authority (in coordination with the MATDEV) makes the decision to implement the recommended controls or accept the risk based on cost, schedule, and mission requirements. Examples of the recommended hierarchy of effectiveness of controls are listed below in priority order:

(1) ***Elimination.*** Design and build systems that have no hazards under normal use and maintenance conditions. For example, a lifting procedure could potentially require numerous lifters in order to move a heavy piece of equipment. If the procedure could be accomplished using a mechanical lifting device, then the lifting hazard would be eliminated.

(2) ***Substitution.*** Substitute less hazardous materials, processes, operations, or equipment. For example, substitute a lead-free ammunition primer for a lead-based ammunition primer to minimize or prevent exposure to lead.

(3) ***Engineering Controls.*** Redesign systems to control hazardous conditions. For example, implement ventilation systems to control weapon combustion products in crew-occupied spaces or automatic lock-out systems to disengage high radio frequency beams before personnel enter a hazardous area.

(4) ***Warnings.*** Add warning devices, labels, and alarms that alert personnel of potential hazards. For example, emission indicators on a laser system may warn operators that the system is energized.

(5) ***Administrative Controls.*** Develop risk reduction work practices (e.g., exposure time limitations, work-rest cycles, and personnel rotations), medical surveillance programs, and training programs.

(6) ***PPE.*** PPE is the least effective control because the risk reduction is dependent on Soldiers consistently wearing their PPE and routinely following the applicable processes and procedures. PPE recommendations may be appropriate when the implemented engineering controls will not sufficiently reduce or eliminate exposure, or engineering controls are not feasible. PPE may include protection such as noise muffs, respirators, clothing, and/or gloves.

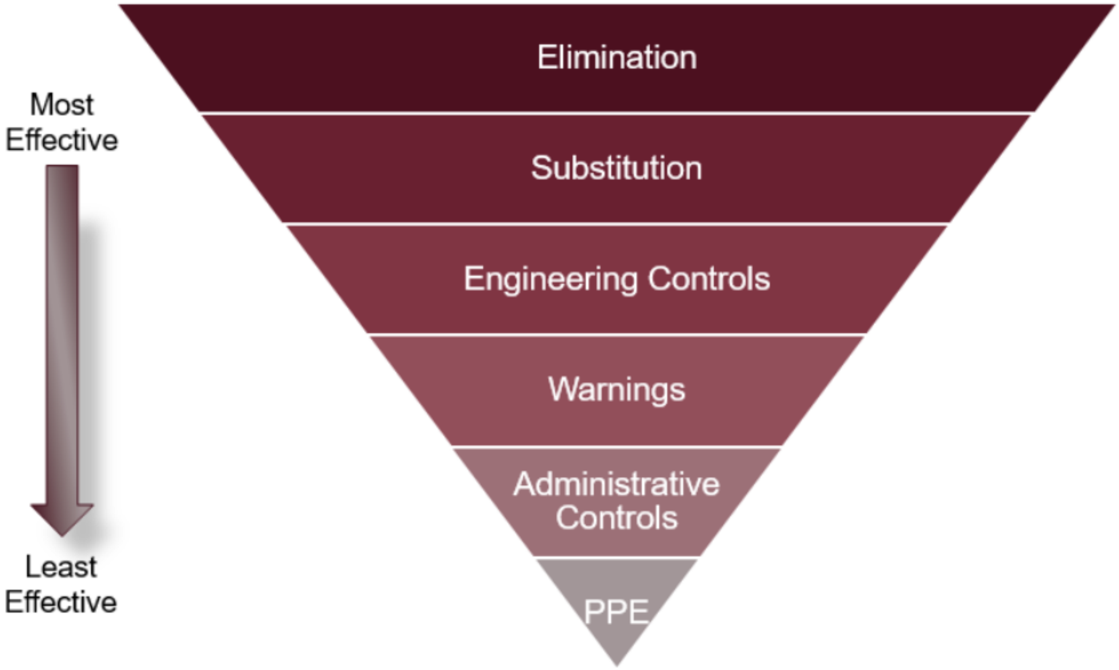


Figure 1–1. Hierarchy of Effectiveness of Controls
(Source: DODI 6055.01)

F. Health Hazard Assessment Report (HHAR). The HHAR presents the formal analysis and assessment of the health risks of materiel systems. The MATDEVs, Army Human Systems Integration (HSI) domain evaluator, and testers comprise the report's target audience. Information from the HHAR is incorporated into the programmatic environment, safety, and occupational health evaluation, a required DOD safety and occupational health, acquisition-related document. Guidance concerning type classification, materiel release, fielding, and transfer requirements is contained in AR 700–142.

(1) A complete HHAR will include the findings, conclusions, and recommendations resulting from the HHA for each applicable health hazard. This includes initial RACs, residual RACs, recommendations for eliminating or controlling the identified hazards, and descriptions of the methods used.

(2) During the early stages of development, sufficient information with which to develop a complete HHAR is not always available. Therefore, the HHA Program may prepare either an initial HHAR listing the identified hazards or a partial HHAR evaluating some identified hazards and requiring additional data for other hazards. These initial reports promote more efficient controls during the development of materiel. In addition, initial reports identify the areas from which data are needed, allowing for coordination of test plans with the ATEC to save time and money. A definitive HHAR is completed after all of the additional data identified in the initial HHAR become available and the materiel is further developed.

(3) Due to Army modernization, an increasing number of systems are undergoing Urgent Materiel Release and other types of rapid acquisition. Since time is of the essence, HHA coordination is typically limited to a review of the documentation provided and an email message from the HHA Program that briefly summarizes the materiel system's potential health hazards during its normal use and maintenance. This HHA input can help inform future data collection needs and the development of controls.

1–8. Format and Content of the Health Hazard Assessor’s Guide

This TG is organized into chapters, each of which focuses on a health hazard category addressed by the Army’s HHA Program, as outlined in AR 40–10. Each chapter in this Guide is organized as follows:

(1) ***Purpose.*** This section describes the health hazard category to be discussed or outlines the intent of the chapter. For example, the purpose of the chapter on whole-body vibration (WBV) is to provide guidelines for the risk assessment of WBV exposure during normal use and operation of materiel systems.

(2) ***Definitions of Key Terms.*** This section provides descriptive information characterizing the health hazard addressed in the chapter, thereby providing both a framework and specific guidance useful in identifying and assessing hazards and their sources. In addition, terms unique to hazard data collection, hazard assessment, or hazard-unique mitigation measures are defined. For example, definitions of terms such as “weighted root mean square” and “blast test device,” or an explanation of the difference between auditory and non-auditory pressure wave effects, may be included. Chapter 1 includes definitions of the terms that are pertinent to all chapters.

(3) ***Applicable References/Health Protection Criteria.*** This section outlines the full range of applicable health protection criteria and standards used in assessing specific health hazards.

(4) ***Health Effects.*** This section includes information on the health effects associated with exposure to the specific health hazard.

(5) ***Pre-assessment Procedures.*** This section includes the collection of information required to support the assessment. Examples include identifying operational scenarios during anticipated Soldier exposures and data collection. The Operational Mode Summary or Mission Profile typically provides the type of exposure information necessary to support the assessment, particularly when the HP is being determined. This section also references the appropriate ATEC TOP to ensure data collected for the specific hazard type are accurate, precise, and usable. The data collection requirements should be sufficiently referenced to enable assessors, SMEs, and MATDEVs to clearly identify the appropriate data collection procedures.

(6) ***Risk Assessment Process.*** This section describes how to compare the collected data and any additional relevant information to the selected health protection

criterion. Based on that comparison and a review of the additional relevant information, a standardized methodology for deriving both the HS and HP is documented. That process should reflect the SME's assessment process and logic and should link each identified hazard with a RAC from the MIL–STD–882E RAC matrix. The goal is not only to document the HS and HP derivation logic to assist others in understanding it but to provide a repeatable process as well.

(a) The assigned RAC will consist of the HS and HP coordinates (3C, for example) and will correspond with the MIL–STD–882E risk levels of High, Serious, Medium, and Low for risk acceptance authority identification (i.e., the level of leadership authorized to accept the assigned risk level). As an outcome of the RAC assignment, the assessor generates recommendations corresponding with the identified HS and HP.

(b) Assigning risk is indeed subjective. Multiple assessors evaluating the same hazard may assign different RACs to it. This is to be expected; however, the goal is to assign risk as consistently as possible.

(c) Certain health hazards, when designed within the applicable design criteria, may have a maximum HS category that is deemed acceptable to the MATDEV. The MATDEV may decide not to collect additional data but assume the risk associated with the hazard exposure. SMEs should identify the maximum HS category capable of occurring under a normal use scenario for each health hazard category.

(7) ***Example Assessment Scenario.*** Because operating conditions may impact the process for deriving both the HS and HP, the final section of each chapter provides brief examples of operationally relevant assessments. For example, assessment of factors such as affected population, user scenario, and exposure duration and frequency may either decrease or increase a RAC. Based on the understanding that not all assessment factors can be documented, the examples provided document the typical health hazard category variables that may affect the RAC assignment.

(8) ***Limitations and Potential Future Work.*** This section further describes known limitations of the current assessment processes and possible ways forward to address these limitations and improve health hazard assessment capabilities.

APPENDIX 1A

CHAPTER 1 REFERENCES

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APPENDIX 1B

CHAPTER 1 GLOSSARY

APHC
U.S. Army Public Health Center

AR
Army Regulation

ATEC
U.S. Army Test and Evaluation Command

CAPDEV
capability developer

DA
Department of the Army

DOD
Department of Defense

DODI
Department of Defense Instruction

HHA
health hazard assessment

HHAR
Health Hazard Assessment Report

HP
hazard probability

HS
hazard severity

IMA
Independent Medical Assessor

MATDEV
materiel developer

MIL–STD
Military Standard

PPE
personal protective equipment

RAC
risk assessment code

SME
subject matter expert

SOH
safety and occupational health

TG
Technical Guide

TOP
Test Operations Procedure

WBV
whole-body vibration

CHAPTER 2. GUIDELINES FOR CONDUCTING HEALTH HAZARD ASSESSMENTS OF EXPOSURE TO LIFT AND CARRY


Source: DVIDS

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2–1. Purpose

This chapter of Technical Guide (TG) 351C provides guidelines for conducting health hazard assessments (HHAs) of Soldier exposure to biomechanical stressors from lift and carry that occurs during the normal use and maintenance of materiel systems.

2–2. Definitions of Key Terms

Carry: A lift with movement.

Coupling: The hand-to-handle interface in a lift operation. For example, well-padded handles that fit the lifter’s hand have good coupling.

Individual allowable weight: The greatest load that an individual is permitted to handle, for a prescribed set of conditions, without incurring significant injury risk. Reduction multipliers for lifting risk factors (e.g., lifting frequency, twisting, obstacles in the lifter’s path, and load depth) are considered in the determination of the safest load that an individual is permitted to handle.

Lift: Task requirement to raise and lower system components without the aid of manual material-handling equipment. Presence of known risk factors (e.g., non-neutral postures, repetitive exposures to biomechanical stressors, poor handle quality) may lead to musculoskeletal trauma.

Maximum design weight limit (MDWL): The value assigned using Table 2–1 for loads lifted, lowered, or carried while being grasped by two hands. The MDWL varies based on the population (e.g., male, female, mixed gender) and the height of the lift or distance of the carry. These values are from Military Standard (MIL–STD) 1472G and were derived from performance capacity data from a young, healthy population. However, these values do not necessarily represent thresholds for injury risk. The MDWL considers ideal conditions and is a starting point from which to calculate the individual allowable weight, which considers lifting risk factors that may reduce the permitted load.

Team allowable weight: The greatest load that a team of mixed gender lifters is permitted to handle, for a prescribed set of conditions, without incurring significant injury risk. Reduction multipliers for lifting risk factors (e.g., lifting frequency, twisting, and obstacles in the lifter’s path) are considered in the determination of the safest load that a team is permitted to handle.

2–3. Applicable References/Health Protection Criteria

A. References. Appendix 2A lists the references applicable to this chapter. The methods and references described in Chapter 1 of this Guide also apply to this chapter.

Important note: This TG chapter references MIL−STD−1472G, which was superseded by version H in September 2020. Version H uses the Revised National Institute for Occupational Safety and Health (NIOSH) Lifting Equation, which changes the MDWL and uses new multipliers to reduce the MDWL, resulting in a more conservative assessment. The APHC is currently working to evaluate required changes to the risk assessment process as a result of the recent changes to the health protection criteria. Current HHAs are to be assessed using both version G and H to determine notable differences and to ascertain which of the two assessments produces the most conservative and acceptable risk level.

B. Scientific Basis of Lifting Assessment Methodology. The NIOSH developed the Revised NIOSH Lifting Equation (RNLE), a lifting formula used to estimate the amount of weight that “nearly all healthy workers are able to perform over a substantial period of time (e.g., up to 8 hours) without incurring an increased risk of developing lifting-related low back pain.” Additionally, the American Conference of Governmental Industrial Hygienists (ACGIH®) has published Threshold Limit Values that impose restrictions on lifting that correspond to the RNLE.

In 2002, Ergonomists at the U.S. Army Public Health Command (now the U.S. Army Public Health Center (APHC)) devised a method to estimate lifting/carrying-related musculoskeletal injury risk associated with the routine use of equipment. This method multiplies the MDWLs resulting from the MIL–STD–1472G lifting calculation by risk factors to define thresholds for hazard severity (HS). Hazard probability (HP) is determined by a scoring system that evaluates other conditions present in the use scenario.

The allowable weights and methodology basis were derived from exertions performed by 20-year-old U.S. Air Force recruits on a lifting machine. The validity of using this human performance data to estimate injury has not been substantiated. However, this methodology will be used until a sound assessment methodology based upon validated injury criteria is developed. The current methodology is quasi-quantitative in nature and presumes a subset of the conditions present in actual work environments. Risk associated with lifts performed outside of these assumptions may be assessed conservatively by a subject matter expert (SME). Specific concerns about the MIL–STD–1472G weight limits and assumptions are discussed in section 2–8 of this chapter.

C. Push and Pull Criteria. MIL–STD–1472G provides limitations on exertable horizontal push and pull forces for male populations. The limits must be modified for female populations (the MIL–STD–1472G recommends 2/3 of the male population push and pull limits). Systems requiring horizontal push and pull forces during normal use are uncommon, and systems are assigned risk assessment codes (RACs) on a case-by-case basis. Systems requiring vertical push and pull forces are not preferred, and the RAC may be greatly increased to account for the differences in horizontal versus vertical strength. Evaluation of push and pull forces involves multiple exposure factors (e.g., coefficient of friction, body position, one vs. two hands, team size) to determine the allowable force.

The preferred method of pushing a component horizontally involves using both hands and is performed on a surface that provides a high coefficient of friction. Pushing activities that involve bracing the back, shoulder, or feet against a wall will likely necessitate high force requirements and therefore place the Soldier at greater risk of suffering a musculoskeletal injury. These types of pushing activities are not recommended, and every effort should be made to ensure systems that require these types of actions are not designed.

2–4. Health Effects of Adverse Biomechanical Stress from Lifting and Carrying

Lifting and carrying yields exposures to biomechanical stressors that vary as a function of the load handled, postures used, and the frequency, duration, and periodicity of the physical activity employed. At moderate levels, given recovery time between bouts of exertion, musculoskeletal tissue may adapt to the stress. However, excessive exposures produce injury in muscles, bursae, tendons, ligaments, cartilage, bone, and discs. Injuries tend to be cumulative and difficult to characterize due to a lack of specific injury criteria, along with other factors that alter individual susceptibility.

2–5. Pre-assessment Procedures

A. Information Required for the Health Hazard Assessment. To formulate concepts of the system's normal use and maintenance, obtain and review the following information from the materiel developers (MATDEVs):

(1) ***System description.*** The system description shall include nomenclature needed to identify and classify the system and system components pertinent to the assessment. The types of items needed to properly describe a specific system vary; at a minimum, the following shall be provided: name of the system and an inventory listing the names, weights, and dimensions of all items weighing more than 31 pounds (lbs) that will be lifted. Table XXXVII of MIL–STD–1472G may be used as a resource to estimate weights and Soldier loads when the actual weights of items are not known. It is important to collect information about the weights of gear worn by lifters because those items increase the adverse biomechanical stresses imparted to musculoskeletal tissues and can have a profound influence on injury risk. For systems used in chemical, biological, radiological, and nuclear environments, MATDEVs should identify the exertions that will be performed while personal protective equipment (PPE) is worn, and the weight of that PPE.

(2) ***Use scenario.*** The use scenario shall include information regarding human-system interactions and the operational environment that is relevant to exposures associated with manual material handling activities. This information shall include descriptions of components handled and the environments in which they are handled. Information provided by MATDEVs should inform independent medical assessors (IMAs) of any environmental conditions that could adversely impact musculoskeletal

injury risk, such as exposures to vibration, mechanical shock, temperature extremes, or excessive humidity; or performing encumbered work (e.g., small spaces, unstable or moving platforms).

(3) ***User population information*****.** The user population information shall include demographic data and information about other physical characteristics that affect injury susceptibility. For lift and carry assessments, the most important characteristics include the users' approximate age, gender, and Military Occupational Specialty.

(4) ***Task information*****.** The MATDEV shall provide information regarding the physical demands of the tasks that Soldiers perform to operate equipment or interact with systems. To improve accuracy, direct observation and measurement of actual systems in operation are preferred over desktop reviews. The APHC SMEs may perform site visits and direct observations for special cases where the task and/or use scenario greatly influences the risk (e.g., loading large mortar rounds inside a cramped platform). Videos demonstrating the tasks may also be helpful. In addition, review any other documents that may assist with the ergonomics assessment such as human factors test reports or the Safety Assessment Report.

(5) ***Documented number of lifters.*** In order to assign an initial risk level, the MATDEV shall provide information identifying the number of lifters currently documented, whether the components are to be labeled with the documented number of lifters, and whether the lifting requirements are specified in the manuals. If the documented number of lifters is not provided, each component is assumed to be lifted by one person.

B. Assessor Qualifications. The IMA should have knowledge of biomechanics and basic medical sciences that supports understanding the pathogenesis of tissue injury from exposure to biomechanical stressors resultant of exertion and non-neutral posture. In addition, the IMA should understand the biopsychosocial aspects of mechanical exposure and how they influence perception and reporting of musculoskeletal symptoms and disorders. The IMA should also be proficient in task analysis and the concepts and application of ergonomics assessment tools.

C. Threshold for Health Hazard Assessment. Although all activities that involve lifting and carrying loads expose individuals to biomechanical stressors that elevate injury risk, the risks imposed by some lifts may not merit a formal assessment. Therefore, for the purpose of assessments performed for HHAs, items weighing less than 31 lbs are excluded.

2–6. Risk Assessment Process

A. Types of Risk Levels. The initial and residual risks assigned depend on the MATDEV's documented number of lifters, the provided system and use information, and the MIL–STD–1472G lifting requirements. Use the number of lifters specified by the MATDEV for the initial risk assessment. If the MATDEV does not specify a number of lifers, assume a one-person lift for the initial risk assessment. Recommend a number of lifters using the MIL–STD–1472G lifting requirements and use scenario. Determine the residual risk based on the recommended number of lifters and the recommended risk mitigation methods.

Because the MIL–STD–1472G is a design criterion and not necessarily a health protection criterion, a risk level is still assigned for systems meeting the MIL–STD–1472G lifting requirements (i.e., there is an inherent probability of injury even when using the recommended number of lifters). When the MIL–STD–1472G lifting requirements are met, the HS is typically limited to an HS 4 (Negligible) which limits the risk level to Medium or Low. Special cases (e.g., excessive team sizes, high frequency of lifts) may increase the risk level.

For systems with multiple components weighing more than 31 lbs, the worst-case (i.e., most restrictive) RAC of all the components is assigned for the system. For example, a system comprised of two components, one with a Low initial risk (RAC: HS 4, HP D) and one with a Medium initial risk (RAC: HS 3, HP D), would be assigned an overall initial risk level of Medium (RAC: HS 3, HP D). Similarly, the residual RAC for the system is assigned as the worst-case residual RAC for all components. The component that has the worst-case initial RAC does not necessarily have the worst-case residual RAC.

B. Determining the Recommended Number of Lifters. Follow the instructions below to identify the recommended number of lifters based on the application of MIL–STD–1472G and the lifting conditions. The maximum permissible number of lifters by size, the individual allowable weight, and the team allowable weight calculated in paragraphs (1) through (4) below are used to determine the recommended number of lifters.

(1) Determine the maximum permissible number of lifters that can physically fit around the component based on the size of the component and the space available. To calculate this value, divide the perimeter of the box by 24 inches (”) (the length required for each lifter) and round down to the nearest number of lifters using the following equation:

$$Maximum\ Permissible\ \#\ of\ Lifters\ by\ Size = \frac{2L + 2W}{24}$$

(Equation 2–1)

Where:
L = length in inches
W = width in inches

Equation 2–1 assumes a rectangular component. For an irregularly shaped component, draw a rectangular shape around the outer edges of the component in order to estimate the maximum permissible number of lifters that can physically fit around the component.

(2) Determine the MDWL for one lifter based on Table 2–1 and the use scenario. The MDWL considers ideal conditions and is a starting point from which to calculate the individual allowable weight, which considers lifting risk factors that may reduce the permitted load. Always assume the lift team is a mixed-gender population.

Table 2–1. Maximum Design Weight Limit[a]

Handing Function	Population	
	Female-Only or Mixed-Gender Team	Male-Only Team[b]
Lift a component from the floor and place it on a surface ≥5 ft above the floor.	14 kg (31 lbs)	21.9 kg (48 lbs)
Lift a component from the floor and place it on a surface <5 ft above the floor.	16.8 kg (37 lbs)	25.4 kg (56 lbs)
Lift a component from the floor and place it on a surface ≤3 ft above the floor.	20.0 kg (44 lbs)	39.5 kg (87 lbs)
Carry a component ≤33 ft[c]	19.0 kg (42 lbs)	37.2 kg (82 lbs)

Source: MIL–STD–1472G
Legend:
ft = feet
kg = kilogram
lbs = pounds
Note:
[a] The maximum design weight limit considers ideal conditions and is a starting point from which to calculate the individual allowable weight, which considers lifting risk factors that may reduce the permitted load.
[b] Not used in health hazard assessments because females are permitted in all Military Occupational Specialties in accordance with Army Regulation 611–1.
[c] For systems requiring carrying distances >33 ft, see Table 2-2.

When components must be carried >33 ft (uncommon during normal use), the limits in Table 2–2 apply.

Table 2–2. Carrying Limits for Distances Over 33 Feet

Handling Function	Weight limits, male and female
Component carried at side with one hand (e.g., tool chest, container with handles)	13.6 kg (30 lbs)
Component with irregular sides (e.g., electronic equipment chassis)	11.4 kg (25 lbs)

Box or other item carried with two hands	14 kg (35 lbs)

Source: MIL–STD–1472G
Legend:
kg = kilograms
lbs = pounds

(3) Determine the individual allowable weight based on the lifting conditions. Reductions in the MDWL are required for repetitive lifts, excessive object depth, obstacles, and twisting. Based on the specific use scenario, SMEs may apply other reductions. Normal use scenarios requiring reductions are not recommended but may be unavoidable for some systems (e.g., loading ammunition in confined vehicles). The reductions for each lifting risk factor are multiplied by the MDWL to yield the individual allowable weight, calculated as follows:

$$Individual\ allowable\ weight = (MDWL)\ \times (reductions\ for\ lifting\ risk\ factors) \quad \text{(Equation 2–2)}$$

Table 2–3 lists the required reductions based on the lifting risk factors. The individual allowable weight calculation column shows how the reduction is applied to the MDWL using Equation 2–2. The depth reduction does not apply to team lifts, due to the assumption that the center of mass does not affect a lifting team in the same way that it affects a single lifter.

Table 2–3. Maximum Design Weight Limit Reductions

Lifting Risk Factor	Criteria	Reduction	Individual Allowable Weight Calculation
Repetitive Lifting	>1 lift per 5 minutes **OR** >20 lifts per 8 hours	Calculated	$MDWL\ \times \left[1 - \frac{(8.33\ \times LF)}{100}\right]$
Obstacles	Lower protruding shelf or other obstacle limiting the lifting approach	33%	$MDWL\ \times (1 - 0.33)$
Twisting	15° < twist* ≤ 45°	20%	$MDWL\ \times (1 - 0.20)$
Depth (individual lifts only)	Depth >24”	33%	$MDWL\ \times (1 - 0.33)$
	Depth >36”	50%	$MDWL\ \times (1 - 0.50)$
	Depth >48”	66%	$MDWL\ \times (1 - 0.66)$

Legend:
LF = lifting frequency in units of lifts per minute
MDWL = maximum design weight limit
Note:
*The twist shall be limited to a maximum of 30° left or right of body centerline.

If the use scenario does not require reductions, the individual allowable weight is equal to the MDWL. If the use scenario requires multiple reductions, each applicable reduction applies. For example, an obstructed lift requiring 30° twisting reduces an MDWL of 37 lbs by both 20% and 33%, or the MDWL times 0.8 times 0.67, resulting in an individual allowable weight of 19.8 lbs.

(4) For components with weights exceeding the individual allowable weight, increase the number of lifters. For two-person lift and carry, use double the individual allowable weight as the team allowable weight, provided the load is uniformly distributed between the two lifters. For lift and carry with three or more persons, no more than 75% of the individual allowable weight may be added for each of the additional lifters, provided that the component is large enough so the lifters do not interfere with one another while lifting/carrying the load. The team allowable weight is calculated using the following equation:

$$Team\ Allowable\ \ Weight = \underbrace{IAW}_{\boxed{\text{1st lifter}}} + \underbrace{IAW}_{\boxed{\text{2nd lifter}}} + (0.75\ \times \underbrace{IAW}_{\boxed{\text{3rd lifter}}}) + (0.75\ \times \underbrace{IAW}_{\boxed{\text{4th lifter}}}) \ldots \tag{Equation 2–3}$$

Where:
IAW = individual allowable weight

When assigning an initial risk, limit the number of lifters used in Equation 2–3 to the documented number of lifters provided by the MATDEV (or one lifter if not provided).

(5) To find the recommended number of lifters, increase the number of lifters used in Equation 2–3 until either 1) the maximum permissible number of lifters by size is reached (Equation 2–1); or 2) the team allowable weight equals or exceeds the actual weight of the system. An additional lifter may be added to improve the load symmetry if size allows (i.e., adjusting from an uneven 3 lifters to 4 lifters for a symmetrically distributed load).

C. Determining Hazard Severity. This methodology includes the following assumptions related to HS:

- The MIL–STD–1472G MDWLs are based upon the capabilities of the average lifter in the population (either all-male or mixed-gender).

- If equipment is designed using the MIL–STD–1472G MDWLs as the criteria for permissible weight, some members of the population will still not be able to lift it, but most will.

- The MIL–STD–1472G MDWLs are design criteria and may not reflect the injury risk of handling components.

- Most members of the population will not incur significant injury risk handling items that weigh less than the MIL–STD–1472G MDWLs.

- The risk of incurring musculoskeletal injury will increase progressively with weights that exceed the MIL–STD–1472G MDWLs.

- The MIL–STD–1472G does not specify a limit on the number of lifters allowed on a team lift.

Use the actual system weight provided by the MATDEV and the team allowable weight calculated in Equation 2–3 to calculate the lifting index (LI) as follows:

$$Lifting\ Index\ (LI) = \frac{Actual\ weight}{Team\ allowable\ weight}$$

(Equation 2–4)

Use the calculated LI and Table 2–4 to determine the HS as defined in MIL–STD–882E. Since lifting components during normal use is unlikely to result in death or permanent total disability, the HS category of 1 (Catastrophic) is not typically assigned. For example, the Department of Veterans Affairs calendar year 2015 permanent total disability compensation rate related to back injuries was 0.05%.

Table 2–4. Hazard Severity Categories for Lifting and Carrying

Lifting Index (LI)	Hazard Severity	
< 1.50	4	Negligible
1.50 ≤ LI ≤ 1.88	3	Marginal
> 1.88	2	Critical
Not assigned	1	Catastrophic

D. Determining Hazard Probability.

(1) Use the operational conditions (e.g., human system interactions, environment, task information) provided by the MATDEV to determine HP. The principal assumption is that there are conditions that, if present, will complicate manual handling. These conditions increase the probability that injury could occur by causing the handler to be exposed to more biomechanical stress. Table 2–5 shows the operational conditions that result in HP points. Further descriptions of the conditions follow. The presence of these conditions results in assignment of one or more HP points. Total the HP points to assign an HP for the system.

Table 2–5. Hazard Probability Point Assignment for Lifting and Carrying

Operational Condition		Hazard Probability Points
Team Size	1 or 2 lifters	0
	3 or 4 lifters	1
	>4 lifters	2
Load Symmetry	Uniform load symmetry	0
	Non-uniform load symmetry	1
Handles	Fair to good coupling	0
	Poor coupling	1
Grasp Type	2-handed lift	0
	1-handed lift	1
Footing	Fair to good footing	0
	Poor footing	1

(a) ***Team size.*** Coordinating lift and carry efforts becomes more difficult as the number of team members increases. Lack of coordination of effort could cause shifting of the component, resulting in one or more team members accepting more than their allowable proportion of weight.

(b) ***Load symmetry.*** Components designed such that weight is not evenly distributed will cause one or more lifters to handle more than their allowable proportion of the weight. This causes them to be subjected to higher loads and more biomechanical force, both of which can elevate risk of musculoskeletal injury. In a similar fashion, lifting symmetrical components with an odd number of lifters can result in unequal distribution of work demands among individual team members. The load symmetry points may be related to the team size points, and the recommended number of lifters may be adjusted to reduce the overall HP.

(c) ***Handles.*** As the quality of the handle declines, lifting becomes more problematic. Items that lack handholds, especially items whose shape makes them more difficult to grasp (such as cylindrical components), create additional hazards, such as slippage, or require the handler to exert more effort to hold them. Larger handles (usually >2” in diameter) cause handlers to exert more force than handles that fit the size of the handlers' hands. Small handles (e.g., ropes used as handles) tend to be very uncomfortable. Unpadded handles present similar difficulty.

(d) ***Grasp type.*** Lifting with two hands results in different weight distribution (onto that handler) than lifting with one hand. In general, one-handed lifting causes more weight to be distributed on one side of the handler's body. Although the MIL–STD–1472G maximum lifting limits should only be applied to two-handed lifts, they are often applied to one-handed lifts. This is not a correct use of the standard. When it is clear that one-handed grasps are in use, increase the HS (reduce the amount of weight that can be lifted), or assign HP points.

(e) ***Footing.*** Handling components on non-optimal ground surfaces increases the probability of injury. Many conditions, such as uneven terrain, or negotiating ramps, steps or ladders, can reduce the quality of the ground surface. Surface conditions, such as the presence of contaminants that can decrease friction, may also contribute to risk. In addition, footing is assumed to be more difficult when handling is performed on moving surfaces or in/on a moving vehicle such as a tank, ship, or airplane. For most combat use scenarios, the footing will be difficult to characterize, and the handling will occur in less than optimal environments.

(2) Using the condition criteria described above in (1), assign and total the HP points. Use the total HP points and Table 2–6 to assign the HP level as defined in MIL–STD–882E.

Table 2–6. Hazard Probability Levels for Lifting and Carrying

Total Hazard Probability Points	Hazard Probability	
≥ 4	A	Frequent
3	B	Probable
2	C	Occasional
1	D	Remote
0	E	Improbable
No manual material handling is required.	F	Eliminated

When assessing systems, analysts may encounter circumstances that are not covered by the conditions described in this chapter. Under such circumstances, the SME is authorized to assign additional HP points to adjust the assessment. Situations that may require such an adjustment include environments in which Soldiers must wear additional gear or are exposed to extreme cold or temperate conditions that elevate the risk of injury.

Exposure to any biomechanical stress from lifting and carrying should be assumed to carry a potential injury risk that would prevent assigning HP F (Eliminated). However, HP F may be assigned if the exposure is eliminated. For example, if the entire handling process is mechanized, the initial HP may be reduced to a residual HP F. Employing a machine to assist with lifting, lowering, or transporting a load does not eliminate risk if the user is required to handle the load in order to use the machine. For example, providing a conveyor to move an item does not eliminate injury risk if users are required to load/unload the item to/from the conveyor.

For the purposes of HHA, there are exposures that are not evaluated because the weight lifted is presumed to not meet the threshold for a potential injury. For example, when Soldiers are exposed to biomechanical stress from lifting and carrying components weighing less than 31 lbs, those components do not meet the criteria for assessment.

E. Risk Mitigation and Recommendations. The implementation of recommendations results in residual risk. According to DODI 6055.01, there is a preferred hierarchy of effectiveness of controls that should be considered: (1) elimination, (2) substitution, (3) engineering controls, (4) warnings, (5) c, and (6) PPE. The IMA shall consider only those controls that are feasible given the design of the system, the use scenario, and the availability of resources such as the work force and manual handling devices. Examples of lift and carry controls in priority order include—

(1) ***Elimination.*** Eliminating the load from the system eliminates the hazard. For example, removing a large carrying case from a system would eliminate the hazard. Elimination is not often feasible, however, as it would likely alter the system's purpose and its use scenario.

(2) ***Substitution.*** Substituting less dense components (e.g., lightweight commercial carrying cases) may reduce the system's overall weight.

(3) ***Engineering Controls.*** Utilizing non-manual, mechanical lifting devices to lift and move components reduces or eliminates the exposure. Note that some lifting devices may still require final manual placement.

(4) ***Warnings.*** Audible warnings and sensors are not applicable to exposures to biomechanical stressors from lift and carry. Warnings placed in technical and user manuals are considered administrative controls.

(5) ***Administrative Controls.*** Labeling components with the recommended number of lifters, and placing warning labels in technical and user manuals reduce the probability of injury.

(6) ***PPE.*** There is no PPE for exposures to biomechanical stressors from lift and carry. When used properly, lifting straps may reduce the risk of injury but are not considered PPE.

2–7. Risk Assessment Example

The APHC received a request to assess a system comprising three transit cases. The transit cases will be lifted once per 8 hours to heights of less than 5 feet (ft). A protruding shelf creates an obstacle limiting the path of the lifters. Twisting is not required. The transit cases have good coupling and can accommodate 2-handed lifting. The lifting environment is anticipated to include less than optimal environments.

Sections A and B below provide an example of the initial and residual risk calculations for transit case #1. The calculations for transit cases #2 and #3 are not shown, but the assessment results are shown in Section C. Transit case #1 has a weight of 75 lbs and dimensions of 45” x 28” x 20” (length x width x height). The MATDEV’s documented number of lifters for transit case #1 is two lifters.

A. Initial Risk Calculation.

Step 1. Determine the MDWL for one lifter based on Table 2–1 and the use scenario. Since the transit case will be lifted to a height of less than 5 ft, and the population is mixed-gender, the MDWL is 37 lbs.

Step 2. Apply reductions to the MDWL to yield the individual allowable weight based on the conditions and risk factor reductions in Table 2–3. Twisting is not required, and the LF is below the threshold. The depth reduction does not apply since this heavy component requires a team lift. However, the protruding shelf creates an obstacle requiring a reduction in the MDWL. Based on Table 2–3, the obstacle reduction is 33%. To calculate the individual allowable weight, reduce the MDWL as follows:

$$Individual\ allowable\ weight = MDWL\ \times (1 - 0.33) = 37\ \times 0.66 = 24.4\ lbs$$

Step 3. The first and second lifters are allowed 24.4 lbs based on the individual allowable weight calculated in Step 2 above. Using Equation 2–3, calculate the team allowable weight with the documented number of lifters and the individual allowable weight.

$$Team\ allowable\ weight =\ (24.4 + 24.4)\ lbs = 48.8\ lbs$$

Step 4. Next, determine the LI using Equation 2–4 based on the actual weight of the transit case and the team allowable weight.

$$LI = \frac{Actual\ weight}{Team\ allowable\ weight} = \frac{75\ lbs}{48.8\ lbs} = 1.54$$

Compare the LI of 1.54 for the documented number of lifters to Table 2–4 to yield an HS of 3 (Marginal).

Step 5. To determine the HP, assign HP points based on the exposure’s operational conditions as stated in Table 2–5. Table 2–7 shows the HP points for this transit case and the documented number of lifters.

Compare the total HP points for the documented number of lifters to Table 2–6 to yield an HP of D (Remote).

Table 2–7. Example Initial Hazard Probability Points Determination

Factor	Use Scenario	Points Assigned
Team size	Two lifters	0
Load symmetry	Uniform load symmetry	0
Handles	Fair to good coupling	0
Grasp type	Two-handed lift	0
Footing	Poor footing	1
Additional assumptions	N/A	0
	Total	**1**

Step 6. By combining the HS and HP found in Steps 4 and 5, transit case #1 is assigned an initial risk level of Medium (RAC: HS 3, HP D).

B. Residual Risk Calculation.

Step 7. To determine the recommended number of lifters, use Equation 2–1 to calculate the maximum permissible number of lifters that can physically lift the component, based on the size of the component and the space available.

$$Maximum\ Permissible\ \#\ of\ Lifters\ by\ Size = \frac{2L + 2W}{24} = \frac{2(45) + 2(28)}{24} = \frac{146}{24} = 6.08$$

Since the result for the maximum permissible number of lifters by size is rounded down, the number of lifters is limited to 6.

Step 8. The first and second lifters are allowed 24.4 lbs based on the individual allowable weight calculated in Step 2 above. Each of the four remaining lifters is allowed 75% of 24.4 lbs, which equals 18.3 lbs. Use Equation 2–3 to calculate the allowed weight limit per lifter until either 1) the number of lifters exceeds the maximum permissible number of lifters by size (6 lifters) or 2) the transit case weight (75 lbs) is reached or exceeded.

When the team size is equal to 4 lifters, the transit case weight is exceeded. For this size case, the team allowable weight is not limited by the maximum permissible number of lifters. The following calculation shows the team allowable weight:

$$Team\ allowable\ weight = (24.4 + 24.4 + 18.3 + 18.3)\ lbs = 85.4\ lbs$$

Step 9. Next, determine the LI using Equation 2–4 based on the actual weight of the transit case and the team allowable weight.

$$LI = \frac{Actual\ weight}{Team\ allowable\ weight} = \frac{75\ lbs}{85.4\ lbs} = 0.88$$

Compare the LI of 0.88 for the recommended number of lifters to Table 2–4 to yield a residual HS of 4 (Negligible).

Step 10. To determine the residual HP, assign HP points based on the exposure's operational conditions as stated in Table 2–5. Table 2–8 shows the HP points for this transit case and the recommended number of lifters.

Table 2–8. Example Residual Hazard Probability Determination

Factor	Use Scenario	Points Assigned
Team size	Four lifters	1
Load symmetry	Uniform load symmetry	0
Handles	Fair to good coupling	0
Grasp type	Two-handed lift	0
Footing	Less than optimal environment	1
Additional assumptions	N/A	0
	Total	**2**

Compare the total HP points for the recommended number of lifters to Table 2–6 to yield an HP of C (Occasional).

Step 11. By combining the HS and HP found in Steps 9 and 10, transit case #1 is assigned a residual risk level of Low (RAC: HS 4, HP C).

C. Risk Level and Recommendations Summary. For transit case #1, add the results from Sections A and B to the HHA as shown in Table 2–9. The results for transit cases #2 and #3 are also shown below (calculations not shown). The worst-case initial risk and residual risk for each component in Table 2–9 are used to assign the overall initial risk and residual risk for the system. In this example, transit case #3 has the most restrictive RAC for the initial risk, and transit cases #1 and #2 have the most restrictive RAC for the residual risk.

Table 2–9. Example Health Hazard Assessment Input

Component	Weight (lbs)	Documented # of Lifters	Initial Risk Level (HS, HP)	Recommended # of Lifters	Residual Risk Level (HS, HP)
Transit Case #1	75	2	Medium (3, D)	4	Low (4, C)
Transit Case #2	85	3	Medium (4, B)	4	Low (4, C)
Transit Case #3	45	1	Medium (3, C)	2	Medium (4, D)

Legend:
HP = hazard probability
HS = hazard severity
lbs = pounds

A risk level of Medium (RAC: HS 3, HP C) is assigned for the system.

A residual risk level of Low (RAC: HS 4, HP C) is assigned for compliance with all of the following recommendations:

- Require the recommended number of lifters (mixed-gender) as stated in Table 2–9 for each transit case.
- Label each component with its weight and recommended number of lifters.
- Include these lifting requirements in all operator and technical manuals, training materials, and materiel fielding plans.

2–8. Limitations and Potential Future Work

Future work involves the development of a risk assessment methodology for exposure(s) associated with push and pull movements. Limitations with the current lift and carry methodology include the following:

(1) Concerns regarding the current MIL–STD–1472G weight limits include the following:

(a) The constraints associated with the human performance data that was collected from individuals performing lifts on a machine create uncertainty in applying the data to unconstrained dynamic lifting activities.

(b) The MIL–STD–1472G weight limits do not directly correspond to the study results; therefore, the manner in which the data were manipulated to produce the weight limits is not known. Finally, the data that the assessment methodology is based on have not been validated, and their association with exposure outcomes or injuries cannot be substantiated.

(2) The conclusions drawn from this methodology apply to 2-handed lifts only.

(3) The conclusions drawn from this methodology cannot be applied to lifts performed by Soldiers wearing body armor. Research studies on the effects of wearing body armor are ongoing; these need to be validated so accurate risk assessment methodology can be developed. Future reductions in the maximum design weight limit may be warranted when Soldiers are required to wear body armor while performing lifts, however, such reductions are unknown at this time.

APPENDIX 2A

CHAPTER 2 REFERENCES

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APPENDIX 2B

CHAPTER 2 GLOSSARY

ACGIH
American Conference of Governmental Industrial Hygienists

APHC
U.S. Army Public Health Center

ft
feet

HHA
health hazard assessment

HP
hazard probability

HS
hazard severity

IMA
independent medical assessor

kg
kilogram

lbs
pounds

LF
lifting frequency

LI
lift index

MATDEV
materiel developer

MDWL
maximum design weight limit

MIL–STD
Military Standard

NIOSH
National Institute for Occupational Safety and Health

PPE
personal protective equipment

RAC
risk assessment code

RNLE
Revised NIOSH Lifting Equation

SME
subject matter expert

TG
Technical Guide

CHAPTER 3. INFORMATION RELEVANT TO HEALTH HAZARD ASSESSMENTS OF EXPOSURE TO LOAD CARRIAGE

Source: DVIDS

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Appendices

3–1. Purpose

This chapter of Technical Guide (TG) 351C provides a definition and background information relevant to Soldier exposure to load carriage during normal use and maintenance operations which may result in musculoskeletal trauma.

The U.S. Army Public Health Center is currently unable to adequately assess the musculoskeletal injury risk from load carriage for specific materiel systems due to the absence of a validated assessment model. In most cases, risk assessment codes (RACs) cannot be assigned due to the lack of a validated assessment methodology. Conservative RACs may be assigned in some instances. The objective of this abbreviated chapter is to define the capability gaps and document the future work required to perform load carriage risk assessments in support of the Army Health Hazard Assessment (HHA) process.

3–2. Definitions of Key Terms

Load carriage: The total loading on the body from carrying clothing and equipment. The load is typically carried over long distances or durations, and may be worn, affixed, or sometimes hand-carried. Load carriage has been associated with musculoskeletal trauma, and movements or exertions while carrying increased loads may elevate the risk of injury. Examples of systems requiring load carriage include body armor, backpacks, personal weapons, radio handsets, and other equipment attached to the body.

Portable: Generally, “portable” components are components carried less than 1.25 miles. For components carried less than 33 feet, refer to TG 351C, Chapter 2, Lift and Carry.

3–3. Applicable References/Health Protection Criteria

Appendix 3A lists the references applicable to this chapter. The methods and references described in Chapter 1 of this Guide also apply to this chapter.

Military Standard (MIL−STD) 1472H provides design criteria for load carriage. Individual portions of portable equipment shall not exceed 35 pounds (lbs), unless the individuals carrying the load do not need to maintain the pace of infantry movement. The total load carried shall not exceed 30% of the user’s body weight for close combat operations, or 45% of the user’s body weight for marching. The total load includes all equipment, clothing, and weapons. When the total load exceeds these criteria, the required load shall be evaluated by user trials, modeling, and data while focusing on performance. MIL−STD−1472H limits the total load carried for the 5th percentile body weight to 41 lbs for close combat operations, and 61 lbs for marching.

Other general design criteria are included in MIL−STD−1472H, such as the following:

- Distribute and balance the load effectively throughout appropriate muscle groups.
- Avoid or minimize pressure on sensitive areas (e.g., nerves, blood vessels, areas lacking muscular padding).
- Consider climatic zone, mission to be performed, and occupational specialty when designing load-carrying systems.
- Design backpacks to permit a second lifter to assist in placing the load on the body for loads over 44 lbs.
- Distribute backpack loads with buttock and hip supports in addition to padded shoulder straps and a chest strap.
- Design backpack straps to be sufficiently wide and padded to distribute pressure over a wider surface area and reduce compression forces where they contact the body.
- Design backpacks with the center of gravity as close to the spine at the waistline as possible without any part of the load contacting the body.
- Design the load to permit freedom of movement.
- Design the load to not interfere with the length of step, movement of head, ability to squat, regulation of body temperature, maintenance of normal posture, ability to raise and lower the load when going over obstacles, and ability to see where the feet are placed when walking.
- Conform to specific design requirements for body armor and wearable portable electronic devices (e.g., shape, weight, weight, body conforming, body wrapping, interior and exterior shape).

For load carriage specifically related to loads supported by the head and neck, refer to TG 351C, Chapter 4, Head-supported Mass. For information about heat stress hazards related to body armor and load-carrying systems, refer to TG 351C, Chapter 9, Thermal Stress.

3–4. Health and Performance Effects of Load Carriage

A. Health Effects. Systems that increase the weight supported by the Soldier increase the risk of acute and chronic musculoskeletal injuries as well as degraded performance. Injuries tend to be cumulative and difficult to characterize due to lack of specific injury criteria and other factors that alter individual susceptibility. Poorly designed backpacks may create a large biomechanical moment and stress on the spine. The intervertebral discs of the back, the menisci of the knee, and the articular cartilage of the joints are usually the most vulnerable. Adverse medical outcomes from this exposure include degenerative joint diseases and internal derangement of joints that, over time, can require surgery or total joint replacements that remain throughout a Soldier’s life. In some cases, these exposures increase the Soldier’s risk of developing end-of-life medical complications that impair mobility and require assistive care (e.g., home health or nursing home). In addition to musculoskeletal issues, load carriage and the associated pressure points or Soldier movements may cause abrasions or rashes.

B. Performance Effects. Large or uncomfortable loads may also affect performance. Combat effectiveness and performance are likely to improve when load weights are reduced; however, equipment design and load weight tradeoffs affecting combat effectiveness or performance must be considered alongside Soldier protection and mission capabilities. Soldier survivability and lethality have been shown to be affected by load weight (U.S. Naval Postgraduate School 2019).

3–5. Load Carriage Health Hazard Assessment Approach

A. Scope. An HHA for load carriage is limited to portable systems intended to be carried as one complete unit, where the other weight supported by the user (besides the system itself) is minimal. For example, communication systems or assistant gunner support equipment may be designed to be carried in a backpack, with all components of both the system and the backpack fielded in one single fielding package. Users are not required to carry other loads while carrying the system (with the exception of general Soldier requirements such as body armor and clothing).

Small, lightweight systems contributing to an overall load are considered a system-of-systems issue. For example, the HHA Program may be unable to assign a risk level to a 5-lb system designed to be carried in a Soldier’s rucksack. The risk of injury is dependent on the total of ***all*** components in the rucksack and the rucksack’s design features, not solely on the single system.

Load carriage differs from the lift and carry health hazard (TG 351C, Chapter 2). Load carriage is applicable to wearable, affixed, and sometimes hand-carried components typically carried for long distances or durations. Alternatively, lift and carry applies to manually lifting, lowering, and placing components; and carrying components for distances of less than 33 feet. Load carriage exposure is typically continuous or long in duration (e.g., daily load requirements), whereas lift and carry exposure is typically temporary, discrete, or countable (e.g., single lift of a component, repetitive loading of mortars onto a vehicle).

B. Assessment Requirements. The following detailed system and use scenario information is required in order to assess the risk of injury associated with load carriage:

- Component weight
- Distribution of weight
- Component size
- Diagram/picture of the item
- Method of attachment to the Soldier (e.g., backpack, vest, straps, clips)
- Backpack design (if applicable)
- Other equipment worn and carried by the Soldiers using the system
- Expected distance, frequency, and duration of load carriage
- Tasks and/or body movements required during load carriage
- Environmental conditions at time of load carriage

C. Risk Assessment Approach. Case-by-case risk assessments are currently based on the design criteria in MIL−STD−1472H. Because these design criteria are not necessarily health-based, other research may also be applied in an assessment. Future development and validation of health protection criteria are needed. Recommendations for lowering risk may include redesigning the distribution of weight to be closer to the center of gravity, dispersing system components throughout squads to lower the individual supported weight, and redesigning the system to meet other applicable design criteria stated in section 3−3 above. The rationale and basis for conducting load carriage assessments should be tied to the "Soldier as a System" Initial Capabilities Document or similar acquisition requirements documents.

Risk assessments will likely require assuming a baseline total Soldier load and average or worst-case anthropometric measurements in order to determine the risk of added weight. The Program Executive Office – Soldier, with support from the U.S. Army Maneuver Center of Excellence, developed the updated Soldier loads and equipment weights published in *Dismounted Baseline for the Soldier System Version 3.0*. The equipment is categorized by weapon subsystem, head subsystem, and body subsystem by duty position for an infantry squad. The total Soldier load commonly exceeds 100 lbs. For system assessment, estimates of Soldier load may be used to quantify a baseline total load carriage.

3–6. Limitations and Potential Future Work

The Army HHA Program requires development and validation of health protection criteria and acute and chronic exposure models in order for adequate load carriage risk assessments to be performed. The exposure models should include health protection criteria to prevent damage to weight-bearing tissues for both males and females at different anthropometric population percentiles. The model should provide guidance on maximum load carriage allowances and be capable of considering multiple use scenario factors (e.g., miles traversed, exposure duration, required tasks and body movements, component weights and configurations). The scope limitations discussed in section 3−5A above do not allow for load carriage HHAs of most equipment. Currently, load carriage assessments are performed on a case-by-case basis only.

The criteria in MIL−STD−1472H should be re-evaluated to determine if they remain applicable to modern Soldier loads and protective of Soldier health. Future work should ensure military occupational specialty-related duties do not place Soldiers at an elevated risk of a musculoskeletal injury from being overexposed to load carriage requirements. Due to system-of-system issues, HHAs are unable to provide RACs for most equipment. Any changes to the total Soldier load will need to be doctrine-driven and coordinated at a higher level among Army senior leaders, risk assessors, and developers.

APPENDIX 3A

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APPENDIX 3B

CHAPTER 3 GLOSSARY

HHA
health hazard assessment

lbs
pounds

MIL−STD
Military Standard

RAC
risk assessment code

TG
technical guide

CHAPTER 4. INFORMATION RELEVANT TO HEALTH HAZARD ASSESSMENTS OF EXPOSURE TO HEAD-SUPPORTED MASS

Source: DVIDS

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4–1. Purpose

This chapter of Technical Guide 351C provides a definition and background information relevant to health hazard assessments (HHAs) of Soldier exposure to head-supported mass (HSM) during normal use and maintenance of materiel systems.

The U.S. Army Public Health Center (APHC) is currently unable to adequately assess the musculoskeletal injury risk from HSM for specific materiel systems due to the absence of a validated assessment model. In most cases, risk assessment codes (RACs) cannot be assigned due to the lack of a validated assessment methodology. Conservative RACs may be assigned in some instances. The objective of this abbreviated chapter is to define the capability gaps and document the future work required to perform comprehensive HSM risk assessments in support of the Army HHA process.

4–2. Definitions of Key Terms

Atlanto-occipital complex (AOC): A pair of condyloid synovial joints that connect the cervical spine to the occiput base. Commonly referred to as C0-C1, the AOC represents the anatomical location at which the head pivots at the junction with the upper C1 cervical vertebra.

Ground Soldier: A Soldier representative of dismounted (infantry) and mounted (ground vehicle) populations who may wear a variation of military combat helmets.

Head protection system: The concept of a military helmet serving as a multi-functional tool, providing ballistic and blunt impact protection in addition to serving as a common mounting platform for critical life-support and operational enhancement technologies (e.g., night vision goggles, helmet-mounted displays (HMDs), and communication systems) which provide capabilities to better ensure Soldier protection, readiness, and lethality.

Head-supported mass (HSM): A quantitatively descriptive property which represents the loading on the neck from wearing head protection systems that may affect Soldier performance and health. This term may also be used to refer to the helmet and helmet-mounted system components.

Mass properties: Parameters or physical properties used to assess head protection system biomechanical behavior, including mass, center of mass (CM), and mass moments of inertia (MOI). The CM is the point at which the entire mass is assumed to be concentrated; it is defined according to the head anatomical coordinate system (Figure 4−1). CM offset related to HSM is most often reported relative to the longitudinal (x-axis: forward and aft) and vertical (z-axis: above and below) directions. The mass MOI is defined as a measure of the resistance to rotational acceleration.

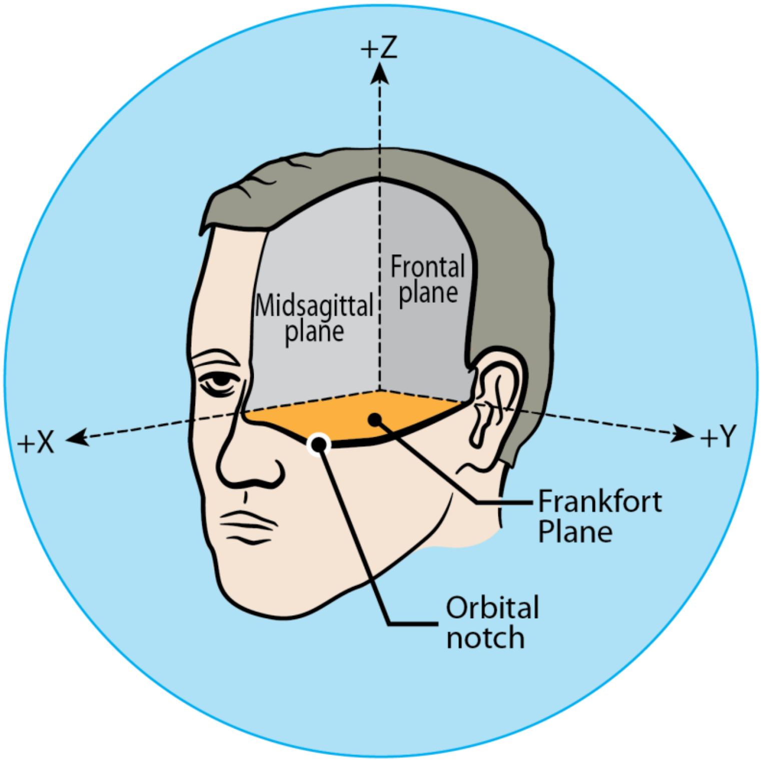

Figure 4−1. Head Anatomical Coordinate System Used to Determine Head-Supported Mass Center of Mass Offset

Performance decrement: Degraded Soldier performance (biomechanical or operational) due to fatigue (physiological, physical, and/or psychological); and medical conditions developed as a result of wearing HSM.

Tragion notch: The notch above the tragus of the ear (Figure 4−2). The tragion notch is an easily identifiable anatomical landmark in the measurement and placement of HSM. Longitudinal and vertical offsets are relative to the tragion notch. The tragion notch is also referred to as the external auditory meatus (EAM).

Weight moment: The moment produced by the head and HSM relative to the pivot point, or the AOC represented in units of Newton centimeters (N-cm). The equation for the moment about the AOC (M_{AOC}), solely due to the helmet in anatomical neutral position in the longitudinal direction, is:

$$M_{AOC} = mg(x + 2) \qquad \text{(Equation 4-1)}$$

Where:
m = mass of the helmet in kilograms
g = acceleration due to gravity (9.81 meters per second squared)
x = longitudinal center of mass (CM) offset in centimeters (cm)

The tragion notch is approximately 2 cm forward of (longitudinal x-axis) and 3 cm above (vertical z-axis) the AOC (Figure 4−2).

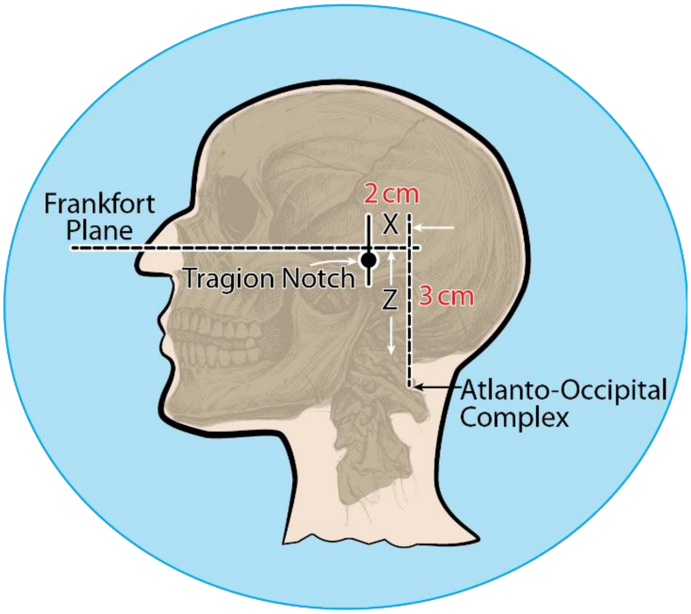

Figure 4−2. Relationship between the Tragion Notch and the Atlanto-Occipital Complex

4–3. Applicable References/Health Protection Criteria

Appendix 4A lists the references applicable to this chapter. The methods and references described in Chapter 1 of this Guide also apply to this chapter.

Currently, approved health protection criteria are not available for health hazards associated with exposure to HSM for mounted or dismounted ground Soldiers. Early neck injury research was focused on automotive and industrial communities while HSM research was focused on military aviation communities; neither included exposures relevant to ground Soldiers. The U.S. Army Aeromedical Research Laboratory (USAARL) developed performance and acute injury risk guidelines for Army aviation (USAARL HSM Curves) which describe acceptable ranges for mass properties of Army aviation-specific HSM. The U.S. Air Force Research Laboratory developed criteria known as the “Knox Box” to provide recommended limits (helmet mass and CM offset) based on ejection safety and HSM effects on pilot fatigue and performance. The automotive industry also uses cervical neck injury data (to inform crash and vibration safety standards); however, these data do not directly apply to the normal use scenarios assessed in an HHA. Medical and safety personnel, specifically those at the USAARL, are currently working to develop applicable health protection criteria that build upon these historical data sets. Although preliminary performance guidelines have been established by completed studies, injury criteria are still being researched.

USAARL Technical Memorandum (TM) 2019-11 provides a starting point for developing health protection criteria specifically for ground and dismounted Soldier populations. This preliminary performance guidance provides thresholds to minimize HSM-related operational and biomechanical performance decrement using correlations to potential medical outcome variables, such as neck pain/discomfort, neck muscle activation, and neck fatigue. These variables could suggest the development of underlying and/or future medical conditions. However, these variables need to be linked to the probability of injury. Applied exposures to the point of injury in HSM-related human subject research is not justified based on the outlined criteria for Institutional Review Board (IRB) approval of research in Title 32, Part 219.111 of the *Code of Federal Regulations* (32 CFR 219.111). As a result, assumptions and extrapolations will always be required to derive design limitations that protect the wearer from the possibility of occupational injury. Such extrapolations include the use of epidemiology, computational models, and post-mortem human specimen testing. Other variables affecting risk of injury (e.g., frequency of wear, duration of wear, wearing in non-dismounted environments) may be investigated in future efforts. The USAARL preliminary performance guidance is expected to progress into health protection criteria that may apply to HHAs.

Preliminary performance guidance is based on the relationship between the longitudinal CM offset from the tragion notch and the weight of the HSM. The tragion notch was chosen as the reference point because it is an easily identifiable anatomical landmark from which HSM components may be measured. Weight moments are presented relative to the AOC because it represents the anatomical location at which the head rotates. Historical data used these same reference points.

The preliminary performance guidance includes short-term HSM weight moment thresholds by relating the mass to the longitudinal (i.e., horizontal) CM offset relative to the tragion notch. All performance decrements were calculated from the Program Executive Office – Soldier baseline configuration, which is the Advanced Combat Helmet (ACH) with the AN/PVS-14 Monocular Night Vision Device deployed. TM 2019-11 concluded that a weight moment of 133 N-cm about the AOC results in a 10% average total performance degradation from this baseline and is thus considered the dismounted performance degradation threshold. It is recommended that the rear and forward offsets relative to the tragion notch be limited to -2 and 9.5 cm, respectively. The preliminary maximum allowable helmet mass is 2.5 kilograms (kg). Figure 4−3 depicts the weight moment thresholds.

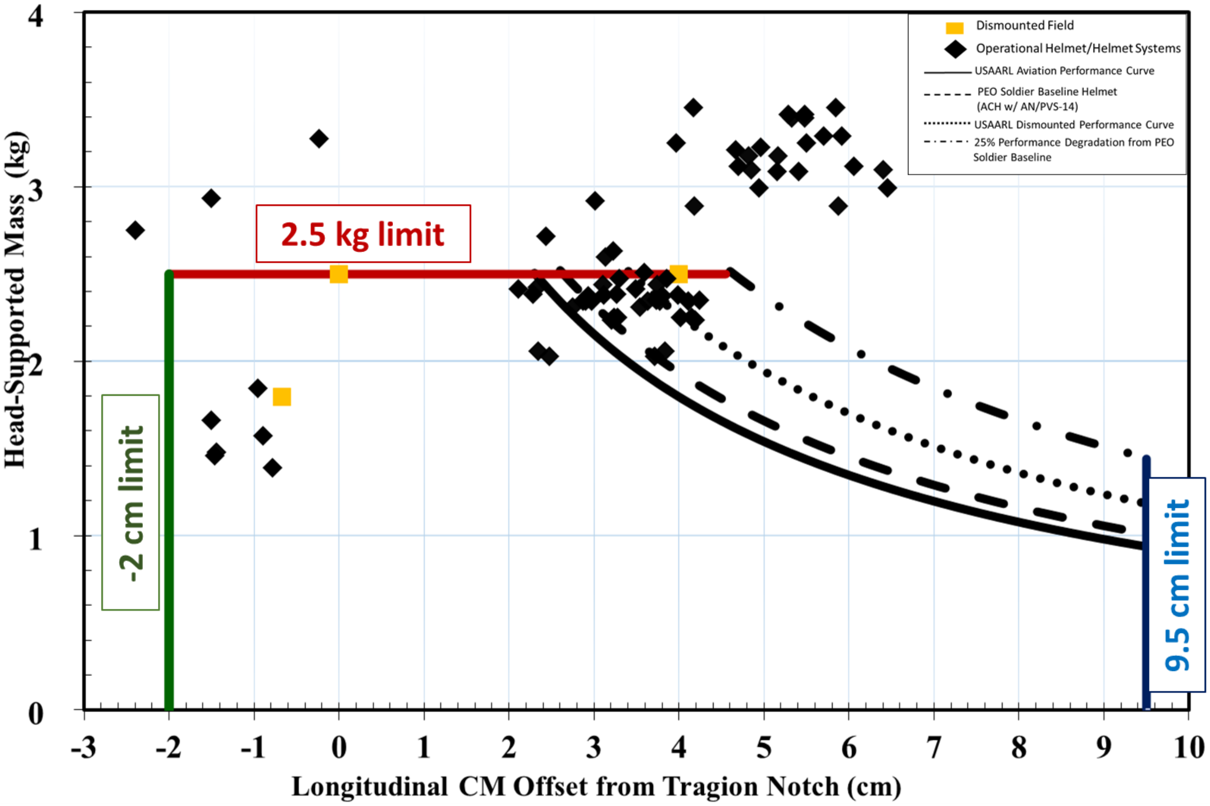

Figure 4−3. Weight Moment Thresholds Relative to Helmet Mass Properties

Legend:
ACH = Advanced Combat Helmet; CM = center of mass; cm = centimeters; kg = kilograms
PEO = Program Executive Office; USAARL = U.S. Army Aeromedical Research Laboratory

Military Standard 1472H includes limited design criteria related to HSM. The criteria state, “Weight distribution of helmet-mounted items shall be balanced to avoid or minimize neck strain, fatigue, and helmet movement relative to the user’s head” and “HMD [helmet-mounted display] designs shall attenuate head vibration for frequencies 10 Hertz and less.” There are no design criteria for HSM weight limits. Ideally, USAARL guidance will inform design requirements.

4–4. Health Effects of Head-Supported Mass Exposure

Components that increase the weight of the HSM and/or cause a CM offset place the user at risk of both acute and chronic spine and/or neck injury and degraded performance. The weight of the HSM and longitudinal offset may affect Soldier performance, whereas the weight of the HSM and vertical offset may affect neck injury risk. Increased stress placed on the musculoskeletal ligamentous neck (muscles, ligaments, discs) may cause both acute musculoskeletal fatigue and potential chronic degenerative changes. The spinal pain from acute injuries and degeneration can lead to chronic and debilitating effects, which may escalate to the point of disqualifying some

Soldiers from specific duties and/or continued military service. The possibility of post-injury rehabilitation for more severe injuries is very limited.

4–5. Head-Supported Mass Health Hazard Assessment Approach

A. Scope. HHA uses a systems approach. Exposure to HSM should be evaluated within the context of the other items in the Soldier's ensemble (e.g., Army combat helmet, helmet-mounted components commonly worn per the Soldier's military occupational specialty (MOS)). However, it may be difficult to assign a RAC for one lightweight head-supported system, even though the total weight supported by the head may be hazardous when the lightweight system is fielded and used in combination with other systems. The total weight may be estimated by assuming a baseline helmet configuration as defined by Army helmet materiel developers and based on the mission. Interactions with other health hazard exposures (e.g., vibration, acceleration, and deceleration) should also be considered.

B. Risk Assessment Approach. The assessment and evaluation of head protection systems is dependent upon the effects of both the quantitative HSM properties and exposure factors on Soldier performance and health. Future risk assessments will require information such as the following:

- Weight of the HSM component.
- CM offset from tragion notch.
- Detailed use scenario, including duration and frequency of use.
- Operational baseline helmet configuration (e.g., MOS, aviation, ground).

This information, along with health protection criteria, forms the basis of the risk assessment approach. Other considerations may be required, such as mission and exposure factors (e.g., vibration exposure and anthropometry).

The agreement with the USAARL is expected to result in criteria to assign consistent hazard severity categories and hazard probability levels based on the weight moment and exposure factors. When health protection criteria are established and a consistent risk assessment methodology is developed, recommendations are expected to include weight and configuration redesigns. For example, an HHA may recommend adjusting the weight moment by lowering the weight to meet a threshold or moving the center of mass. In some instances, the USAARL HSM Curves for aviation and the preliminary performance guidance may be used as a basis for assessments.

Because there are no current design criteria, recommendations may be limited to use scenario modifications due to Soldier discomfort. These recommendations are not preventive, and health protection criteria are needed to improve the prevention of injury and effectiveness of controls. If discomfort develops in vibration environments (e.g., riding in military vehicles) when the system is attached and deployed, Soldiers should be advised to either stow or remove the item from the helmet unless operational conditions dictate otherwise. Soldiers should continue to wear the basic helmet for its blunt and ballistic impact protection.

4–6. Limitations and Potential Future Work

To perform adequate HSM risk assessments, the HHA Program requires development and validation of health protection criteria and models. Related research is ongoing under an agreement with the USAARL to determine injury risk associated with exposure to HSM and to develop a risk assessment methodology. The final deliverable is expected by Fiscal Year (FY) 23. Some related research studies (e.g., acute injuries associated with HSM) are expected to be completed by FY22.

The results of ongoing and future USAARL studies should be incorporated into HSM risk assessments to bridge existing assessment capability gaps. For example, the preliminary performance guidance includes considerations for longitudinal offset of the HSM but does not include vertical offset, which may be associated with acute injury risk. The performance guidance was developed based on effects of short-term HSM exposures (less than 1 hour per 24-hour period of HSM wear) only; however, longer exposures (4 to 8 hours per 24-hour period of HSM wear) are currently being considered. The research should include distribution data relevant to determining the effects of individual anthropometry on risk level. Duration and frequency of wear may be added as variables to account for the effects of long-term exposure. The weight moment range studied is being increased to improve the accuracy of the model over a wider range. Health protection criteria and models may need to be adapted to assess injury risk associated with HSM exposure during simultaneous exposure to vibration (e.g., vehicles over different terrains) and to acceleration and deceleration (e.g., parachute operations).

APPENDIX 4A

CHAPTER 4 REFERENCES

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APPENDIX 4B

CHAPTER 4 GLOSSARY

ACH
Advanced Combat Helmet

AFRL
Air Force Research Laboratory

AOC
Atlanto-occipital complex

APHC
U.S. Army Public Health Center

CFR
Code of Federal Regulations

CM
center of mass

cm
centimeter

FY
fiscal year

HHA
health hazard assessment

HMD
helmet-mounted display

HSM
head-supported mass

kg
kilogram

M_{AOC}
moment about the AOC

MOI
moment of inertia

MOS
military occupational specialty

N-cm
Newton centimeters

PEO
Program Executive Office

RAC
risk assessment code

TM
technical memorandum

USAARL
U.S. Army Aeromedical Research Laboratory

CHAPTER 5. GUIDELINES FOR CONDUCTING HEALTH HAZARD ASSESSMENTS OF EXPOSURE TO WHOLE-BODY VIBRATION

Source: DVIDS

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5–1. Purpose

This chapter of Technical Guide (TG) 351C provides guidelines for conducting health hazard assessments (HHAs) of Soldier exposure to whole-body vibration (WBV) that occurs during the normal use and maintenance of materiel systems.

5–2. Definitions of Key Terms

Crest factor: The modulus of the ratio of the maximum instantaneous peak value of the frequency-weighted acceleration (a_w) signal to its root mean square (RMS) value. The crest factor may characterize the type of vibration but does not necessarily indicate the severity of vibration.

Daily exposure limit (DEL): The maximum allowable WBV exposure in a 24-hour period based on the upper limit of the health guidance caution zone in International Organization for Standardization (ISO) 2631–1. Note that the maximum DEL is 24 hours (i.e., DEL calculations ≥24 are 24 hours). The DEL is calculated as follows:

$$DEL = 6/a_{wi}^2 \quad \text{(Equation 5–1)}$$

Where:
DEL = the daily exposure limit
a_{wi} = the frequency weighted acceleration for the i-axis (X, Y, or Z)

Frequency weighted root mean square (RMS) acceleration (a_w): The square root of the average of the squared values of the acceleration signal frequency weighted according to ISO 2631–1. The a_w is calculated using the following for each of the three orthogonal axes (X, Y, Z):

$$a_w = \left[\frac{1}{T}\int_0^T a_w^2(t)dt\right]^{\frac{1}{2}} \quad \text{(Equation 5–2)}$$

Where:
a_w = the frequency weighted RMS acceleration
$a_w(t)$ = the frequency weighted RMS acceleration as a function of time (expressed in meters per second squared (m/s^2) for translational acceleration)
T = the duration of the measurement, in seconds

Gravitational force (G-force): Measurement of acceleration that causes a perception of weight. G-force is expressed as “G,” where one G is equal to the gravitational acceleration on Earth (9.8 m/s^2).

Multiple shock: Mechanical shocks of different magnitude and shape that occur frequently at regular and irregular intervals during the measurement period**.** Multiple shock is also known as “jolt.”

Whole-body vibration (WBV): The movement that occurs when oscillatory motions are transmitted to the entire human body through contact with a vibrating source at the feet for a standing individual, at the buttocks for a seated individual, and along an entire side of the body for a supine individual. Transportation vehicles, including ground, air, and water vehicles, are the primary source of WBV. In motor vehicles, vibration originates from the engine and the movement of wheels on different surfaces. Vibration frequencies and accelerations will change as a result of road irregularities (jolts/shocks), vehicle speed, and gear shift changes. Vibration is transmitted through the vehicle frame and the seat to an occupant’s buttocks and spine. If vibration experienced by the body occurs at the resonance frequency of a body part, then a maximum amount of energy can be repetitively transferred to that body part, possibly increasing the likelihood of injury or illness over time.

5–3. Applicable References/Health Protection Criteria

A. References. Appendix 5A lists the references applicable to this chapter. The methods and references described in Chapter 1 of this Guide also apply to this chapter.

Important note: This TG chapter references Military Standard (MIL–STD) 1472G, which was superseded by version H in September 2020. The major change in Version H is the use of the vector sum (x, y, and z) instead of the highest orthogonal axis (x, y, or z) in determining the limiting frequency-weighted RMS acceleration, which will likely result in a more conservative WBV assessment. The APHC is currently working to evaluate required changes (if any) to the risk assessment process and algorithm as a result of the recent changes to the health protection criteria. Current HHAs are to be assessed using both version G and H to determine notable differences and to ascertain which of the two assessments produces the most conservative and acceptable risk level.

B. Health Protection Criteria. The following provides a brief summary of health protection criteria from MIL–STD–1472G, ISO 2631–1, and ISO 2631–5. A trained WBV subject matter expert (SME) must become familiar with the standards and health protection criteria in their entirety in order to conduct an HHA.

Evaluation methodology of military vehicle vibration and its possible effects on the health of Soldiers is documented in MIL–STD–1472G. This standard divides the evaluation of vibration and shock into three categories of environments, as shown in Table 5–1.

Table 5–1. Operational Environment Types

Category	Description of Environment
A	The environment is classified as strictly vibration and can be characterized as oscillatory in nature (periodic).
B	The environment is classified as predominately vibration and can be characterized as oscillatory in nature (periodic) but also contains occasional shocks or transient vibration (aperiodic).
C	The environment may contain some underlying vibration but is dominated by repeated or multiple shocks or transient vibration.

Source: MIL–STD–1472G

The three categories of environments described in Table 5–1 require different health protection criteria and risk assessment methodologies:

(1) ***Category A.*** Triaxial acceleration data shall be processed in accordance with ISO 2631–1 using the basic evaluation method and the frequency weightings and multiplying factors for health. The majority of Army vehicles will fall within this category.

(2) ***Category B (occasional shock).*** If the crest factor exceeds 9.0, or the criteria described in MIL–STD–1472G suggest that additional evaluation methods be considered, either the fourth power vibration dose value (VDV) method described in ISO 2631–1 or the multiple shocks method described in ISO 2631–5, or both, shall be applied in addition to the basic method.

(3) ***Category C (multiple shock).*** Category C is dominated by transient vibration exceeding 1.0 G. The primary evaluation methodology and limits for this environment shall be in accordance with ISO 2631–5. It is highly unlikely this method will be applied to Army vehicles.

5–4. Health Effects of Whole-body Vibration Exposure

WBV exposure and its consequences are unique in the military environment as compared to the civilian community. In the military environment, the exposures are typically longer due to the need for extended operations, and the vibrations are more severe due to the adverse conditions present during the operation of military vehicles. The resulting effects are a consequence of the greater maneuverability and speed required of these vehicles for combat readiness, effectiveness, and survivability. Low doses of vibration over a long period of time can produce the same health effects that high doses produce over a short period of time.

Field studies have associated clinical symptoms of injury with WBV exposure, particularly among heavy-vehicle and heavy-equipment operators who are exposed daily to relatively high levels of vibration at frequencies of greatest human sensitivity (4 to 8 hertz). A condition initially reported as low back discomfort can ultimately lead to clinical diagnoses of degenerative diseases, including herniated discs, osteochondrosis, spondylosis, and other disorders of the spinal column. Stomach and intestinal tract disorders have also been reported. Among the field studies, however, back disorders were by far the most widely reported illness or injury associated with WBV.

Also reported in field studies, an increase in heart rate, respiration rate, cardiac output, mean arterial blood pressure, pulmonary ventilation, and oxygen uptake can occur during exposures to moderate and high vertical vibration. These responses are similar to those that can occur during moderate exercise; they are greatest around major body resonances and increase as the vibration magnitude increases. Hyperventilation has also been observed during WBV, possibly caused by resonance in the visceral organs (4 to 8 hertz) that is transmitted into motions in the diaphragm and abdominal wall. There is also evidence that exposure to WBV produces a decrease in the high-frequency content of electromyography activity in the muscles of the back and neck; this occurrence has been associated with fatigue.

While in operation, all vehicles, including military vehicles, produce vibration and expose operators to WBV. It is possible to reduce the effects of vibration on operators by lowering the exposure to levels below that of the lower limit of the ISO 2631–1 health guidance caution zone. Health effects from exposures below the zone have not been clearly documented and/or objectively observed.

5–5. Pre-assessment Procedures

A. Use Scenario Information. The materiel developer (MATDEV) should provide detailed information about the system and its normal use scenario in the theater and training environment (e.g., terrain, speeds, occupied seat locations, load conditions). Most systems will have a formal Operational Mode Summary/Mission Profile (OMS/MP) that documents some of this required information. Record any user information provided (e.g., military occupational specialty).

Operational environment factors derived from the use scenario should be considered in both hazard identification and risk assessment. These factors include exposure duration, exposure frequency, and exposure magnitude.

B. Data Requirements. Vibration data must be collected according to MIL–STD–1472G, ISO 2631–1, and U.S. Army Test and Evaluation Command Test Operations Procedure (TOP) 01–1–014A. The data must be representative of the vehicle's use scenario, which may be found in the OMS/MP. These data include, but are not limited to, the following:

- All terrain conditions (primary, secondary, and/or cross-country).
- All speeds for each terrain condition.
- All occupied seat locations.

- All vehicle load conditions.

For all combinations of conditions presented above, the test center must measure the a_w, crest factor, and VDV for each of the three orthogonal axes (X, Y, Z) at the seat pan. (Note: The test engineer should specify whether the 1.4 health multiplier from ISO 2631–1 has already been applied to a_{wx} and a_{wy}.)

The following information should accompany the test data to help the SME better understand how the test was conducted:

- System information (system name, test conditions).
- Test center information (test center name, test date, courses used).
- Description of the test tracks (i.e., primary, secondary, or cross-country/trail classified by the RMS roughness values of the course surface, as detailed in TOP 01–1–010).

If adequate data are not provided, a conservative risk assessment code (RAC) may be assigned based on the data available, analogy, and SME judgment. When data are collected to verify the WBV levels, the RAC may be adjusted in an updated HHA. Commonly, a risk level of Serious is assigned for systems lacking data, but the level may vary by system.

5–6. Risk Assessment Process

The risk assessment process described in this section applies to surface vehicles in Category A and Category B with crest factors below 9.0. Category B with crest factors above 9.0 and Category C are assessed on a case-by-case basis using criteria in ISO 2631–5 (refer to section 5–3B).

A. Determining Hazard Severity. The severity of an occupant's exposure to WBV is based on the DEL calculation for the upper limit of the health guidance caution zone in ISO 2631–1 (refer to section 5–2 and Equation 5–1).

Because the ISO guidance does not coincide with the hazard severity (HS) categories defined in Army Regulation 40–10, the U.S. Army Aeromedical Research Laboratory (USAARL) developed guidance published in 2005 to assign HS categories based on the exposure limits from the upper limit of the ISO health guidance caution zone. Table 5–2 states the USAARL guidelines for determining the HS category based on the DEL.

Table 5–2. Hazard Severity Categories for Whole-body Vibration Exposure

Category and Description		Result Criteria	USAARL Guidelines for WBV Daily Exposure Limits
1	Catastrophic	Could result in death or permanent total disability.	<10 minutes
2	Critical	Could result in permanent partial disability, injuries, or occupational illness that may result in hospitalization.	10 to <30 minutes
3	Marginal	Could result in injury or occupational illness resulting in one or more lost work days.	30 minutes to 3 hours
4	Negligible	Could result in injury or occupational illness not resulting in a lost work day.	>3 hours

Legend:
USAARL = U.S. Army Aeromedical Research Laboratory
WBV = whole-body vibration

For WBV assessments, the a_{wi} is used to calculate the DEL for each test condition. The worst-case scenario is interpreted as the maximum a_w, and, in turn, the lowest DEL, in any orthogonal direction, obtained during the testing of the vehicle. Because WBV test conditions include multiple combinations of speed, track, and accelerometer location, data from each of the test conditions are evaluated separately according to the guidance in Table 5–2. An HS category for each test condition is determined from the DEL. The maximum HS category of the test conditions is assigned as the overall HS category for unmitigated WBV exposure.

The process for determining the HS category for each test condition and for the overall system is analytical and methodical. However, the determination of the HS category should also incorporate subjective criteria and the judgment of the SME to ensure the data and, subsequently, the HS category are truly representative of the WBV exposure risk. Such criteria can include, but are not limited to, the following:

(1) ***Unusual data.*** An HS category that seems “rogue” may need to be further investigated or ruled out. For example, if an HS 1 (Catastrophic) is indicated for a wheeled vehicle on a paved surface at 15 miles per hour (mph), but other test conditions indicated an HS 3 (Marginal) for the same surface at different speeds, there is reason to reconsider the HS category.

(2) ***Missing data.*** Vibration data is assumed to have been collected in a manner that is representative of the use scenario. However, this is not the case in many instances. For example, a vehicle’s use scenario may indicate the vehicle is expected to reach speeds of 40 mph on cross-country terrain, but the vehicle was tested up to 20 mph only. In this case, the HS category can be modified to account for the lack of data obtained at test conditions that are known to produce more severe WBV.

(3) ***Data set size.*** If the data set for a vehicle is small, each data point carries more weight when the HS category is determined. Likewise, if the data set is large, each individual data point carries less weight. Examples follow for vehicles with 10 and 100 conditions, respectively:

(a) *10 test conditions:* 1 condition warrants an HS 2 (Critical); the others are HS 3 (Marginal) and HS 4 (Negligible). The vehicle warrants an HS 2 (Critical).

(b) *100 test conditions:* 1 condition warrants an HS 2 (Critical); the remaining conditions are HS 3 (Marginal) and HS 4 (Negligible). The vehicle warrants an HS 3 (Marginal).

(4) ***Insufficient number of seat locations tested.*** Often, only the vehicle's driver's seat is tested, usually due to lack of instrumentation, personnel, or funding. This warrants consideration because drivers' seats are usually the best constructed and exhibit the lowest WBV exposure values. Additionally, drivers control the vehicles and can self-regulate their WBV exposure, whereas passengers' exposure is at the discretion of the driver. Therefore, a higher HS category warrants more consideration under these circumstances.

(5) ***Insufficient number of load conditions tested.*** A vehicle's dynamic response varies based on different load conditions. For example, additional weight causes a vehicle's springs to compress, possibly increasing or decreasing the amount of WBV exposure. If the data set does not include all load conditions, the assessor must determine whether the current data set is truly representative of the WBV exposure risk.

B. Determining Hazard Probability. WBV is a unique hazard in the determination of hazard probability (HP) because low-magnitude vibration over long time periods can produce health effects similar to those produced by high-magnitude vibration over a shorter time period. Both dosage and duration have to be considered in the determination of the HP level. The HP level is assigned based on the probability of exposure (P(E)), which is a function of the HS probability (HSP) (Equation 5–3) and the terrain exposure probability (TEP) (Equation 5–4). The TEP is a combination of overexposures (Equations 5–5 through 5–7) that will occur on the individual terrains (primary, secondary, and cross-country). The individual TEPs are based on the use scenarios provided by the MATDEV. The following algorithm is provided as a guideline for estimating the overall HP level for WBV exposure. The algorithm may be unusable if the data set size is insufficient, resulting in a conservative HP. Table 5–3 is used throughout multiple stages of the algorithm as a weighting scheme to determine the probability.

Table 5–3. Hazard Probability Levels for Whole-body Vibration Exposure

Level and Description		Likelihood of Occurrence	Probability (%) [a]	Weight/P(E) [b]
A	Frequent	Likely to occur often	50–100	6
B	Probable	Will occur several times	20–49.99	5
C	Occasional	Likely to occur sometime	5–19.99	4
D	Remote	Unlikely but possible to occur	1–4.99	3
E	Improbable	So unlikely, it can be assumed occurrence may not be experienced	0.1–0.99	2
F	Eliminated	Incapable of occurring. This level is used when potential hazards are identified and later eliminated.	0	1

Note:

[a] The probability (%) column corresponds to the hazard severity probability (HSP), primary terrain probability (PTP), secondary terrain probability (STP), and cross-country terrain probability (CCTP) and is used to determine the weights for each.

[b] This column is used to assign a weight to each probability range for HSP, PTP, STP, and CCTP. This column is also used to convert a probability of exposure (P(E)) weight to a hazard probability level.

(1) Short-term, high-intensity exposure is determined via the HSP equal to:

$$Hazard\ severity\ probability\ (HSP) = \frac{Number\ of\ most\ severe\ HS\ level\ exposures}{Total\ number\ of\ data\ points}$$

(Equation 5–3)

The resulting HSP percentage is assigned a weight from Table 5–3 in order to be used in the overall probability of exposure calculation.

(2) Each type of terrain is a factor of the overall probability of exposure. The terrain exposure duration for each of the specific terrains is the product of usage specifications from the use scenario:

$$Terrain\ exposure\ duration = Duration \times Terrain\ Usage\ Percentage$$

(Equation 5–4)

Compare each terrain exposure duration to the upper limit exposure durations to calculate the Primary Terrain Probability (PTP), Secondary Terrain Probability (STP), and Cross-Country Terrain Probability (CCTP). The three terrain probabilities are defined as follows:

$$Primary\ Terrain\ Probability\ (PTP) = \frac{Number\ of\ overexposures\ on\ primary\ terrain}{Total\ number\ of\ primary\ terrain\ data\ points}$$

(Equation 5–5)

$$Secondary\ Terrain\ Probability\ (STP) = \frac{Number\ of\ overexposures\ on\ secondary\ terrain}{Total\ number\ of\ secondary\ terrain\ data\ points}$$

(Equation 5–6)

$$Cross-country\ Terrain\ Probability\ (CCTP) = \frac{Number\ of\ overexposures\ on\ cross-country\ terrain}{Total\ number\ of\ cross-country\ terrain\ data\ points}$$

(Equation 5–7)

The number of overexposures is the number of times the DEL exceeds the terrain exposure duration for each data point on the respective terrain. Each of the resulting PTP, STP, and CCTP percentages is assigned a weight as per the weighting scheme in Table 5–3. The weights, rather than the percentages, are used in the equation for TEP. Therefore, the overall long-term, low-intensity exposure is determined via the TEP equal to:

$$Terrain\ Exposure\ Probability\ (TEP) = \frac{PTP\ weight + STP\ weight + CCTP\ weight}{3}$$

(Equation 5–8)

Where:
PTP = primary terrain probability
STP = secondary terrain probability
CCTP = cross-country terrain probability

(3) The overall P(E) weight is equal to the average of the HSP and TEP weights calculated above and is equal to:

$$Probability\ of\ Exposure = P(E) = \frac{HSP + TEP}{2}$$

(Equation 5–9)

Where:
HSP = hazard severity probability
TEP = terrain exposure probability

The resulting P(E) weight is rounded up to the nearest whole number. The P(E) weight corresponds to an overall HP level in Table 5–3.

C. Residual Risk. If risk mitigation strategies are applied to reduce the amount of vibration in a vehicle, the risk level may be reassessed using the new vibration data and the process described in sections 5–A and 5–B above. The residual risk level may be reduced to Low (RAC: HS 4, HP E) when a vehicle employs vibration mitigation strategies such that acceleration levels fall below the lower limit of the ISO 2631–1 health guidance caution zone and the probability of Soldier's overexposures is less than 1% per guidance set forth in Table 5−3. Supporting data must be submitted to the U.S. Army Public Health Center (APHC) for verification.

D. Risk Mitigation and Recommendations. The implementation of recommendations results in the residual RACs. According to Department of Defense Instruction 6055.01, there is a preferred hierarchy of effectiveness of controls that should be considered: (1) elimination, (2) substitution, (3) engineering controls, (4) warnings, (5) administrative controls, and (6) personal protective equipment (PPE). Following are examples of these WBV controls in priority order:

(1) ***Elimination.*** Vibration in a vehicle is never truly "eliminated." It can be reduced to a level where concerns of injury from exposure are minimalized. Vibration is present in all vehicles; therefore, WBV exposure cannot be eliminated in any system requiring Soldiers to ride in a vehicle.

(2) ***Substitution.*** Use similar vehicles that have lower vibration characteristics.

(3) ***Engineering Controls.*** Redesign the seats to lower the occupants' exposure to WBV. This may include adding active vibration damping systems to existing seats, replacing current seating with air ride seats, modifying suspension systems, or isolating the engine and/or cab from the vehicle.

(4) ***Warnings.*** Audible warnings and sensors are not typically applicable to WBV exposures. Warnings placed in technical and user manuals are considered administrative controls.

(5) ***Administrative Controls*** such as reducing speeds or operational times, adding more frequent rest breaks, keeping vehicles properly maintained, periodically training operators regarding procedures, and publishing warnings in manuals will reduce exposure to WBV.

(6) ***PPE.*** Not applicable to WBV exposure.

5–7. Example Assessment Scenario

The APHC received a request to assess the WBV associated with an armored combat vehicle (ACV). The data set shown in this example scenario is a larger data set that has been simplified for purposes of the example. Complete assessments require larger data sets, whereas smaller sets typically require conservative assumptions to be made. For this example, it is assumed that the data adequately represent the WBV and use scenario of the ACV.

Step 1. From the MATDEV, obtain the use scenario, which states the following vehicle use specifications of an ACV:

- Primary roads: 70%
- Secondary roads: 25%
- Cross-country/trail: 5%
- Drive time: 10 hours

Step 2. Obtain data from an ACV testing event. The test conditions and data set state the following:

- Testing was conducted on primary, secondary, and cross-country test courses.
- On-board instrumentation collected the necessary acceleration data from which the shock and vibration exposure levels were calculated for analysis of the driver and passenger seat locations.
- Data were collected and processed according to ISO 2631–1 and TOP 01–1–014A.
- The test engineers provided test track classifications based on TOP 01–1–010.

Table 5–4 lists the WBV weighted acceleration data for the ACV for all test conditions.

Table 5–4. Armored Combat Vehicle Example Weighted Acceleration Data

Seat Location	Terrain	Speed (miles per hour)	X-axis	Y-axis	Z-axis
			a_w (m/s^2)	a_w (m/s^2)	a_w (m/s^2)
Driver	Primary	50	0.16	0.12	0.88
			0.21	0.14	0.97
	Secondary	35	0.22	0.2	0.88
			0.47	0.4	2.12
		10	0.38	0.37	2.23
			0.4	0.31	1.74
	Trail	10	0.57	1.67	1.37
			0.42	0.61	1.8
Passenger	Primary	50	0.33	0.16	0.86
			0.39	0.19	0.89
	Secondary	35	0.33	0.19	0.92
			0.76	0.56	2.12
		10	0.95	0.44	1.61
			0.76	0.4	1.84
	Trail	10	1.36	0.72	1.6
			1.7	1.89	1.39

Legend:
a_w = weighted acceleration
m/s^2 = meters per second squared

Step 3. From this data, calculate the DEL using Equation 5–1 for each of the test conditions (i.e., each combination of seat location/terrain/speed) and each orthogonal axis. For example, the first data point in Table 5–4 (driver's seat location, primary terrain, 50 mph) had an a_w of 0.16 m/s^2 in the X-axis, and the DEL is equal to:

$$DEL = \frac{6}{a_{wx}^2} = \frac{6}{0.16^2} = 234\ hours = 24\ hours$$

Where:
DEL = the daily exposure limit
a_{wx} = the frequency weighted acceleration for the X-axis

Note that because the DEL is ≥24 hours, the DEL is 24 hours (i.e., daily exposure is not limited). Table 5–5 lists the DEL calculations for all test conditions.

Step 4. Compare each DEL in Table 5–5 to Table 5–2 to assign an HS to each test condition. For example, the first data point in Table 5–4 (driver's seat location, primary terrain, 50 mph) has a DEL of 24 hours in the X-axis (calculated in Step 3 above) which corresponds to an HS 4 (Negligible). Table 5–5 provides the HS assignments for all test conditions.

Table 5–5. Armored Combat Vehicle Example Exposure Limits and HS

Seat Location	Terrain	Speed (mph)	X-axis			Y-axis			Z-axis		
			a_w (m/s^2)	DEL (hr)	HS	a_w (m/s^2)	DEL (hr)	HS	a_w (m/s^2)	DEL (hr)	HS
Driver	Primary	50	0.16	24	4	0.12	24	4	0.88	7.3	4
			0.21	24	4	0.14	24	4	0.97	6	4
	Secondary	35	0.22	24	4	0.2	24	4	0.88	7.4	4
			0.47	24	4	0.4	24	4	2.12	1.3	3
		10	0.38	24	4	0.37	24	4	2.23	1.1	3
			0.4	24	4	0.31	24	4	1.74	1.9	3
	Trail	10	0.57	24	4	1.67	2	3	1.37	3	3
			0.42	24	4	0.61	24	4	1.8	1.8	3
Passenger	Primary	50	0.33	24	4	0.16	24	4	0.86	7.7	4
			0.39	24	4	0.19	24	4	0.89	7.2	4
	Secondary	35	0.33	24	4	0.19	24	4	0.92	6.7	4
			0.76	9.9	4	0.56	18.4	4	2.12	1.3	3
		10	0.95	6.3	4	0.44	24	4	1.61	2.2	3
			0.76	9.8	4	0.4	24	4	1.84	1.7	3
	Trail	10	1.36	3.1	4	0.72	10.9	4	1.6	2.2	3
			1.7	2	3	1.89	1.6	3	1.39	3	3

Legend:
a_w = weighted acceleration
DEL = daily exposure limit
hr = hour
HS = hazard severity
mph = miles per hour

m/s^2 = meters per second squared
Note:
Red text indicates the worst-case HS category.

Step 5. Analyze the data set in Table 5–5 to determine that WBV levels in 13 test conditions warranted an HS 3 (Marginal) (i.e., the worst-case HS categories shown in red text). There were 48 total data points that captured a variety of seat locations, terrains, and speeds. Because the data set is simplified for this example and assumed to be adequate, there is no need to adjust the HS determination. Assign an HS 3 (Marginal) for the ACV.

Step 6. To determine the HP level, calculate the likelihood of exposure to both short-term, high-intensity and long-term, low-intensity WBV. A combination of the two probabilities then determines the overall HP. The algorithm in section 5–7C is applied to Steps 6a through 6f below to estimate the HP level for the ACV WBV.

Step 6a. The HSP is the percentage of the number of times the highest HS occurs. In the example data set, the highest HS exposure was HS 3 (Marginal). Of the 48 data points (seat location/terrain/speed), there were 13 instances for which the vibration levels warranted an HS 3 (Marginal). Calculate the HSP using Equation 5–3 as follows:

$$HSP = \frac{Number\ of\ worst\ hazard\ severity\ exposures}{Total\ number\ of\ data\ points} = \frac{13}{48} = 27.1\%$$

Where:
HSP = hazard severity probability

Using the weighting scheme in Table 5–3, assign a weighting factor of 5 for the HSP of 27.1%.

Step 6b. The occupant’s exposure time is estimated based on the use scenario of the vehicle (refer to Step 1). Estimate the occupant’s exposure time using Equation 5–4 as follows:

$$Primary\ terrain\ exposure\ duration = 10\ hours \times 70\% = 7\ hours$$

$$Secondary\ terrain\ exposure\ duration = 10\ hours \times 25\% = 2.5\ hours$$

$$Cross - country/trail\ terrain\ exposure\ duration = 10\ hours\ \times 5\% = 0.5\ hour$$

Step 6c. Compare each DEL shown in Table 5–5 to the appropriate terrain exposure duration calculated in Step 6b, and count the number of overexposures. Table 5–6 highlights the overexposures for each terrain.

Table 5–6. Armored Combat Vehicle Example Overexposures

Seat Location	Terrain	Speed (mph)	X-axis			Y-axis			Z-axis		
			a_w (m/s^2)	DEL (hr)	HS	a_w (m/s^2)	DEL (hr)	HS	a_w (m/s^2)	DEL (hr)	HS
Driver	Primary	50	0.16	24	4	0.12	24	4	0.88	7.3	4
			0.21	24	4	0.14	24	4	0.97	6	4
	Secondary	35	0.22	24	4	0.2	24	4	0.88	7.4	4
			0.47	24	4	0.4	24	4	2.12	1.3	3
		10	0.38	24	4	0.37	24	4	2.23	1.1	3
			0.4	24	4	0.31	24	4	1.74	1.9	3
	Trail	10	0.57	24	4	1.67	2	3	1.37	3	3
			0.42	24	4	0.61	24	4	1.8	1.8	3
Passenger	Primary	50	0.33	24	4	0.16	24	4	0.86	7.7	4
			0.39	24	4	0.19	24	4	0.89	7.2	4
	Secondary	35	0.33	24	4	0.19	24	4	0.92	6.7	4
			0.76	9.9	4	0.56	18.4	4	2.12	1.3	3
		10	0.95	6.3	4	0.44	24	4	1.61	2.2	3
			0.76	9.8	4	0.4	24	4	1.84	2.7	3
	Trail	10	1.36	3.1	4	0.72	10.9	4	1.6	2.2	3
			1.7	2	3	1.89	1.6	3	1.39	3	3

Legend:
a_w = weighted acceleration
DEL = daily exposure limit
hr = hour
HS = hazard severity
mph = miles per hour
m/s^2 = meters per second squared
Note:
Blue highlight indicates a primary terrain overexposure for an exposure duration of 7 hours (affects primary terrain probability).
Yellow highlight indicates a secondary terrain overexposure for an exposure duration of 2.5 hours (affects secondary terrain probability).

Step 6d. Use Equations 5–5 through 5–7 to calculate the probability of overexposure for each type of terrain. The PTP is equal to:

$$PTP = \frac{1\ primary\ overexposures\ for\ 7\ hour\ duration}{12\ primary\ terrain\ data\ points} = 8.3\%$$

Where:
PTP = primary terrain probability

The STP is equal to:

$$STP = \frac{5\ secondary\ overexposures\ for\ 2.5\ hour\ duration}{24\ \ secondary\ terrain\ data\ points} = 20.8\%$$

Where:
STP = secondary terrain probability

The CCTP is equal to:

$$CCTP = \frac{0\ cross - country\ overexposures\ for\ 0.5\ hour\ duration}{12\ cross - country\ terrain\ data\ points} = 0\%$$

Where:
CCTP = cross-country terrain probability

Based on each terrain probability (PTP, STP, and CCTP) and Table 5–3, the weighting values for each terrain are as follows:

- PTP = 8.3% → weight of 4
- STP = 20.8% → weight of 5
- CCTP = 0% → weight of 1

Step 6e. The TEP is the number of times the occupant's exposure time exceeds the DEL, as determined by ISO 2631–1, for all tested terrains (i.e., the PTP, STP, and CCTP combined). Calculate the TEP using the weighting values (determined in Step 6d) and Equation 5–8, as follows:

$$TEP = \frac{PTP\ weight + STP\ weight + CCTP\ weight}{3} = \frac{4 + 5 + 1}{3} = 3.33$$

Where:
TEP = terrain exposure probability
PTP = primary terrain probability
STP = secondary terrain probability
CCTP = cross-country terrain probability

Step 6f. Based on the HSP and TEP calculated in Steps 6a and 6e, calculate the P(E) using Equation 5–9 as follows:

$$P(E) = \frac{HSP + TEP}{2} = \frac{5 + 3}{2} = 4$$

Where:
P(E) = probability of exposure
HSP = hazard severity probability
TEP = terrain exposure probability

According to Table 5–3, a P(E) of 4 warrants an overall HP level of C (Occasional).

Step 7. After the HS category and HP level have been determined, use the risk matrix in Chapter 1 of this Guide to assign a RAC and risk level to the ACV WBV. In the steps above, an HS 3 (Marginal), and an HP C (Occasional) were calculated. This combination results in a RAC of 3C, which corresponds to a risk level of Medium.

Step 8. The residual risk is based on risk mitigation strategies. A residual risk level of Low (RAC: HS 4, HP D) will be assigned to any vehicle that employs vibration mitigation strategies such that accelerations levels fall below the lower limit of the ISO 2631–1 health guidance caution zone. Supporting data must be submitted to the APHC for verification via the same methodology discussed above.

5–8. Limitations and Potential Future Work

(1) In 2005, the USAARL provided the APHC with a computer program ("WBV-JOLT") to process vibration data and assist in the assessment of WBV exposure. Numerous patches installed by the USAARL since then have enhanced the program's capabilities and corrected its software glitches. Jolt needs to be updated both for compatibility with current operating systems and to include the updated ISO Standard 2631–5. The revised standard includes a new neuro network model that assesses vertical axis accelerations up to 9 G.

(2) Health protection criteria and a risk assessment methodology for multiple shock exposures need to be developed and validated. The criteria should include levels above 9 G in the vertical axis and levels above 2 G in the tangential and longitudinal directions.

(3) The WBV standards in ISO 2631–1, ISO 2631–5, and MIL–STD–1472G do not apply to ultrasonic vibration exposure. Health protection criteria and a risk assessment methodology need to be developed and validated for this type of exposure.

APPENDIX 5A

CHAPTER 5 REFERENCES

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APPENDIX 5B

CHAPTER 5 GLOSSARY

ACV
armored combat vehicle

APHC
U.S. Army Public Health Center

a_w
frequency-weighted acceleration

CCTP
cross-country terrain probability

DEL
daily exposure limit

G
unit of gravitational force

HHA
health hazard assessment

HP
hazard probability

HS
hazard severity

HSP
hazard severity probability

ISO
International Organization for Standardization

$\mathrm{m/s}^2$
meters per second squared

MATDEV
materiel developer

MIL–STD
Military Standard

mph
miles per hour

OMS/MP
Operational Mode Summary/Mission Profile

P(E)
probability of exposure

PPE
personal protective equipment

PTP
primary terrain probability

RAC
risk assessment code

RMS
root mean square

SME
subject matter expert

STP
secondary terrain probability

TEP
terrain exposure probability

TG
Technical Guide

TOP
Test Operations Procedure

USAARL
U.S. Army Aeromedical Research Laboratory

VDV
vibration dose value

WBV
whole-body vibration

CHAPTER 6. GUIDELINES FOR CONDUCTING HEALTH HAZARD ASSESSMENTS OF EXPOSURE TO HAND-ARM VIBRATION

Source: DVIDS

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6–1. Purpose

This chapter of Technical Guide (TG) 351C provides guidelines for conducting health hazard assessments (HHAs) of Soldier exposure to hand-arm vibration (HAV) that occurs during the normal use and maintenance of materiel systems.

6–2. Definitions of Key Terms

Average sample vibration magnitude (a_{hw}): The average vibration magnitude of a series of *N* vibration magnitude samples from the same vibration source is given by:

$$a_{hw} = \sqrt{\frac{1}{T}\sum_{j=1}^{N} a_{hwj}^{2} t_j}$$

(Equation 6–1)

Where:
N = number of vibration magnitude measurements
a_{hwj} = measured vibration magnitude for sample j
t_j = measurement duration of sample j
T = summation of all measurement durations (t) from j to N

Note: This value of a_{hw} averages multiple frequency-weighted vibration magnitude measurements of the same vibration source, whereas the frequency-weighted hand-transmitted vibration (a_{hwi}) is a single measurement made for a time duration of t_j. Typically, this will occur for each of the triaxial measurements at time t_j.

Daily exposure action value (DEAV): The vibration total value (VTV) (a_{hv}) above which HAV exposure may increase the risk of injury. The American National Standards Institute/Acoustical Society of America S2.70-2006(R2020) (ANSI S2.70) sets a DEAV of 2.5 meters per second squared (m/s^2) averaged over an 8-hour exposure period. This is the level at which action should be taken to limit the operator's exposure.

Daily exposure limit value (DELV): The maximum allowable a_{hv} for HAV exposure. The ANSI S2.70 sets a DELV of 5 m/s^2 averaged over an 8-hour period. Continuous exposure above this limit is considered a high health risk.

Daily personal vibration exposure (*A*(8)): The daily vibration magnitude averaged over a reference duration of 8 hours for comparison to the DEAV and DELV, expressed in units of m/s^2. The *A*(8) for a single source of HAV is equal to:

$$A(8) = a_{hv}\sqrt{\frac{T}{T_o}}$$

(Equation 6–2)

Where:
a_{hv} = vibration total value (VTV)
T = duration of exposure to the a_{hv}
T_o = reference duration (8 hours)

Total daily vibration exposure consisting of several operations with two or more HAV sources with different vibration magnitudes and exposures is equal to:

$$A(8) = \sqrt{\frac{1}{T_o}\sum_{i=1}^{n} a_{hvi}^2\, T_i}$$

(Equation 6–3)

Where:
T_o = reference duration (8 hours)
n = number of individual HAV sources within the working day
a_{hvi} = VTV for source i
T_i = exposure duration of source i

Hand-arm vibration (HAV): The mechanical vibration that, when transmitted to the human hand-arm system, causes risks to the health and safety of workers. Observable health effects that may result are vascular, bone or joint, neurological, or muscular disorders.

Root mean square (RMS) single-axis acceleration value of the frequency-weighted hand-transmitted vibration (a_{hwi}): The acceleration value from one-third-octave band analysis weighted according to International Organization for Standardization (ISO) 5349–1. The a_{hwi} is calculated using the following equation for each of the three orthogonal axes (a_{hwx}, a_{hwy}, a_{hwz}):

$$a_{hwi} = \sqrt{\sum_{i} (W_{hi} a_{hi})^2}$$

(Equation 6–4)

Where:
W_{hi} = weighting factor for the i th one-third octave band frequency
a_{hi} = RMS acceleration measured in the i th one-third octave band in m/s^2

Notes:

(1) Most human vibration meters used to collect HAV data automatically apply this equation and provide the weighted acceleration.

(2) This value of a_{hwi} averages a single measurement based on frequency, whereas the average sample vibration magnitude (a_{hw}) averages multiple vibration magnitude measurements from the same sources. Each vibration measurement must be frequency-weighted first, then the total number of frequency-weighted measurements are averaged.

Vibration total value (VTV) (a_{hv}): The root-sum-of-squares of the a_{hw} values for the three measured axes of vibration, expressed in units of m/s^2. The a_{hv} represents the vibration magnitude, and is calculated by:

$$a_{hv} = \sqrt{a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2} \qquad \text{(Equation 6–5)}$$

Where:
a_{hwx}, a_{hwy}, and a_{hwz} = RMS single-axis acceleration values of the frequency-weighted hand-transmitted vibration for the x-, y-, and z-axis, respectively.

6–3. Applicable References/Health Protection Criteria

A. References. Appendix 6A lists the references applicable to this chapter. The methods and references described in Chapter 1 of this Guide also apply to this chapter.

B. Health Protection Criteria. The following paragraphs provide a brief summary of health protection criteria from Military Standard (MIL–STD) 1472G, ISO 5349–2, and ANSI S2.70. To conduct an HHA, a trained HAV subject matter expert (SME) must become familiar with the standards and health protection criteria in their entirety.

Important note: MIL−STD−1472G was superseded by version H in September 2020; however, version H does not include a critical section stating the HAV limit. Version G is being used in the interim while the reason for the paragraph omission is determined.

MIL–STD–1472H states an operator’s exposure to HAV shall not exceed the health risk zone (i.e., not exceed the DELV) for the expected daily exposures defined by ANSI S2.70. Furthermore, for daily exposures exceeding the DEAV, a program should be implemented to reduce health risks, thereby increasing performance.

ANSI S2.70 calls for a frequency-weighted analysis of vibration data in three orthogonal axes (a_{hwx}, a_{hwy}, a_{hwz}) calculated using Equation 6–4. The three axes are used to calculate the VTV (a_{hv}) using Equation 6–5. The upper limit of the health risk zone is defined as the DELV equal to 5 m/s^2. The lower limit of the health risk zone is defined as the DEAV equal to 2.5 m/s^2. For instances where the operator is not exposed to HAV for 8 hours, the $A(8)$ is calculated using Equation 6–2. For instances where an operator is exposed to two or more HAV sources, Equation 6–3 is used. Figure 6–1 shows the ANSI S2.70 DEAV and DELV as a function of exposure duration.

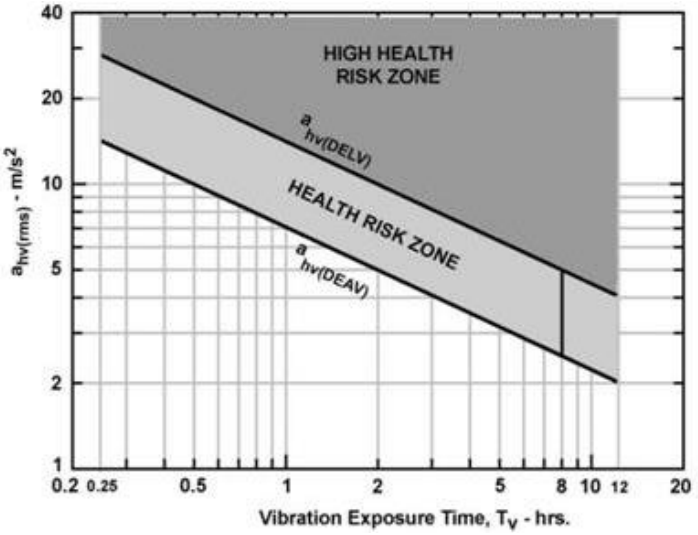

Figure 6–1. Hand-arm Vibration Daily Exposure Action and Limit Values
Source: ANSI S2.70

6–4. Health Effects of Hand-Arm Vibration Exposure

Exposure to HAV results in various disorders of the hand and arm and can be grouped into four main types: vascular, bone and joint, peripheral neurological, and muscular. Frequent exposure to HAV has been linked to loss of grip strength, loss of reaction time, inflammatory changes (e.g., carpal tunnel syndrome), and vibration-induced white finger syndrome.

6–5. Pre-assessment Procedures

A. Use Scenario Information. In order to properly asses the HAV exposure risk, the materiel developer (MATDEV) shall provide detailed information about the system and its normal use in the theater and training environment, including daily use scenarios for each piece of equipment that produces HAV. The use scenarios must include the time of operation, number of operators, and work/rest schedule. Exposure duration for each HAV source is estimated based on the use scenario information.

Operational environment factors derived from the use scenario should be considered in both hazard identification and risk assessment. These factors include exposure duration, exposure frequency, and exposure magnitude.

B. Data Requirements. Data sufficient to determine the VTV must be provided according to one of two methods. The preferred method of data collection is field data collection via ISO 5349–2. This method most represents the exposures that operators encounter. The second method estimates the VTV based on guidance found in U.S. Army Public Health Command (now Center (APHC)) TG 356. This method involves using manufacturer’s laboratory vibration exposure data found in the user’s manual or searching numerous online vibration databases to determine whether the same make and model of equipment being assessed was previously measured according to ISO 5349–2.

Note: Both scenarios in the second method will severely reduce the accuracy of the actual operator’s vibration exposure; they should be used with caution and according to the guidance in TG 356. If the MATDEV does not provide adequate data, a conservative risk assessment code (RAC) may be assigned based on the data available, analogy, and SME judgement. When data are collected to verify the HAV levels, the RAC may be adjusted in an updated HHA.

Following are the two methods used to determine the VTV:

1) Field data collection (preferred): Provide frequency-weighted vibration magnitude data recorded per requirements in ISO 5349–2 for each piece of equipment under consideration. Data collected via this method are recorded in the field and must be representative of the equipment’s intended operating conditions. These include, but are not limited to, the following:

- Exact make and model number.
- Identical power conditions (e.g., air supply pressure).
- Identical tool condition (e.g., tool bit, feed force, personal protective equipment (PPE) use).
- Several data points with varying operators.

2) Manufacturer’s information: Provide frequency-weighted vibration magnitude per manufacturer’s specifications. Manufacturers test their tools according to either the ISO 8662 or ISO 28927 series of standards. These series values are vibration values measured by the manufacturer that conform to the testing standard for a specific tool classification. If the tool was tested via the older ISO 8662 standard, the value will be a single-axis value. (Note: ANSI S2.70 requires measurement in three axes.) These values can usually be found in the manuals and documentation that accompany each tool. These are laboratory values and require use of a safety factor when determining field exposure. A safety factor of 2 is typically used for this method (Rimell et al. 2008). Refer to TG 356 for more information about safety factors.

6–6. Risk Assessment Process

The risk assessment process described in this section applies to equipment operation that exposes operators to a continuous random vibration source. The equipment’s vibration signature may include random peaks of acceleration such as those seen in the vibration signature of impact wrenches. However, this assessment process will not be used for equipment, such as weapons, whose vibration signature primarily consists of high-frequency acceleration peaks.

A. Hazard Severity and Hazard Probability Determination. The ANSI S2.70 standard does not employ a risk assessment terminology and methodology that are consistent with the risk levels found in MIL−STD−882E discussed in Chapter 1 of this Guide. Since the *A*(8) is dependent on both the measured vibration level and exposure time, hazard severity (HS) and hazard probability (HP) may both be assigned based on the single value. The classification scheme shown in Table 6−1 was developed to translate HAV exposure limits to both the HS categories and HP levels of Army Regulation 40−10. The initial risk is based on unprotected exposure to the vibration level.

To evaluate the HS and HP, determine the *A*(8) and compare the *A*(8) to the DEAV and DELV. The *A*(8) is based on the operator's exposure duration, identified as (*T*), and the vibration magnitude, defined as VTV (a_{hv}). Calculate the VTV using the provided HAV data and Equation 6–5. Apply a safety factor of 2 if the provided data is supplied by the manufacturer and was collected according to the ISO 8662 or ISO 28927 series instead of field measurement data recorded according to ISO 5349-2 (refer to section 6–5B).

Note: Exposure duration (*T*) is to be provided by the MATDEV; refer to section 6–5A. If a system with multiple tools is being evaluated, each individual tool exposure duration (T_i) is to be supplied.

To calculate *A*(8) for a single HAV source, input the exposure duration and VTV into Equation 6–2; use Equation 6–3 to calculate *A*(8) for two or more HAV sources. Assign the HS and HP by comparing the calculated *A*(8) value to the DELV (2.5 m/s^2) and DEAV (5 m/s^2) in Table 6–1. Note that the RACs for systems with insufficient data and assumed exposures may vary conservatively from Table 6−1 based on SME judgment.

Table 6–1. Risk Assessment for Hand-arm Vibration Exposure

***A*(8) Criteria (frequency-weighted)**	**Hazard Severity (HS)**		**Hazard Probability (HP)**		**Risk Level**	**ANSI S2.70 Nomenclature**
≥2x DELV	2	Critical	A	Frequent	High	Immediate
DELV to <2x DELV	3	Marginal	B	Probable	Serious	
DEAV to <DELV	3	Marginal	C	Occasional	Medium	Action Plan
1.0 m/s^2 to <DEAV	4	Negligible	D	Remote	Low	Low Risk
<1.0 m/s^2	Not assigned*		F	Eliminated	Eliminated	

Legend:
ANSI = American National Standards Institute
DEAV = daily exposure action value (equal to 2.5 m/s^2 averaged over an 8-hour period)
DELV = daily exposure limit value (equal to 5 m/s^2 averaged over an 8-hour period)
m/s^2 = meters per second squared
Note:
*No initial risk level is assigned for hand-arm vibration meeting this *A*(8) criterion. If applicable, the hazard severity (HS) category assigned for residual risk is the same as the initial HS, while the hazard probability (HP) moves to HP F to eliminate the risk.

The risk assessment is based on the DELV and DEAV levels of ANSI S2.70 and relevant scientific literature. According to the standard, the health risk threshold for

DEAV is defined as the dose of hand-transmitted vibration exposure sufficient to produce abnormal signs, symptoms, and laboratory findings in the vascular, bone or joint, neurological, or muscular systems of the hands and arms in ***some*** exposed individuals. ANSI S2.70 gives further guidance stating that ***Immediate Action*** should be taken to lower workers' exposures to levels below the DELV. The DELV represents the health risk threshold where exposure above the dose limit will produce symptoms in a ***high proportion*** of exposed individuals. (Note: The numerical values of "***some***" and "***high proportion***" are not specifically defined in ANSI S2.70.) ANSI S2.70 further states that an ***Action Plan*** needs to be developed to lower workers' exposures to levels below the DEAV.

ANSI S2.70 states that levels below the DEAV are a ***Low Risk*** but does not provide a threshold for onset of injury. Other studies have researched the possible onset of injury. The threshold of weighted acceleration for the production of vibration white finger in the range of 1.0 m/s^2 produced a 10% prevalence in the population after 30 years of exposure (Brammer 1982). Roadworkers exposed to an $A(8)$ of 1.2 m/s^2 via an impact wrench experienced a shift in their vibration perception threshold response at the fingertips (Clemm 2020). VPT is a tool commonly used to diagnose HAV. Finally, ISO 5349−1 states, "Studies suggest that symptoms of the hand-arm vibration syndrome are rare in persons exposed with an $A(8)$, at a surface in contact with the hand, of less than 2 m/s^2 and unreported for $A(8)$ values of less than 1 m/s^2" (ISO 2001a). Therefore, an $A(8)$ of less than 1.0 m/s^2 is assumed to reduce HAV exposure to a level that will not be detrimental to operators, and no risk level is assigned.

B. Risk Mitigation and Recommendations. According to Department of Defense Instruction 6055.01, there is a preferred hierarchy of effectiveness of controls that should be considered: (1) elimination, (2) substitution, (3) engineering controls, (4) warnings, (5) administrative controls, and (6) personal protective equipment (PPE). Following are examples of these HAV controls in priority order:

(1) ***Elimination.*** Changing the process such that operators do not come in contact with power equipment can eliminate HAV exposure. Automatic or robotic systems may replace the need for operators to use power tools, thus eliminating subsequent HAV exposure.

(2) ***Substitution.*** Use similar equipment that has lower vibration characteristics.

(3) ***Engineering Controls.*** Redesign the equipment to lower the operator's exposure to HAV. These modifications may include adding active vibration damping systems to counteract the vibration caused by the motor and contact with the workpiece, or incorporating vibration-reducing materials in the handles.

(4) ***Warnings.*** Provide wearable technology that can be programed to determine when an operator has reached a threshold such as the DEAV. Warnings placed in technical and user manuals are considered administrative controls.

(5) ***Administrative Controls.*** Administrative controls such as reducing operational times, increasing frequency of rest breaks, keeping equipment properly maintained, periodically training operators regarding procedures, and publishing warnings in manuals will reduce exposure to HAV.

(6) ***PPE.*** In some cases, the use of anti-vibration gloves certified by ISO 10819:2013 can reduce operator exposure. Typically, it is assumed that anti-vibration gloves reduce exposure levels by 10%. However, the level of protection is dependent on the vibration frequencies of the tools in use. Reduced manual dexterity and grip strength resulting from glove use may hinder certain tasks.

C. Residual Risk. If risk mitigation strategies are applied to reduce the amount of HAV exposure, the risk level may be reassessed. The residual risk may be Eliminated (HP F) when equipment employs vibration mitigation strategies such that the $A(8)$ is less than 1.0 m/s^2. Supporting data must be submitted to the APHC for verification. The HP level may be reduced if work/rest cycles and/or other controls are implemented that reduce the exposure, thereby lowering the $A(8)$. Additionally, the VTV may be recalculated for PPE use if data are collected in the field from persons wearing anti-vibration gloves.

6–7. Example Assessment Scenario

The APHC received a request to assess the HAV associated with a vibratory plate compactor (VPC) that will be used as part of tool kit for an engineering battalion.

Step 1. Obtain the use scenario from the MATDEV, which states the following:

- Typical use scenario is 5 hours per day.
- Usage in theater is up to 5 days per week and in garrison is 3 days per week.

Step 2. Obtain data from a testing event for the VPC. The test conditions and data set state—

- Testing was conducted at the U.S. Army Aberdeen Test Center on a test course of 120 feet in length.
- On-board instrumentation collected the necessary acceleration data used to calculate the vibration levels for analysis of the operator’s exposure.
- Data were collected and processed according to ISO 5349−2 and ANSI S2.70, meaning the acceleration measurements were already frequency-weighted according to Equation 6–4.

Table 6–2 contains the HAV weighted acceleration data for the VPC for all test conditions.

Table 6–2. Vibratory Plate Compactor Sample Weighted Acceleration Data

Run		Weighted Acceleration (m/s^2)		
Number	**Time (seconds)**	**X-axis**	**Y-axis**	**Z-axis**
1	187.5	1.97	2.08	1.70
2	156.3	1.86	2.05	1.74
3	167.2	1.77	1.97	1.75
4	138.9	2.50	2.55	2.34
Average Vibration Magnitude (a_{hw})		**2.02**	**2.16**	**1.88**

Legend:
m/s^2 = meters per second squared

Step 3. There are four samples consisting of data from each axis with weighted accelerations (a_{hw}) and run times. The average vibration magnitude is calculated for each of the axes independently, using Equation 6−1. The x-axis example appears below:

$$a_{hwx} = \sqrt{\frac{1}{T}\sum_{j=1}^{N} a_{hwj}^2 t_j} = \sqrt{\frac{1}{649.9}\sum_{j=1}^{4}(1.97^2\,(187.5) + 1.86^2(156.3) + \cdots)} = 2.02\ m/s^2$$

Where:
N = number of vibration magnitude measurements
a_{hwj} = measured vibration magnitude for sample j
t_j = measurement duration of sample j
T = summation of all measurement durations (t) from j to N

Step 4. Calculate the VTV (a_{hv}) using Equation 6–5 using a_{hwx}, a_{hwy}, a_{hwz}.

$$a_{hv} = \sqrt{a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2} = \sqrt{2.02 + 2.16 + 1.88} = 3.50\ m/s^2$$

Where:
a_{hwx}, a_{hwy}, and a_{hwz} = RMS single-axis acceleration values of the frequency-weighted hand-transmitted vibration for the x-, y-, and z-axis, respectively.

Step 5. Calculate the $A(8)$ using Equation 6–2 where a_{hv} equals 3.50 m/s^2, T equals 5 hours, and T_o equals 8 hours.

$$A(8) = a_{hv}\sqrt{\frac{T}{T_o}} = \ 3.50\ m/s^2\sqrt{\frac{5\ hours}{8\ hours}} = 2.77\ m/s^2$$

Where:
a_{hv} = vibration total value (VTV)
T = duration of exposure to the a_{hv}
T_o = reference duration (8 hours)

Step 6. Compare the calculated *A*(8) value of 2.77 m/s^2 to Table 6–1 to assign an HS and HP. Because 2.76 m/s^2 is between the DELV and DEAV, assign an HS 3 (Marginal) and HP C (Occasional). This combination results in a RAC of 3C, which corresponds to a risk level of Medium.

Step 7. Recommend the exposure duration be lowered to reduce exposure below the DEAV or threshold of injury (1.0 m/s^2). To reduce the *A*(8) to less than 1.0 m/s^2, the exposure duration (*T*) must be reduced to 4 hours. If the daily exposure duration is limited to 4 hours, assign a residual risk level of Low (RAC: HS 4, HP D). To reduce the *A*(8) to less than 1.0 m/s^2, the exposure duration (*T*) must be reduced to 0.65 hours, or about 40 minutes. If the daily exposure duration is limited to 40 minutes, the risk is Eliminated (RAC: HS 3, HP F).

6–8. Limitations and Potential Future Work

This TG chapter relies on the weighting criteria in ISO 5349–1, which is state-of-the-art as of 2020, to address HAV exposure-related health concerns affecting the blood vessels, nerves, bones, joints, muscles, or connective tissues of the hand and forearm. Researchers continue to investigate the effects of hand-transmitted vibration on the hand and forearm, as well as other sections of the upper extremities (Xu 2017). Similarly, development of new frequency-weighting curves specifically designed to address health concerns related to the fingers and to better classify exposure to highly percussive tools (riveting hammers, bucking bars, etc.) is ongoing (Krajnak 2018). This TG chapter will be updated as the applicable standards are updated.

APPENDIX 6A

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APPENDIX 6B

CHAPTER 6 GLOSSARY

$A(8)$
daily personal vibration exposure

a_{hv}
vibration total value

a_{hw}
average vibration magnitude

a_{hwi}
root mean square single-axis acceleration value of the frequency-weighted hand-transmitted vibration

ANSI
American National Standards Institute

APHC
U.S. Army Public Health Center

DEAV
daily exposure action value

DELV
daily exposure limit value

HAV
hand-arm vibration

HHA
health hazard assessment

HP
hazard probability

HS
hazard severity

ISO
International Organization for Standardization

m/s^2
meters per second squared

MATDEV
materiel developer

MIL–STD
Military Standard

PPE
personal protective equipment

RAC
risk assessment code

RMS
root mean square

SME
subject matter expert

TG
technical guide

VPC
vibratory plate compactor

VPT
vibration perception threshold

VTV
vibration total value

CHAPTER 7. INFORMATION RELEVANT TO HEALTH HAZARD ASSESSMENTS OF EXPOSURE TO MECHANICAL SHOCK (ACCELERATION/DECELERATION)

Source: DVIDS

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7–1. Purpose

This chapter of Technical Guide (TG) 351C provides a definition and background information relevant to Soldier exposure to mechanical shock, commonly referred to as acceleration/deceleration, during normal use and maintenance of materiel systems.

The U.S. Army Public Health Center (APHC) is currently unable to adequately assess the musculoskeletal injury risk from mechanical shock for specific materiel systems due to the absence of a validated assessment model. In most cases, risk assessment codes (RACs) cannot be assigned due to the lack of a validated assessment methodology. Conservative RACs may be assigned in some instances. The objective of this abbreviated chapter is to define the capability gaps and document the future work required to perform mechanical shock risk assessments in support of the Army Health Hazard Assessment (HHA) process.

7–2. Definitions of Key Terms

Acceleration: Increasing rate of change of the velocity of an object with respect to time, usually represented in units of meters per second squared (m/s^2).

Deceleration: Decreasing rate of change of the velocity of an object with respect to time (i.e., acceleration in the opposite direction of velocity), usually represented in units of meters per second squared (m/s^2).

Inertial force: A force opposite in direction to an accelerating (or decelerating) force acting on a body and equal to the product of the accelerating force and the mass of the body.

Mechanical shock: The delivery of a mechanical impulse transmitted to an individual or body part by the acceleration or deceleration of an inertial force. Potential exposures to mechanical shock include the opening force of a paratrooper’s parachute harness and the firing of large caliber weapon systems exhibiting whole-body recoil forces (e.g., howitzers).

Multiple shock: Mechanical shocks of different magnitude and shape that occur frequently during a measurement period. Multiple shock is addressed as a whole-body exposure from vehicles in TG 351C, Chapter 5, Whole-body Vibration.

7–3. Applicable References/Health Protection Criteria

Appendix 7A lists the references applicable to this chapter. The methods and references described in Chapter 1 of this Guide also apply to this chapter.

Numerous biomechanical studies provide useful insights into the amount of mechanical shock that specific human tissues tolerate. Because most studies have either been conducted on cadavers or, most commonly, on isolated anatomical specimens, it is often difficult to apply the study data to the types of exposures encountered in dynamic military work environments. Mechanical shock interacts differently with intact, living subjects than with tissues studied in isolation. To ensure similarity between the research conditions and the military operation being targeted, caution should be observed when applying biomechanical injury criteria to military operations.

7–4. Health Effects of Mechanical Shock (Acceleration/ Deceleration) Exposure

Exposure to acceleration/deceleration mechanical shock as a consequence of normal use of materiel can result in adverse health outcomes ranging from minor soft tissue damage to death. Examples include musculoskeletal conditions associated with parachute operations, and traumatic brain injury from repeated acceleration and deceleration.

The types and mechanisms of injury vary based on the type of exposure and the body part exposed to the mechanical shock. Exposures to low levels of mechanical shock may only cause pain or clinically insignificant injury. However, repeated exposures to low levels of mechanical shock may also yield cumulative trauma that could impair function over time (e.g., increased risk of degenerative joint disease and osteoarthritis in the cervical spine). Moderate levels of mechanical force often produce pain, superficial ecchymosis, or deep tissue hematoma at contact locations. Exposures to high levels of mechanical shock increase the depth of the shock wave’s penetration and the likelihood of injury to a critical organ. More severe injuries include (but are not limited to) sprains, fractures, dislocations, visceral damage, nerve injury, ocular damage, auditory damage, head/neck trauma, and traumatic brain injury. Both acute and chronic injuries should be addressed.

7–5. Mechanical Shock (Acceleration/Deceleration) Health Hazard Assessment Approach

A. Scope. This chapter is limited to the effects of acceleration and deceleration on the body as a whole or to an individual body segment. The focus is on injuries that occur from the act of the person/body part accelerating or decelerating and the physiologic changes that result from exposure to the inertial force. The inertial force must be part of the normal use of the item being assessed. Examples include whiplash to Paladin occupants caused by the sudden acceleration associated with the firing of large-caliber rounds, or the hematoma and trauma to shoulder joint structures caused by parachute straps during deployment of the canopy.

B. Test Data Requirements. The APHC has not established data requirements for assessing mechanical shock. It is anticipated that data requirements will include a method to measure acceleration either directly from an accelerometer or indirectly through calculation. Since most exposures occur while the body is in close contact with equipment, it may also be necessary to use a force gauge to measure forces transmitted to the body at those contact locations.

C. Types of Exposure. The type of exposure and the body part exposed to the mechanical shock affect the mechanism and risk of injury. Figure 7–1 shows a breakdown of the types of mechanical shock exposure. Comprehensive HHAs require the development of health protection criteria and models applicable to each type of exposure.

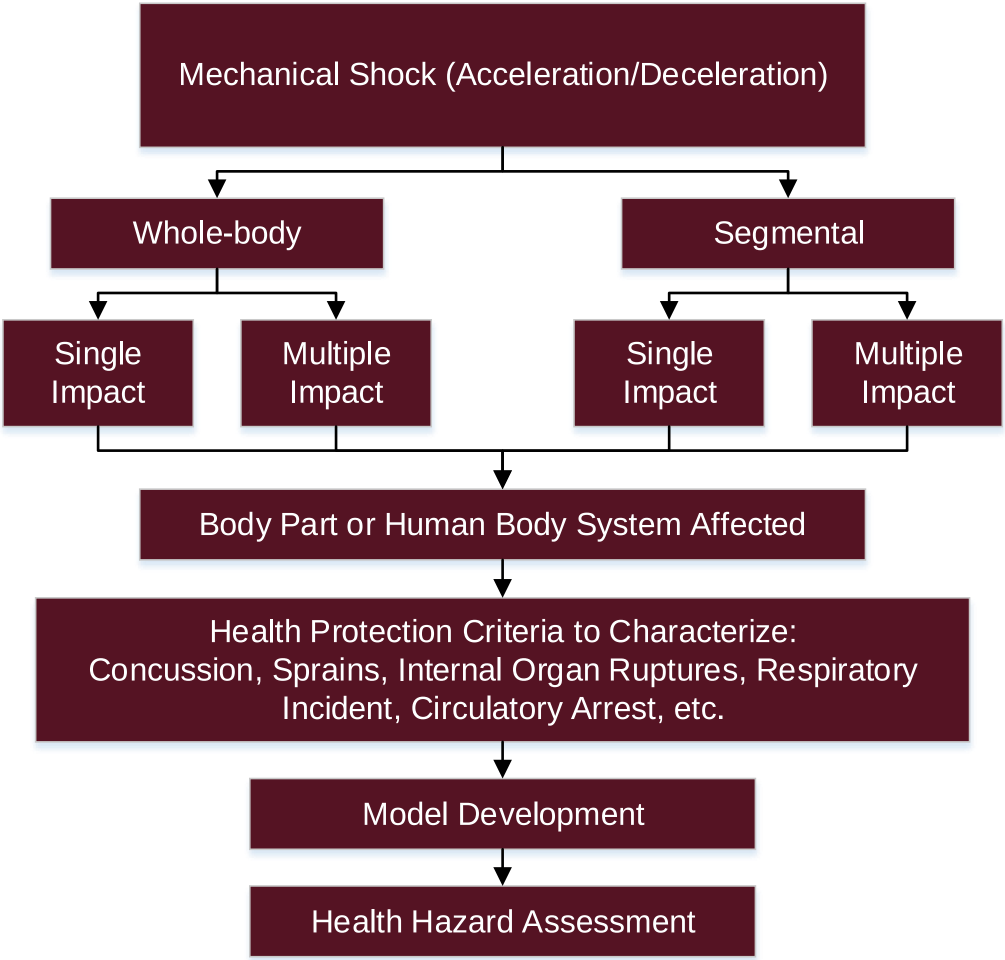

Figure 7–1. Types of Mechanical Shock (Acceleration/Deceleration) and the Health Hazard Assessment Capability Development Process

Examples of sources of mechanical shock exposures include the following:

(1) ***Parachute operations.*** In parachute operations, two types of exposure to acceleration/deceleration may negatively impact the health of musculoskeletal tissues: parachute deployment and parachute landing fall (PLF). In addition, personnel will also need to don, doff, and wear the parachute. This chapter does not discuss these load-bearing tasks since they do not include exposure to mechanical shock. Refer to TG 351C, Chapter 3, Load Carriage, for information regarding load-bearing forces.

(a) ***Parachute deployment.*** Parachute deployment subjects personnel to mechanical stress. After jumping from the plane, the paratrooper accelerates during the fall. Typically, the magnitude of this acceleration is below the injury threshold and not significant enough to merit assessment. However, the abrupt deceleration that occurs after the parachute opens transmits a profound jerk through the shoulder girdle and the axial skeleton. The magnitude of this force should be assessed to determine risk of shoulder and spinal injury. The body's reaction to the jerk from the canopy opening includes rapid, forceful head and neck motion. The health effects of this reaction should be analyzed using a head-supported mass model that considers the mechanical shock and the weight of the helmet worn.

(b) ***PLF.*** Since the rate of acceleration during the fall is strongly influenced by parachute design, the health effects of the ground reaction force when the paratrooper impacts the ground should be assessed. The HHA should assume the paratrooper's weight along with the weight of the equipment that the paratrooper is required to wear for the mission. Nominal wind speed and weather conditions should also be assumed. Since the scope of an HHA is limited to the normal-use scenario, the modeling should assume that the paratrooper uses proper PLF technique. In other words, the HHA for the parachute should not be negatively impacted by improper user technique that increases the probability of injury from mishaps and accidents.

(2) ***Whole-body acceleration/deceleration.*** Another example of exposure to mechanical shock is the effect of firing large-caliber weapon systems such as the M109A7 Paladin, a self-propelled artillery system operated by a 4-person crew. When inside the Paladin, the crew members can experience mechanical shock in the form of recoil as the weapon is fired. They experience instantaneous peak accelerations of up to 100 m/s^2over their entire body. The effect of the sudden acceleration can cause musculoskeletal issues (e.g., joint and intervertebral disc injuries) as well as mild traumatic brain injury (e.g., concussions). These issues are separate from those related to blast overpressure from a detonation, and blunt trauma to body parts that have been struck by objects inside a vehicle.

D. Risk Assessment Approach. Exposure to mechanical shock will be evaluated with a systems approach in the context of the Soldier's clothing and equipment. In other words, the Soldier, uniform, personal protective equipment (PPE), and other equipment carried will be assessed as a unitary system that considers the interactions between all components. Therefore, assessment of mechanical shock will also require a description of all system components, including PPE, clothing, and equipment.

Recommendations to mitigate mechanical shock will depend upon the design of the equipment involved with the exposure. Typical recommendations may include implementing interventions to control the rate of velocity change or alter the forces transmitted through contact points with the human. Forces at contact locations may be moderated by increasing the surface area of the contact, adding cushioning, or incorporating a harness or suspension.

7–6. Limitations and Potential Future Work

The Army HHA Program requires development and validation of health protection criteria and models in order to adequately perform mechanical shock risk assessments. Review of related research models (e.g., motor vehicle safety testing, amusement park ride safety testing) is ongoing to determine if data may be adapted for military-unique environments. A common limitation of industry and academia research and standards is their focus on single-event injuries that occur infrequently as opposed to cumulative trauma from normal use.

The body part affected, and the mechanism of injury, will drive model development. Examples include the following:

(1) ***Mobile howitzer firing.*** Estimate maximum permissible exposure limits to abrupt neck/head motion for different Soldier masses, head/helmet masses, and different levels of acceleration and deceleration.

(2) ***Parachute operations.*** Develop a model to generate a maximum number of allowable jumps, considering head/helmet mass and the transitions among different levels of acceleration and deceleration.

(3) ***Shoulder-fired weapons.*** Develop models for mechanisms of injury and injury outcomes for varying parts of the body exposed to mechanical shock. The types of injuries vary based on the part of the body exposed; therefore, models need to be validated for each.

APPENDIX 7A

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APPENDIX 7B

CHAPTER 7 GLOSSARY

APHC
U.S. Army Public Health Center

HHA
Health Hazard Assessment

ISO
International Organization for Standardization

m/s^2
meters per second squared

PLF
parachute landing fall

PPE
personal protective equipment

RAC
risk assessment code

TG
Technical Guide

CHAPTER 8. INFORMATION RELEVANT TO HEALTH HAZARD ASSESSMENTS OF EXPOSURE TO RECOIL

Source: DVIDS

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8–1. Purpose

This chapter of Technical Guide 351C provides a definition and background information relevant to Soldier exposure to recoil during normal use and maintenance of materiel systems.

The U.S. Army Public Health Center is currently unable to adequately assess the injury risk from recoil for specific materiel systems due to the absence of a validated medical assessment model. In most cases, risk assessment codes (RACs) cannot be assigned. Conservative RACs may be assigned in some instances. The objective of this abbreviated chapter is to define the capability gaps and document the future work required to perform recoil risk assessments in support of the Army health hazard assessment (HHA) process.

8–2. Definitions of Key Terms

Recoil: Reactive force from the discharge of a firearm, often called “kick,” that propels the weapon backwards and imparts mechanical force to the point of contact with the Soldier's body (usually the shoulder or wrist). The recoil momentum balances the forward momentum of the projectile and propellant gases according to Newton’s Third Law, the conservation of momentum. The magnitude of recoil force delivered to the operator is dependent upon several factors, including the design of the weapon as well as firing technique. The most common recoil parameters include recoil energy, recoil velocity, recoil impulse, and weapon acceleration.

8–3. Applicable References/Health Protection Criteria

A. References. Appendix 8A lists the references applicable to this chapter. The methods and references described in Chapter 1 of this Guide also apply to this chapter.

B. Health Protection Criteria. Currently, no Army-approved health protection criteria or medical models have been established for recoil exposures. Personal factors that increase susceptibility to injury include the thickness of soft tissues (particularly, the thickness of the pectoral muscles overlying the more vulnerable soft tissues in the pocket of the shoulder). Anthropometrically smaller individuals with less body weight and muscle mass are at higher risk of injury. Table 8–1 provides the recoil energy design criteria and recommended test weapon firing limitations in accordance with the U.S. Army Test and Evaluation Command (ATEC) Test Operations Procedure (TOP) 03–2–504A.

Table 8–1. Recoil-based Firing Limitations for Test Weapons

Calculated Recoil Energy	Limitations on Rounds
<15 ft-lb (20.3 J)	Unlimited firing
15 to 30 ft-lb (20.3 to 40.7 J)	200 rounds/day/individual
30 to 45 ft-lb (40.7 to 61.0 J)	100 rounds/day/individual
45 to 60 ft-lb (61.0 to 81.4 J)	25 rounds/day/individual
>60 ft-lb (81.4 J)	No shoulder firing

Source: Test Operations Procedure 03–2–504A
Legend:
ft-lb = foot pound(s)
J = joules

The validity of these design criteria as a basis for health protection criteria for HHAs has not been substantiated. A preliminary study by the U.S. Army Medical Research Institute of Environmental Medicine (USARIEM) questioned applying the firing limitations proposed by TOP 03–2–504A for the 45 to 60 foot pound (ft-lb) range as health protection criteria for firing a shoulder-fired weapon with a uniform covering the shoulder (USARIEM 2004). An Army Research Laboratory (ARL) study reviewed the physics of recoil impulses and suggested that the distribution of recoil impulse or energy over time should be a key assessment factor (ARL 2012). Both studies advised additional research to obtain the data needed to develop a more definitive characterization of recoil exposure and health protection criteria (USARIEM 2004; ARL 2012).

8–4. Health Effects of Recoil Exposure

Exposures to recoil force that occur as a consequence of normal use of a weapon can result in soft tissue injury such as contusion or laceration. High dosages of force directed at the anterior shoulder may also produce tendonitis, focal bursitis, nerve injury, or fracture of the clavicle. Military exposures to recoil are frequent, and repeated exposures may increase the hazard probability and/or severity of operator injury. Due to the design of shoulder-fired weapons, the anatomical contact point is nearly always unchangeable, and repeated recoil exposure to the contact point may result in cumulative injuries. Common symptoms of such injuries include pain, superficial ecchymosis, deep tissue hematoma, minor reduction in the active range of motion of the shoulder, and slight decrement in lifting capacity.

8–5. Recoil Health Hazard Assessment Approach

A. Test Data Requirements. Data requirements for recoil are currently being developed. It is anticipated that data requirements will necessitate conducting a weapon kinetics study similar to that described in TOP 03−2−826A and TOP 03–2–045. Specific data items required to assess the risk of injury from recoil will likely include measurements of weapon acceleration, weapon speed, and displacement along the axis of the weapon that aligns with the anatomical point of contact with the operator. In addition, the data items described in TOP 03–2–504A for calculating recoil energy are needed such as the weights of the gun, propellant, and bullet. Information about the use scenario is needed, including a description of the intended operators, the duration of exposure, and the anticipated number of rounds that may be fired on a typical training or operational day.

B. Risk Assessment Approach. An HHA employs a systems approach. Exposure to recoil force should be evaluated within the context of the other items in the Soldier's ensemble (e.g., individual body armor that may act as personal protective equipment for recoil). Because firing technique influences recoil transmission, a description of the weapon’s firing postures and holding methods is needed.

Until specific health protection criteria dictate otherwise, initial recommendations to mitigate injury include enforcing the firing limitations described in Table 8–1. This includes limiting exposures from shoulder-fired weapons to less than 60 ft-lbs of recoil energy.

8–6. Limitations and Potential Future Work

The Army HHA Program requires development and validation of health protection criteria and models to facilitate adequate recoil risk assessments. Examples include a model to predict recoil injury risk to the upper quadrant (to include the shoulder, upper extremities, and torso) using data currently collected by weapon testers across a multitude of shooting postures (e.g., standing, kneeling, sitting, and prone). The model should also estimate the effects of selective wearable uniform items (e.g., individual body armor) and estimate injury risk for the bare shoulder as a reference. The model should be scalable to include considerations for accessories and weapon attachments that would change the overall weight of the weapon or shooter. The model may also need to consider the relationship between the thickness of the anterior shoulder tissue (subcutaneous fat and pectoral muscles) and the probability of injuring the brachial plexus (i.e., nerve injury). The model developer should also consider investigating the effect that gender and body type (e.g., weight, muscle mass) have on injury. Additional modeling should consider vibration injuries from rapid fire systems such as machine guns, as well as longitudinal and rotational factors related to wrist injuries from weapon systems with vertical fore-grips or pistol grips.

APPENDIX 8A

CHAPTER 8 REFERENCES

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APPENDIX 8B

CHAPTER 8 GLOSSARY

ARL
Army Research Laboratory

ATEC
U.S. Army Test and Evaluation Command

ft-lb
foot pound

HHA
health hazard assessment

J
joule

RAC
risk assessment code

TOP
Test Operations Procedure

USARIEM
U.S. Army Research Institute of Environmental Medicine

CHAPTER 9. GUIDELINES FOR CONDUCTING HEALTH HAZARD ASSESSMENTS OF EXPOSURE TO THERMAL STRESS

Source: DVIDS

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9–1. Purpose

This chapter of Technical Guide (TG) 351C provides guidelines for conducting health hazard assessments (HHAs) of Soldier exposure to thermal stress (heat stress and cold stress) during normal use and maintenance of materiel systems.

9–2. Definitions of Key Terms

Cold strain: The body's response to cold stress, characterized by one or more of the following physiological responses: hypothermia, shivering, and peripheral injuries. Cold-induced peripheral injuries fall into two categories: freezing and nonfreezing.

Cold stress: Physical stress that is the product of an interaction of environmental factors (e.g., ambient air or water temperature, humidity, wind speed), mission factors (e.g., metabolic rate, clothing, equipment, work duration and intensity, terrain, exposure to moisture), and physiological/biomedical factors (e.g., medication, health, fatigue, previous cold injury).

Dry bulb temperature (T_{db} or T_a): The common air temperature collected in weather data, measured with a shaded thermometer. In this chapter, T_a designates the outdoor temperature, and T_{db} designates the temperature measured inside a vehicle or shelter.

Dew point temperature: The temperature at which water vapor starts to condense out of the air (the temperature at which air becomes completely saturated with water vapor).

Globe temperature (T_g): Temperature measured inside a 6 inch diameter globe painted dull black, or measurement from an instrument with a smaller globe after correction for the size difference. T_g combines the influences of the dry bulb temperature, the heat gain from solar and ambient radiation, and the cooling effect of air movement.

Heat strain: The body's response to heat stress, characterized by one or more of the following physiological responses: hyperthermia (elevated skin and core temperatures), increased sweating rate, dehydration, increased heart rate, and compromised cardiovascular control. Heat strain can result in serious heat illnesses, including heat exhaustion and heat stroke.

Heat stress: Physical stress that is the product of an interaction of environmental factors (e.g., ambient air temperature, humidity, wind speed, radiant/solar load), mission factors (e.g., metabolic rate, clothing, equipment, work duration and intensity, terrain), and physiological/biomedical factors (e.g., medication, health, heat acclimatization, hydration, physical fitness).

Latent heat gain: Energy added to the space when moisture is added to the space by means of vapor emitted by the occupants, generated by a process or through air infiltration from outside or adjacent areas.

Natural wet bulb temperature (T_{nwb}): Temperature recorded by a thermometer with a wetted wick exposed to ambient air movement and radiation. It is the main factor in calculating the wet bulb globe temperature (WBGT). It is always equal to or higher than wet bulb temperature (T_{wb}), especially as radiative heat gains increase, and as relative humidity (RH) or air velocity decreases.

Radiant heat gain: Heat transmitted directly by photons emitted by a warm object. Sources of radiant heat include solar radiation, radiation from the surroundings, and hot equipment.

Relative humidity (RH): The mass ratio between the moisture content of air at a certain T_{db} and the maximum amount of moisture that it can hold at that temperature. The RH is collected in weather data and certain test data.

Sensible heat gain: Energy added to the space by conduction, convection, and/or radiation.

Soak: A term used in the testing community to describe the act of stabilizing a test item or location of interest (e.g., inside a vehicle cab or shelter) to a prescribed temperature. Typically, the test item is placed inside a test chamber with a specific ambient dry bulb temperature for the amount of time it takes the test item temperature readings to stabilize plus 2 hours. The additional 2 hours are to ensure stabilization has occurred.

Thermal stress index: Approximation of the thermal effects of the environment on the human body, combining the influences of ambient air temperature, air velocity, humidity level, and (ideally) radiative heat exchange, expressed as a single value in units of degrees of temperature. The WBGT is an example of a thermal stress index.

Thermoregulation: The set of the body’s physiological responses to thermal stress that maintains safe body core temperatures (e.g., sweating, shivering). Multiple physiological and biomedical factors (e.g., fever, dehydration, medication) negatively affect the body’s ability to thermoregulate, which increases the risk of illness and degrades physical work performance.

Wet bulb globe temperature (WBGT): Most commonly used thermal stress index by the Army and other institutions in general. The WBGT screening criteria must be adjusted for the contributions of work demands and clothing. Use the following equation to calculate the WBGT:

$$WBGT_{outside} = 0.7\,T_{nwb} + 0.2\,T_g + 0.1\,T_a \qquad \text{(Equation 9–1)}$$

Where:
$WBGT_{outside}$ = wet bulb globe temperature when outdoors
T_{nwb} = natural wet bulb temperature
T_g = globe temperature
T_a = dry bulb temperature

When indoors, the solar radiation is negligible, and Equation 9–1 becomes:

$$WBGT_{inside} = 0.7\,T_{nwb} + 0.3\,T_g \qquad \text{(Equation 9–2)}$$

Where:
$WBGT_{inside}$ = wet bulb globe temperature when indoors
T_{nwb} = natural wet bulb temperature
T_g = globe temperature

The effective WBGT ($WBGT_{eff}$) accounts for clothing-adjustment factors (CAF) (refer to Table 9−1), and is equal to:

$$WBGT_{eff} = WBGT + CAF \qquad \text{(Equation 9−3)}$$

Where:
$WBGT$ = wet bulb globe temperature
CAF = clothing-adjustment factor

Wet bulb temperature (T_{wb}): The temperature recorded by a thermometer with a wetted wick exposed to constant air movement. Also known as the psychometric wet bulb temperature. The T_{wb} is the wet bulb temperature collected in weather data and certain test data.

Wind chill temperature index (WCT): A thermal stress index combining the influence of T_a and wind velocity that is used to evaluate the potential for frostbite. The WCT is mainly of interest for evaluating personnel working outdoors or in open vehicles. Figure 9−1 provides the WCT adjustments.

9–3. Applicable References/Health Protection Criteria

A. References. Appendix 9A lists the references applicable to this chapter. The methods and references described in Chapter 1 of this Guide also apply to this chapter.

B. Health Protection Criteria. Currently, the Army HHA Division uses the criteria for heat and cold stress in MIL−STD−1472H as its basis for health standards. The American Conference of Governmental Industrial Hygienists (ACGIH®) has established thermal stress Threshold Limit Values® (TLVs) for varying work rest cycles and metabolic rate (MR) categories which are often more conservative than MIL−STD−1472H; applying TLVs allows for a risk assessment process based on more than a single-point threshold. When the TLVs are less stringent than those in

MIL−STD−1472H (e.g., light metabolic category), the MIL−STD−1472H limits apply. HHAs do not apply ACGIH Action Limits (ALs) to thermal stress because Army populations are assumed to be acclimatized, and the ALs are based on unacclimatized individuals. The Occupational Safety and Health Administration has not established exposure limits for thermal stress. MIL−STD−1472H includes indoor climate requirements for "manned spaces." A space is considered "manned" if it is designed for manned entry and is routinely occupied for a short, continuous interval, typically defined as less than 20 minutes.

The MIL−STD−1472H requires the following related to ***heat stress***:

- The $WBGT_{eff}$ within manned spaces shall not be greater than 86 °F under normal operational internal heat loads and the worst-case design climatic conditions as specified in Army Regulation (AR) 70−38.
- For prolonged work at MR above 250 watts (W), use the ACGIH TLV for the maximum $WBGT_{eff}$.
- The temperature difference between floor and head level shall not differ by greater than 10 °F.
- When special protective clothing or personal equipment (e.g., full and partial pressure suits, fuel handler suits, body armor, arctic clothing, and temperature-regulated clothing) is required and worn, a comfort micro-climate between 68 °F, 14 millimeters mercury (mm Hg) ambient water vapor pressure, and 95 °F, 3.0 mm Hg ambient water vapor pressure is desirable and, where possible, shall be maintained by heat transfer systems.
- In ground vehicles, air flow rates for hot climate operation (temperatures above 90 °F) shall be maintained between 4.2 and 5.7 cubic meters (150 and 200 cubic feet) per minute per person, unless air conditioning or individual (microclimate) cooling is provided.

The MIL−STD−1472H requires the following related to ***cold stress***:

- Within work environments (including, but not limited to, mobile personnel enclosures) occupied during extended periods of time, heating systems shall maintain an interior T_{db} above 50 °F.
- If precise work is performed for more than 20 minutes in an environment below 60 °F, special provisions should be made to keep hands warm.
- Vehicles occupied for more than 3 hours must be equipped with heating systems capable of maintaining a T_{db} greater than 68 °F, or greater than 41 °F when arctic clothing is worn, within 1 hour of starting the heater.
- In occupied vehicles, temperatures around the body shall not vary by more than 9 °F.

9–4. Health Effects of Thermal Stress

A. Heat Strain Health Effects. The body's heat dissipation normally occurs by radiation, convection, and evaporation (sweating). However, the environment may affect the normal response. For example, if the ambient temperature (measured as dry-bulb temperature, T_{db}) is sufficiently hot (i.e., greater than body temperature), direct heat transfer away from the body by convection, conduction, and radiation is hindered. Evaporation will therefore be the primary means of heat loss. If the ambient humidity (measured as dew-point temperature, T_{wb}, vapor pressure, or RH) is high, evaporative heat loss is compromised. Wind speed may aid evaporative heat loss, but clothing, vehicles, and shelters will impede air flow and thus evaporative heat loss. Radiant heat, such as solar load and radiation from hot surroundings, directly increases body temperature but may be reduced by shades or reflective coatings on windows, or may be spread over time by insulation in vehicles and shelters.

Heat dissipation is facilitated by peripheral vasodilation, which is the transfer of heat from the body core to the skin through redistribution of blood flow. Blood flow to the gastrointestinal tract and other inactive tissues is reduced, and the heart rate increases to maintain the required blood flow to the skin. Under normal heat stress conditions, these responses are sufficient to maintain thermal balance and limit performance degradation.

When the heat load exceeds the body’s ability to dissipate heat, heat strain develops. An increase in sweating rate combined with insufficient fluid intake can lead to dehydration and/or electrolyte loss or imbalance. Electrolyte losses may also suppress thirst and contribute to the development of muscle cramps. Cardiovascular strain may occur as the result of reduced blood volume and the competition for blood distribution between the skin and central circulation. Physiological responses to heat strain include hyperthermia (elevated skin and core temperatures), increased sweating rate, dehydration, increased heart rate, and compromised cardiovascular control.

Heat strain may result in serious and possibly fatal heat illnesses such as heat exhaustion and heat stroke. Additionally, physical and cognitive performance decrements may occur at body temperatures and/or hydration levels lower than those causing heat illness or injury.

There are two levels of heat stress: compensated and uncompensated. Under compensated heat stress, the body’s thermoregulatory processes are able to keep its core temperature within a safe range, and the body can maintain its metabolic rate for long periods. Under uncompensated heat stress, the body is either unable to keep its core temperature from rising to an unsafe level, or it experiences unsustainable cardiovascular strain from high metabolic rate and warm skin, even at what would otherwise be considered a “safe” core temperature. The body then starts to experience heat injury.

Heat exhaustion is the most common form of heat casualty and is not associated with organ damage. It occurs when the body cannot sustain the level of cardiac output necessary to meet the combined demands of skin blood flow for thermoregulation and blood flow for the metabolic requirements of exercising skeletal muscle and vital organs. The body continues to sweat and experiences only transient neurological symptoms such as fatigue, nausea, and dizziness. Exposed personnel will recover completely if removed from the overexposure but should not be re-exposed to heat stress for a minimum of 24 hours. If the overexposure continues without relief, heat exhaustion will progress to more serious injury.

Exertional heat injury (EHI) represents a range of heat injuries between heat exhaustion and heat stroke. EHI includes organ and muscle damage but without significant neurological symptoms.

Heat stroke is a life-threatening failure of the thermoregulatory system, where the core temperature exceeds 104 °F. The most common form of heat stroke injury in healthy populations is exertional heat stroke, where sweating is often present (unlike the classical form, in which sweating has ceased). Heat stroke is characterized by profound neuropsychological symptoms, including irrational behavior, delirium, confusion, seizures, and coma. Severe liver, kidney, and muscle damage may also occur.

Personnel who experience EHI or heat stroke may subsequently have permanently reduced heat tolerance.

Additional detailed information is available in Technical Bulletin, Medical (TB MED) 507.

B. Cold Strain Health Effects. The normal responses to cold stress are (1) shivering, and (2) vasoconstriction in peripheral and superficial (skin) blood vessels, especially in the extremities, nose, and ears. Both excessive skin cooling and core cooling can result in cold injury. During cold exposures longer than an hour’s duration, skin cooling and reduced blood flow to the hands and feet can lead to blunted sensations of touch and pain, as well as loss of dexterity and agility. Dehydration is a response to cold-induced diuresis and/or inadequate fluid intake or nutrition. Pathological states, or cold-induced injuries and illnesses, include nonfreezing cold injuries associated with wet skin (e.g., chilblains (pernio), trench foot, and immersion foot), freezing cold injuries (e.g., frostnip and frostbite), and hypothermia (defined as reduction in core body temperatures to less than 95 °F). Hypothermia may occur in freezing or in nonfreezing conditions. Personal discomfort increases as T_a drops below 10 °F, even when proper cold weather clothing is worn. The performance decrement increases in temperatures below 0 °F.

Additional detailed information is available in TB MED 508.

C. Exposure Factors. The relationship between thermal stress exposure and thermoregulatory responses, heat balance, and the risk of injury is affected by multiple factors. Many of the following factors apply to both heat and cold stress; those that apply to only one or the other are noted as such.

(1) ***Mission factors*** impact both heat and cold strain risk. Regarding heat stress, the Army Combat Uniform (ACU) reduces air flow and evaporative cooling. The addition of body armor or load-bearing equipment further blocks evaporative heat loss and also adds weight which increases the physical load. Impermeable or semi-permeable

protective clothing can severely impede the ability of heat loss mechanisms to balance heat production. The physical work intensity and the duration of the mission directly affect metabolic heat production, thus escalating the heat loss requirements. Conversely, arctic clothing provides insulation and reduces the risk of cold injury. Mission factors include, but are not limited to, the following:

- Frequency and duration of the mission
- Type of clothing worn and equipment used
- Metabolic rate and type of physical work

(2) ***Environmental factors*** are typically tested for the worst-case scenario because most weapon systems are required to operate in a wide variety of environmental conditions. Environmental factors include, but are not limited to, the following:

- Humidity
- Ambient air temperature
- Wind speed
- Terrain (e.g., snow consistency and depth, sand)
- Exposure to moisture (cold stress only)
- Water temperature, if immersion is a possibility (cold stress only)
- Radiant/solar load (heat stress only)

(3) ***Physiological and biomedical factors*** (e.g., medication, health, fatigue, and acclimatization) affect the risk of injury; however, individual factors are not necessarily representative of the population and are difficult to apply to HHAs. For purposes of an HHA, Army populations are considered acclimatized and relatively young and healthy. Installation and unit commanders should monitor individual physiological and biomedical factors of system users post-fielding. Refer to TB MED 507 and TB MED 508 for more information.

9–5. Pre-assessment Procedures

A. Hazard Identification. First, identify the possibility of heat and/or cold stress exposure based on a qualitative exposure assessment of the system’s normal use and operation (e.g., potential operation in desert and/or below-freezing environments, use of clothing systems). The heat loads associated with personnel and operating equipment (e.g., engines, computers) must also be considered. Reports of discomfort and performance ineffectiveness due to high or low temperature conditions may also indicate heat and cold stress potential, respectively.

Most commonly, systems that enclose Soldiers in vehicles or shelters are the source of the temperature extreme risk assessment in an HHA. However, some systems may have unique design considerations that affect the risk of heat and cold stress. For example, use of a “fly” on a chemical, biological, radiological, and nuclear shelter tent limits air circulation through the shelter's chemical/biological filter, and the impermeable shelter material otherwise seals occupants inside.

B. Test Data or Calculations. Although core body temperature data provide the ideal means of assessing heat and cold strain, collecting such data is not practical for the Army testing community. As a substitute, cooling loads of vehicles and shelters are measured to determine if their respective systems are maintaining a safe environment. For information regarding thermal stress associated with clothing and equipment, refer to section 9−5D.

(1) ***Vehicles.*** The U.S. Army Test and Evaluation Command (ATEC) uses Test Operations Procedures (TOPs) for vehicles. Data from tactical vehicles are collected in climatic test chambers in accordance with TOP 02−2−820. Thermocouples are placed inside vehicles at Soldiers' head, hand, and foot positions and at vents to measure T_{db}. For heat stress tests, T_{wb} and RH are also measured at a single point. With all its doors and hatches open, the vehicle is soaked at a chamber T_a of 120 °F until at least 2 hours after the T_{db} levels stabilize. Then, the doors and hatches are closed, and the vehicle is subjected to 1120 Watts per square meter (W/m^2) of radiant heat from directly above for at least 1 hour. The air conditioning system is run for 1 hour with T_a and the radiant heat load held steady. For cold stress tests, the vehicle is soaked until stabilized, and T_{db} readings are collected using the same method as heat stress while the heater is run for at least 1 hour. Internal heat gains from personnel and equipment are not required to be simulated, although doing so would be desirable.

Data for heat stress in truck cabs are collected in accordance with TOP 01−2−807. The tests are carried out in ambient hot weather at a minimum T_a of 85 °F and a minimum outdoor RH of 55%, rather than in a climatic chamber. T_{db} readings are collected according to TOP 02−2−820, and WBGT and T_g are collected at one central location in the cab.

If solar radiation is not simulated during a climatic chamber heat stress test, the *Textbook of Military Medicine: Medical Aspects of Harsh Environments, Volume 1* recommends adding a factor of 13 °F to the measured T_{db} to compensate.

(2) ***Shelters.*** Cooling loads in shelters are significantly different from those in vehicles, the more so as insulation levels in the shelter envelope increase. The heat gains from solar radiation and T_a on the exterior surfaces transmit to the interior surfaces over time, and some of the heat is stored in the shelter heat envelope and released later. The peak loads are delayed and attenuated by the total load over time.

Proper evaluation of the cooling load requires a 24-hour analysis using the hourly T_a from the most extreme daily climatic cycle specified in AR 70−38. Solar factors vary according to latitude. The latitude that represents the worst-case solar factors for the defined daily climatic cycle should be selected using the maps in AR 70−38. The American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) has identified several methods to perform this analysis in its quadrennial *Fundamentals*

Handbook. The course notes for “Cooling Load Calculations and Principles” provide useful simple explanations of these methods. Consult the mechanical engineers in the U.S. Army Public Health Center (APHC) Industrial Hygiene Field Services Division for more details regarding these methods, if necessary, and for the evaluation of any calculations submitted for the HHA.

If output from a commercial calculation program is provided in lieu of test data, it should identify the inputted data, the calculation method used, and the name of the software package to ensure that it can be adequately reviewed. Calculations and submissions should be in accordance with American National Standards Institute (ANSI)/ASHRAE/Air Conditioning Contractors of America (ACCA) Standard 183−2007 (RA 2017).

By contrast, TOP 2−2−820 calls for 1 hour of testing at the maximum T_a and solar radiation level of the hot-dry cycle after a vehicle is soaked at that T_a and air conditioning systems are started. There is no TOP specific to shelter testing.

C. Use Scenario. The materiel developer should provide an Operational Mode Summary/Mission Profile (OMS/MP) or detailed use scenario including operational environment information that is relevant to extreme thermal exposures. The climate types per AR 70−38, or the temperature range, should be reported. Positions occupied by Soldiers should also be reported, along with expected durations of exposure. An additional exposure consideration is whether operators are required to be in the enclosure during start-up, shut-down, and maintenance periods because required temperatures will not be reached immediately once heating, ventilation, and air conditioning (HVAC) equipment is turned on.

D. Clothing and Individual Equipment. The type(s) of clothing and individual equipment used when operating a system must be identified because they may alter thermal criteria. Heat stress risk associated with new clothing and individual equipment (e.g., mission-oriented protective posture (MOPP)-4 or Level A ensembles, fully encapsulated suits, bomb protective suits, and body armor) is assessed on a case-by-case basis and may require guidance from the U.S. Army Research Institute of Environmental Medicine (USARIEM).

9–6. Risk Assessment Process

A. Heat Stress Temperature Calculations.

(1) ***Estimating Heat Gains.*** An occupant of a vehicle or shelter produces both a sensible heat gain (SHG) and latent heat gain (LHG) that are a function of T_{db}, RH, and MR. In addition to heat gains due to occupants, the average electrical load of interior equipment, and/or heat gains from other sources (e.g., engines, hydraulics) also affect SHG. The SHG and LHG raise T_{db} and T_{nwb}, respectively, thus increasing the WBGT. The influence of LHG is much stronger than that of SHG because of how the WBGT is weighted.

At a given MR, as T_{db} approaches body temperature, the SHG falls toward zero as convection and radiation become increasingly unable to cool the body. The SHG can actually become negative as the body starts to pick up heat from these processes. Meanwhile, the LHG from sweating increases, as it becomes the only remaining means for the body to shed heat.

Refer to Appendix 9B to calculate the SHG and LHG.

(2) ***Estimating Effective Wet Bulb Globe Temperature.*** Use the data received from thermal testing and air exchange testing to estimate WBGT, if feasible. Figure 9−1 provides the process for estimating WBGT. The estimation includes multiple assumptions and estimations, demonstrating why direct measurements for WBGT are preferable to other types of measurements.

WBGT is estimated using the available T_{db} data and approximation of T_{wb}, with the methods for approximating the latter varying according the provided measurements. The T_{db} is adjusted using the SHG and average electrical load. The T_{wb} is adjusted using the LHG. The T_{db} and T_{wb} may be substituted into adjusted indoor WBGT equations, depending on the air velocity. The CAF is then added to the WBGT to calculate $WBGT_{eff}$.

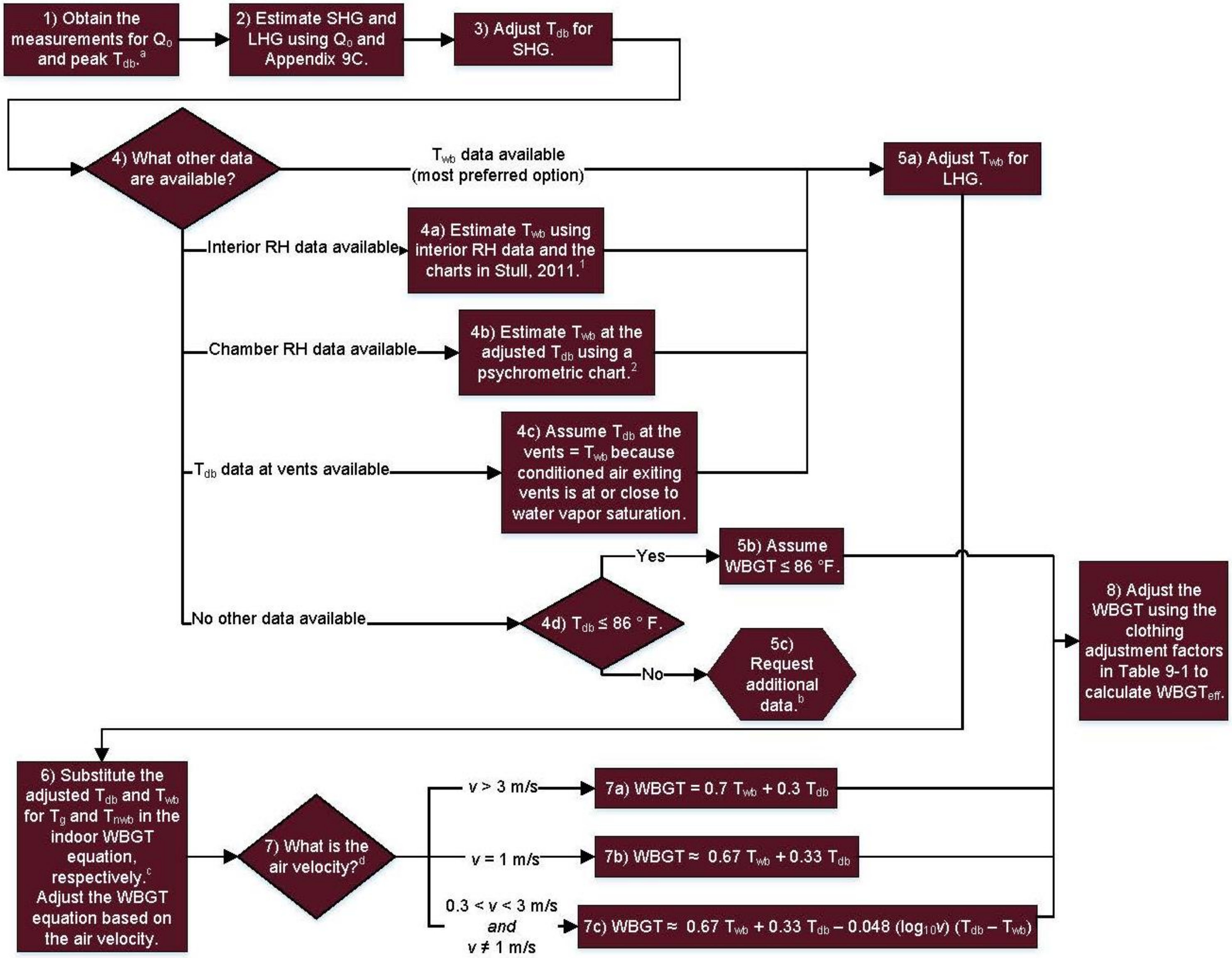


Figure 9−1. Process for Estimating Effective Wet Bulb Globe Temperature

Legend:
LHL = latent head load
m/s = meters per second
Q_o = airflow
RH = relative humidity
SHL = sensible heat load
T_{db} = dry bulb temperature
T_g = globe temperature
T_{nwb} = natural wet bulb temperature
T_{wb} = wet bulb temperature
v = air velocity
WBGT = wet-bulb globe temperature
$WBGT_{eff}$ = effective wet-bulb globe temperature

Notes:

[a] The WBGT is typically estimated from the peak (i.e., worst-case) value. However, data collected over longer periods of time (e.g., 24 hours) is preferred and may allow for calculation of a time-weighted average.

[b] Refer to section 9−6E for more information about requesting additional data to support the health hazard assessment.

[c] Note that T_g captures not only the effect of heat gains from radiation from outer surfaces but also the cooling effect of air movement; these effects tend to offset each other. The assumption is unlikely to be realistic if there is a significant area of windows, such as in a helicopter cockpit or truck cab, or if there is little insulation in outer surfaces.

[d] The *v* is difficult to estimate in a cramped vehicle compartment. One possibility is to divide the ventilation air flow rate by the cross-sectional area of the compartment. Given the usual amount of objects obstructing air flow, this estimate will be conservative.

References:

[1] Stull R. 2011. Wet bulb Temperature from Relative Humidity and Air Temperature. *Journal of Applied Meteorology and Climatology,* 50(11):2267–2269. doi: 10.1175/JAMC-D-11-0143.1.

[2] Psychrometric charts may be found online at varying barometric pressure. For example, The Engineering Toolbox website provides psychrometric charts at standard atmospheric conditions: https://www.engineeringtoolbox.com/psychrometric-chart-d_816.html.

Step 7 of the process in Figure 9−1 provides various calculations for WBGT depending on the air velocity. The equations in steps 7a through 7c are reproduced below as Equations 9−5 through 9−7. For air velocity (*v*) greater than 3 meters per second (m/s), the equation reduces to:

$$WBGT = 0.7\ T_{wb} + 0.3\ T_{db} \qquad \text{(Equation 9–5)}$$

Where:
WBGT = wet bulb globe temperature
T_{wb} = wet bulb temperature
T_{db} = dry bulb temperature

For *v* between 0.3 and 3 m/s, the equation is:

$$WBGT \sim 0.67\ T_{wb} + 0.33\ T_{db} - 0.048\ (log_{10}v)\ (T_{db} - T_{wb})$$

(Equation 9–6)

Where:
WBGT = wet bulb globe temperature
T_{wb} = wet bulb temperature
T_{db} = dry bulb temperature
v = air velocity in meters per second

At a *v* of 1 m/s, the formula reduces to:

$$WBGT \sim 0.67\, T_{wb} + 0.33\, T_{db} \qquad \text{(Equation 9–7)}$$

Where:
WBGT = wet bulb globe temperature
T_{wb} = wet bulb temperature
T_{db} = dry bulb temperature

After estimating the WBGT using steps 1 through 7 in Figure 9−1 above, perform step 8 of the process by identifying the type of clothing worn by operators of the system (e.g., ACU, Level A, B, or C). Calculate the WBGT_{eff} by adding the applicable CAF to the WBGT. Table 9−1 provides corrections for different types of clothing and personal protective equipment (PPE).

Table 9−1. Wet Bulb Globe Temperature Clothing-Adjustment Factors

Type of Clothing	Clothing-Adjustment Factor	Source
Long-sleeve Shirt and Pants	0 °F	ACGIH
Plastic Coveralls over Underwear	0.9 °F	ACGIH
Woven Cloth Coveralls	6.3 °F	NEHC-TM-OEM 6260.6
Double Cloth Coveralls	9.0 °F	NEHC-TM-OEM 6260.6
Turnout Gear or Ground Crew Ensemble	10.0 °F	AFI 48-151
Body Armor (Humid Climates)	5 °F	TB MED 507
MOPP-4 (Easy Work)	10 °F	TB MED 507
MOPP-4 (Moderate or Hard Work)	20 °F	TB MED 507

Legend:
ACGIH = American Conference of Governmental Industrial Hygienists
AFI = Air Force Instruction
°F = degrees Fahrenheit
MOPP = mission-oriented protective posture
NEHC-TM-OEM = Navy Environmental Health Center Technical Manual Occupational and Environmental Medicine
TB MED = Technical Bulletin, Medical

B. Heat Stress Risk Level Determination. To determine the applicable temperature limit, first estimate the MR using Table 9−2.

Table 9−2. Metabolic Work Rates

Work Category	Metabolic Rate (Watts)	Examples
Rest	115	Sitting
Light	180	Sitting, standing, light arm/hand work and occasional walking
Moderate	300	Normal walking, moderate lifting
Heavy	415	Heavy material handling, walking at a fast pace
Very Heavy	520	Pick and shovel work

Source: OSHA 2017

In fighting vehicles, assume a MR of 300 W during weapons firing (moderate work category). For ordinary driving or flying, assume a MR of 180 W (light work category). Estimate a TLV time-weighted average (TLV-TWA) if MRs are known to vary at different known time intervals based on the use scenario; otherwise, assume the TLV is equal to the TLV-TWA. Use Table 9−3 and the MR to determine the applicable TLV.

Table 9−3. Wet Bulb Globe Temperature Threshold Limit Values for Heat Stress Exposure

% Work	Workload			
	Light (180 W)	Moderate (300 W)	Heavy (415 W)	Very Heavy (520 W)
75 to 100% (Continuous)	87.8 °F	82.4 °F	N/A*	N/A*
50 to 75%	87.8 °F	84.2 °F	81.5 °F	N/A*
25 to 50%	89.6 °F	86 °F	84.2 °F	82.4 °F
0 to 25%	90.5 °F	88.7 °F	86.9 °F	86 °F

Source: OSHA 2017
Legend:
°F = degrees Fahrenheit
N/A = not applicable. Criteria not provided because of the extreme physical strain. Detailed job hazard analyses and physiological monitoring should be used for these cases rather than these screening criteria.
W = watts

When the applicable TLV is higher (i.e., less stringent) than the MIL−STD−1472H requirement of 86 °F (e.g., MR category for light work, 0 to 25% work), the MIL−STD−1472H limit applies. This means that 86 °F is the highest possible WBGT threshold for heat stress. Use Table 9–4 to determine the initial and residual risk levels associated with the $WBGT_{eff}$ and applicable temperature limit.

Table 9−4. Heat Stress Risk Level Determination Based on the Effective Wet Bulb Globe Temperature

Exposure Status	Hazard Severity (HS)	Hazard Probability (HP)	Risk Level
Unmitigated	WBGT_{eff} >> TLV[1] **HS 1**	**HP B**	High
	WBGT_{eff} > TLV **HS 2**	WBGT_{eff} > TLV-TWA **HP B**	High
		WBGT_{eff} < TLV-TWA **HP C**	Serious
	WBGT_{eff} < TLV **n/a**	**n/a**	None Assigned
Mitigated (via Engineering Control, i.e., Adequate ECU)	WBGT_{eff} > TLV **HS 3**	WBGT_{eff} < TLV-TWA **HP C**	Medium
	WBGT_{eff} < TLV Same as Unmitigated	**HP F**	Eliminated[2]
Mitigated (via Admin Control)	Same as Unmitigated	*Likely* WBGT_{eff} < TLV-TWA **HP C**	Per MIL−STD−882E
		Definitely WBGT_{eff} < TLV-TWA **HP E**	

Legend:
ECU = environmental control unit
n/a = not applicable
TLV = Threshold Limit Value
TWA = 8-hour time-weighted average

Note:

[1] The TLV is the American Conference of Governmental Industrial Hygienists TLV. Where the TLV is less stringent (i.e., higher) than the Military Standard 1472H requirement (WBGT of 86 °F), the MIL−STD−1472H limit applies.

[2] This assumes that an ECU has been shown to maintain the temperatures below the appropriate TLV. If the ECU's performance falls short of this, the RAC would be based on the unmitigated risk level; however, while the risk may not be totally eliminated, some degree of cooling by the ECU will lessen the risk.

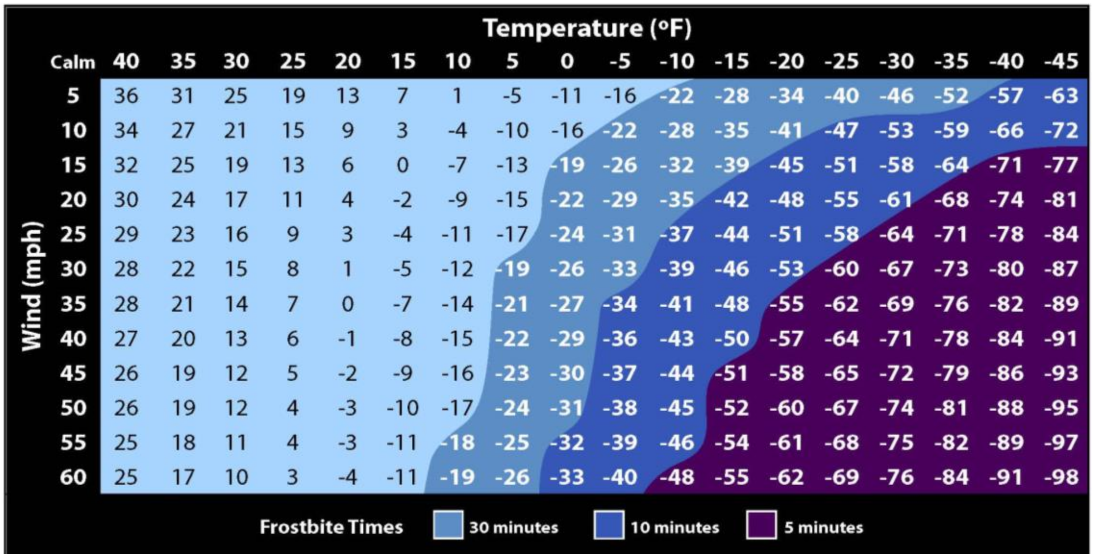
When the WBGT_{eff} exceeds the TLV, the hazard severity (HS) is either 1 or 2 depending on the degree of the overexposure. It is not possible to draw a hard line between the two severity categories. In general, an HS of 1 should be reserved for situations where Soldiers may be overexposed for long periods under uncompensated heat stress, especially while wearing MOPP-4 or other clothing that inhibits the evaporation of sweat. During a long mission in a vehicle, there will be no opportunity for recovery, leaving the possibility of progressively serious heat injury.

As an extreme example, the OMS/MP for a vehicle states that the occupants must be able to maintain silent watch for up to 12 hours while dressed in MOPP-4. The enginepowered cooling system cannot be operated. This warrants an HS of 1 because the degree of uncompensated heat stress in hot climates is likely to be lethal.

Systems using a sufficient microclimate cooling system (MCS) that directs chilled air or liquid to individual Soldiers' vests are not assigned a heat stress risk level. MCSs are considered effective in alleviating heat stress for Soldiers exposed to uncompensated heat stress conditions, such as while in armored vehicles and in MOPP-4. They are not typically suitable for dismounted Soldiers working at high metabolic rates. Refer to TB MED 507 for more information.

Assessors may encounter special circumstances, uncertainties, or lack of data for some systems. Applying professional judgment based on the known information may be necessary to estimate temperature and risk levels. Risk assessment codes may vary conservatively from Table 9−4 if adequately justified by a subject matter expert. The justification should include a rationale for why the table was not followed.

C. Cold Stress Temperature Calculations. Evaluate the temperature measurements provided. Typically, the data are provided as T_{db} inside a vehicle or enclosure at the head, hand, and foot locations at crew positions. These T_{db} values are directly comparable to the MIL−STD−1472H requirements of 68 °F for shelters and 50 °F for shelters. If applicable, ensure the equivalent wind chill temperature is factored into the measurement (Figure 9–2). (Note: TB MED 508 provides the same wind chill adjustments.)



	Temperature (°F)																	
Wind (mph) Calm	40	35	30	25	20	15	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45
5	36	31	25	19	13	7	1	-5	-11	-16	-22	-28	-34	-40	-46	-52	-57	-63
10	34	27	21	15	9	3	-4	-10	-16	-22	-28	-35	-41	-47	-53	-59	-66	-72
15	32	25	19	13	6	0	-7	-13	-19	-26	-32	-39	-45	-51	-58	-64	-71	-77
20	30	24	17	11	4	-2	-9	-15	-22	-29	-35	-42	-48	-55	-61	-68	-74	-81
25	29	23	16	9	3	-4	-11	-17	-24	-31	-37	-44	-51	-58	-64	-71	-78	-84
30	28	22	15	8	1	-5	-12	-19	-26	-33	-39	-46	-53	-60	-67	-73	-80	-87
35	28	21	14	7	0	-7	-14	-21	-27	-34	-41	-48	-55	-62	-69	-76	-82	-89
40	27	20	13	6	-1	-8	-15	-22	-29	-36	-43	-50	-57	-64	-71	-78	-84	-91
45	26	19	12	5	-2	-9	-16	-23	-30	-37	-44	-51	-58	-65	-72	-79	-86	-93
50	26	19	12	4	-3	-10	-17	-24	-31	-38	-45	-52	-60	-67	-74	-81	-88	-95
55	25	18	11	4	-3	-11	-18	-25	-32	-39	-46	-54	-61	-68	-75	-82	-89	-97
60	25	17	10	3	-4	-11	-19	-26	-33	-40	-48	-55	-62	-69	-76	-84	-91	-98

Frostbite Times ▨ 30 minutes ▨ 10 minutes ▨ 5 minutes

Figure 9–2. Wind Chill Temperature Adjustment
Source: National Weather Service

For shelters, if output from a commercial calculation program is provided in lieu of test data, the provided information should identify the inputted data, the calculation method used, and the name of the software package to ensure that it can be adequately reviewed. Calculations and submissions should be in accordance with ANSI/ASHRAE/ACCA Standard 183−2007 (RA 2017).

D. Cold Stress Risk Level Determination. If the temperature remains above the MIL−STD−1472H requirements of 68 °F for vehicles and 50 °F for shelters, no risk level is assigned. For temperatures below these limits, use Tables 9–5 and 9–6 to determine the initial and residual risk levels for vehicles and shelters, respectively. Determine the HS based on the T_{db} of the provided data. Determine the hazard probability (HP) based on the type and adequacy of controls used to mitigate the risk. Partial mitigation includes administrative controls and PPE (e.g., limiting exposure time, requiring arctic clothing at temperatures less than 41 °F). Partial mitigation may also include engineering controls that are unable to raise temperatures consistently above the appropriate MIL−STD−1472H requirement. Risks that are fully mitigated are managed with engineering controls (e.g., HVAC systems) that keep temperatures above the appropriate MIL−STD−1472H requirement.

Table 9–5. Cold Stress Risk Level Determination for Vehicles

Temperature (T_{db})	Hazard Severity (HS)	Hazard Probability (HP)	Risk Level
≤ 32 °F	**HS 2**	Inadequate Controls **HP C**	Serious
		Partially Mitigated **HP D**	Medium
> 32 °F to < 41 °F	**HS 3**	Inadequate Controls **HP C**	Medium
		Partially Mitigated **HP D**	Medium
41 °F to < 68 °F	**HS 4**	**HP E**	Low
≥ 68 °F	**n/a** (or same as initial for residual risk)	**n/a** (or HP F for residual risk)	None

Legend:
°F = degrees Fahrenheit
T_{db} = dry bulb temperature

Table 9–6. Cold Stress Risk Level Determination for Shelters

Temperature (T_{db})	Hazard Severity (HS)	Hazard Probability (HP)	Risk Level
≤ 32 °F	**HS 2**	Inadequate Controls **HP C**	Serious
		Partially Mitigated **HP D**	Medium
> 32 °F to < 41 °F	**HS 3**	Inadequate Controls **HP C**	Medium
		Partially Mitigated **HP D**	Medium
41 °F to < 50 °F	**HS 4**	**HP E**	Low
≥ 50 °F	**N/A** (or same as initial for residual risk)	**N/A** (or HP F for residual risk)	None

Legend:
°F = degrees Fahrenheit
T_{db} = dry bulb temperature

Tables 9–5 and 9–6 assign risk levels based on the average temperature. Systems not meeting additional MIL−STD−1472H requirements (e.g., temperature uniformity) may be subject to an increase in HP level.

Assessors may encounter special circumstances, uncertainties, or lack of data for some systems. Applying professional judgment based on the known information may be necessary to estimate temperature and risk levels. Risk assessment codes may vary conservatively from Tables 9−5 and 9−6 if adequately justified by a subject matter expert. The justification should include a rationale for why the table was not followed.

E. Risk Mitigation Strategies. Residual risk may remain after the implementation of recommendations and risk mitigation strategies. The heat and cold stress risk determinations described in Tables 9−4 through 9−6 above apply to both initial risk and residual risk. In some cases, additional data may be required to support an HHA. For example, additional heat stress data may be needed if there is insufficient information to estimate the WBGT according to the methods in section 9−6A. A conservative initial risk may be assigned based on the provided data. Residual risk is not assigned until adequate data are provided to the APHC.

According to Department of Defense Instruction 6055.01, there is a preferred hierarchy of effectiveness of controls that should be considered: (1) elimination, (2) substitution, (3) engineering controls, (4) warnings, (5) administrative controls, and (6) PPE. Examples of temperature extreme controls in priority order include the following:

(1) ***Elimination.*** The most desirable hazard control option is to eliminate the temperature extreme exposure by altering operational requirements. However, this is not feasible in most scenarios where exposure to varying environmental conditions is required to complete the mission.

(2) ***Substitution.*** There is no feasible substitute for heat and cold stress.

(3) ***Engineering Controls.*** Cooling may be provided by an air conditioning unit that cools an entire enclosure or by an MCS that directs chilled air or liquid to individual Soldiers' vests. Cooling vests that provide a few hours of relief may be practical when facilities are available to precool them and missions are strictly limited in duration, such as helicopter sorties. The MCSs intended for crew in MOPP-4 also provide air to the protective masks. Heating may be provided by vehicle engine waste heat, an environmental control unit (ECU) with a heating coil, or a fuel-fired heater.

(4) ***Warnings.*** Systems may be equipped with internal thermometers to alert Soldiers when specific temperature conditions are not met.

(5) ***Administrative Controls.*** Work/rest cycles, modified work schedules (to allow recovery time in temperature-controlled quarters), and adequate hydration and nutrition can help to minimize the risks of heat and cold strain injury. The operator manual should describe heat and cold stress countermeasures to be implemented under specific conditions when the ability of the system to manage the temperature is inadequate.

(6) ***PPE.*** Clothing systems designed for cold temperatures rely on the principles of insulation, layering, and ventilation. Besides wearing the appropriate type of clothing, the Soldier must ensure the clothing fits properly and is dry, loose, and non-restrictive to allow air-layering, movement, and unimpeded blood flow to the extremities. Tight, restrictive clothing, equipment, or work spaces may compromise blood flow to the extremities and may not allow air-layering to insulate adequately.

Provisions should be made for removing or adding layers and for removing and drying wet garments. Even ambient temperatures as warm as 10 °C (50 °F) have been associated with nonfreezing cold injury (if clothing restricts circulation and hands or feet become wet). Layers of loose clothing with air spaces between them, under a wind- and water-resistant outer garment, along with insulated boots and gloves (if they remain dry) play key roles in preventing cold injury. Wet clothing insulates poorly and hastens the loss of body heat.

9–7. Example Assessment Scenario

A new tactical vehicle is required to operate in ambient temperatures ranging from −50 to 120 °F and is intended to operate anywhere in the world. These temperatures encompass the hot-dry, hot-humid, and basic cold daily climatic cycles specified in AR 70–38. There is an ECU in the vehicle, but its performance has not been verified.

Temperature and RH data were collected inside the vehicle by ATEC to assess the vehicle and ECU performance during extreme climatic conditions in which the system may be deployed. These data were collected in accordance with TOP 02−2−820. The exposure scenario and results from the tests indicate that personnel inside the vehicles may be adversely exposed to potentially hazardous climatic conditions. The occupancy inside the tactical vehicle is four personnel.

A. Heat Stress Assessment.

Step 1. Assess the heat stress test data from the hot-dry daily climatic cycle. The ECU's air conditioning system was set to high for the duration of the test. T_{db} measurements were monitored at the crew positions' head, hand, and foot locations, as well as at the air conditioning vents. The average T_{db} at crew positions was 95 °F, with high and low temperatures of 105 °F and 90 °F. The average T_{db} at the air conditioning vents was 65 °F. The outside airflow rate (Q_o) was 80 cfm.

Step 2. Use the process diagram in Figure 9−1 to estimate the $WBGT_{eff}$ based on the provided measurements.

Step 2a. Use Equation 9A−1 in Appendix 9B to estimate the SHG produced by occupants. Soldiers would likely be in a moderate work category inside the tactical vehicle. Assume a MR of 300 W (moderate work). Be sure to convert the average T_{db} of 95 °F to 35 °C for use in the equation.

$$\begin{aligned} SHG = {} & 6.461927 + (0.946892 \times 300\,W) + (0.0000255737 \times (300\,W)^2) \\ & + (7.139322 \times 35\,℃) - (0.0627909 \times 35\,℃ \times 300\,W) \\ & + (0.0000589172 \times 35\,℃ \times (300\,W)^2) - (0.198550 \times (35\,℃)^2) \\ & + (0.000940018 \times (35\,℃)^2 \times (300\,W)^2) = 6\,W = 22\,btu/hr \end{aligned}$$

Where:
SHG = sensible heat gain in British Thermal Units per hour (btu/hr)

Step 2b. Following Equation 9A−2, use the SHG, due to occupants and the electrical load, to calculate the additive effect of SHG on T_{db}. Assume an electrical load of 0.5 kilowatts (kW) in the tactical vehicle.

$$\Delta T_{db} = \frac{\left(22\frac{btu}{hr} \times\ 4\,occupants\right) + (0.5\,kW\ \times\ 3413)}{1.08\ \times 80\,cfm} = 20.8\,°F$$

Where:
ΔT_{db} = change in dry bulb temperature

Add the change in T_{db} (20.8 °F) to the average T_{db} (95 °F), so the adjusted T_{db} is 115.8 °F.

Step 2c. Because T_{db} measurements at both the crew positions and air conditioning vents were collected, use step 4c in the process diagram in Figure 9−1. Assume T_{db} at the vents is equal to T_{wb} because conditioned air exiting the vents is at or close to water vapor saturation. Assume the T_{wb} is equal to 65 °F.

Step 2d. Use Appendix 9B to calculate the LHG and adjust the T_{wb}. Assume a sweating rate (Q_s) of 0.018 liters per minute (L/min) for this example. Use Equation 9A−3 to calculate the respiratory vapor release rate (Q_r). The minute respiratory volume of oxygen (V_{O2}) in liters per minute (L/min) is approximately equal to the MR divided by 170, or 1.76 L/min for this example. The vapor pressure of water (P_w) can be read from a psychrometric chart. Assume a P_w of 33.43 mm Hg for this example.

$$Q_r = 0.019 \times 1.76\frac{L}{min} \times (44 - 33.43\, mmHg) \times \frac{1}{1000} = 0.00035\frac{L}{min}$$

Where:
Q_r = respiratory vapor release rate

Step 2e. Use the Q_s and Q_r from Step 2d and Equation 9A−4 to calculate the total moisture release per occupant.

$$ER = Q_s + Q_r = (0.018 + \ 0.00035)\frac{L}{min} = 0.01835\ \frac{L}{min} = 0.039\ \frac{pints}{min}$$

Where:
Q_s = sweating rate
Q_r = respiratory vapor release rate

Step 2f. Calculate the change in the humidity ratio caused by the LHG using Equation 9A−7.

$$\Delta HR = \frac{1601\ \times 0.039\ \frac{pints}{min}\ \times\ 4\, occupants}{80\, cfm} = 3.1\, grains\ per\ pound\ of\ dry\ air$$

Where:
ΔHR = change in humidity ratio

To estimate the change in T_{wb} due to the LHG, use a psychrometric chart to determine the humidity ratio (HR) associated with the adjusted T_{db} of 115.8 °F and the assumed T_{wb} of 65 °F. Using the chart, the HR is equal to approximately 15 grains per pound of dry air.

Add the change in HR (3.1 grains per pound of dry air) to the ambient HR (15 grains per pound of dry air) and read the interior T_{wb} using the revised HR, which equals about 66 °F. The adjusted T_{wb} is 66 °F.

Step 2g. For this example, assume the air velocity is greater than 3 m/s and use Equation 9−5 to calculate the WBGT inside the vehicle. The adjusted T_{wb} is 73.5 °F (from step 2f) and the adjusted T_{db} is 103.3 °F (from step 2b).

$$WBGT = 0.7\,T_{wb} + 0.3\,T_{db} = (0.7 \times\ 66\,°\mathrm{F}) + (0.3 \times 115.8\,°\mathrm{F}) = 80.9\,°\mathrm{F}$$

Where:
$WBGT$ = wet bulb globe temperature
T_{wb} = wet bulb temperature
T_{db} = dry bulb temperature

Step 2h. According to the use scenario, Soldiers typically wear ACUs and body armor while in the vehicle. Using Table 9−1, add a CAF to the WBGT for the body armor (5 °F), so the $WBGT_{eff}$ is equal to 85.9 °F.

Step 3. Use Table 9−3 to determine that the TLV at moderate work and the most conservative work/rest cycle (75 to 100%) is equal to 82.4 °F. This TLV is more stringent than the MIL−STD−1472H limit of 86 °F, so the TLV applies.

Step 4. The $WBGT_{eff}$ (85.9 °F from step 2h) is above the TLV (82.4 °F from step 3). Using Table 9–2, assign an HS of 2 (Critical).

Step 5. Soldiers may spend greater than 8 hours in the vehicle per day. Using Table 9–2, assign an HP of B (Probable).

Step 6. Based on the HS and HP determined in Steps 6 and 7, assign an initial risk level to the tactical vehicle of High (RAC: HS 2, HP B).

Step 7. To reduce the risk level, recommend mitigation strategies. The most preferred mitigation would be to replace the ECU with one capable of meeting the MIL−STD−1472H requirement. Replacement of the ECU would require collection of additional data and an update to the HHA report. If the new heat stress data is shown to meet the MIL−STD−1472H requirements, the risk is eliminated (RAC: HS 2, HP F).

B. Cold Stress Assessment.

Step 1. Assess the cold stress test data from the cold climate. The ECU was on for the duration of the test with the heater set to high. The cold stress data were collected at an ambient temperature of −24 °F during five trials at the head, hand, and foot locations of each crew position. The average crew position T_{db} of 63 °F was reached within 49 minutes of running the heater.

Step 2. Consider the test data and setup compared to the expected use scenario of the tactical vehicle. The ambient temperature of −24 °F was well above the expected lowest operational temperature for the vehicle (−50 °F). Because the ambient temperature of the operational environment is 26 °F colder than the test environment, the average T_{db}

is also expected to be 26 °F lower, or 37 °F. However, temperatures below −24 °F are uncommon and may cause reductions in mission type and length, so the probability is reduced.

Step 3. Because the occupants are not exposed to wind, do not add a wind chill factor from Figure 9–1 to the T_a.

Step 4. Using Table 9–3, assign an HS 3 based on the lowest T_{db} expected inside the vehicle with the heater running (37 °F).

Step 5. Using Table 9–3, assign an HP C for the initial risk because the ECU cannot maintain the required temperature, and there are no other controls in place.

Step 6. Based on the HS and HP determined in Steps 4 and 5, assign an initial risk level to the tactical vehicle of Medium (RAC: HS 3, HP C).

Step 7. To reduce the risk level, recommend mitigation strategies. The most preferred mitigation would be to replace the ECU with one capable of meeting MIL−STD−1472H requirements (i.e., temperatures greater than or equal to 68 °F). This design change would require the collection of additional data and an update to the HHA report. If the new cold stress data is shown to meet the MIL−STD−1472H requirements, the risk is Eliminated (RAC: HS 3, HP F).

Step 8. If the ECU design change is not feasible, recommend that arctic clothing be worn during extreme climate conditions, and implement warnings. Using Table 9–3, assign a residual risk level for implementing these recommendations of Medium (RAC: HS 3, HP D). Note that although the lowest T_{db} expected (37 °F) is below the criterion for arctic clothing (41 °F), the probability of being exposed to environmental temperatures below the ambient test temperature of −24 °F is low. Ambient temperatures above −46 °F would likely result in the T_{db} meeting the criterion for arctic clothing.

9–8. Limitations and Potential Future Work

(1) Information provided by the Army testing community typically requires multiple assumptions and estimations to compare test data to thermal stress index requirements. Current assumptions may include adjusting for an assumed solar radiation heat gain, estimating WBGT from single temperature measurements, and estimating peak loads associated with insulated shelters. Ideally, WBGT measurements would be provided to more accurately determine the risk associated with thermal stress. Data collected over longer durations may also allow for time-weighted average calculations rather than basing risk on worst-case, peak values. Additionally, shelter system risk assessment may be improved with the development of a TOP specific to those types of systems.

(2) Potential future work includes developing and validating a core body temperature model and an associated risk assessment methodology. Previous work to support this development was produced by the USARIEM. Its Heat Strain Decision Aid predicts thermal stress for specific training and operational scenarios based on predicted body temperature and physiological, environmental, and mission factors. Clothing and individual equipment evaluations may also benefit from comprehensive evaluations of environmental and metabolic stressors and biophysical measurements. Capability gaps remain due to testing limitations.

APPENDIX 9A

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APPENDIX 9B

SENSIBLE AND LATENT HEAT GAIN CALCULATIONS

This appendix provides calculations for estimating the sensible heat gain (SHG) and latent heat gain (LHG) as a continuation of section 9−6A(1) of this chapter. These calculations use psychrometric charts. A psychrometric chart for standard atmospheric conditions may be found at:
https://www.engineeringtoolbox.com/psychrometric-chart-d_816.html

A. Sensible Heat Gain. Use a spreadsheet to calculate sensible heat gain (SHG). In the spreadsheet, estimate the SHG produced by occupants as a function of dry bulb temperature (T_{db}) and metabolic rate (MR) using the following equation (Big Ladder Software):

$$\begin{aligned} SHG = 6.461927 + (0.946892 \times MR) + (0.0000255737 \times MR^2) + (7.139322 \times T_{db}) \\ - (0.0627909 \times T_{db} \times MR) + (0.0000589172 \times T_{db} \times MR^2) \\ - (0.198550 \times T_{db}^2) + (0.000940018 \times T_{db}^2 \times MR^2) \end{aligned}$$

(Equation 9A−1)

Where:
SHG = sensible heat gain in watts
MR = metabolic rate in watts
T_{db} = dry bulb temperature in degrees Celsius (°C)

Convert the SHG from Equation 9A−1 to British Thermal Units per hour (btu/hr) (1 W = 3.413 btu/hr). In addition to the SHG produced by occupants, the electrical load contributes to the SHG and increase in T_{db}.

Calculate the additive effect of SHG on T_{db} as follows:

$$\Delta T_{db} = \frac{(SHG \times n) + (EL \times 3413)}{1.08 \times Q_o}$$

(Equation 9A−2)

Where:
ΔT_{db} = change in dry bulb temperature in degrees Fahrenheit (°F)
SHG = sensible heat gain in btu/hr
EL = mean electrical load in kilowatts (kW) (1 kW = 3413 btu/hr)
n = number of occupants
Q_o = outside airflow rate in cubic feet per minute

Add the result to the initial T_{db} in °F.

B. Latent Heat Gain. Use a spreadsheet to calculate LHG. The main sources of LHG are the sweating rate, Q_s, and the respiratory vapor release rate, Q_r.

There are limited data for Q_s as a function of T_{db} and MR. Use the tables in Gonzalez et al. 2009 and Cheuvront et al. 2007 (see paragraph C) to make a best estimate. (Note: These tables have been converted into a spreadsheet for use in health hazard assessments.)

The Q_r is a function of the humidity level in the air, will decrease as humidity increases, and is equal to:

$$Q_r = 0.019 \times V_{O2} \times (44 - P_w) \times \frac{1}{1000} \qquad \text{(Equation 9A−3)}$$

Where:
Q_r = respiratory vapor release rate in liters per minute (L/min)
V_{O2} = minute respiratory volume of oxygen in liters per minute (approximately equal to metabolic rate divided by 170)
P_w = vapor pressure of water, in millimeters mercury (mm Hg). This value can be read from a psychrometric chart using T_{db} and relative humidity (RH. Note: Most charts give the pressure in inches Hg (1 inch Hg = 25.4 mm Hg).

The total moisture release per occupant is then equal to:

$$ER = Q_s + Q_r \qquad \text{(Equation 9A−4)}$$

Where:
ER = evaporation rate in L/min
Q_s = sweating rate in L/min
Q_r = respiratory vapor release rate in L/min

Convert the evaporation rate (ER) to pints per minute (1 liter = 2.113 pints)

The dilution ventilation formula for evaporating liquids is rearranged to determine the concentration of the water vapor added by the occupants:

$$Q = \frac{403 \times 10^6 \times SG \times ER \times n}{MW \times C} \qquad \text{(Equation 9A−5)}$$

Where:
Q = airflow in cubic feet per minute (in this case, the Q_o)
SG = specific gravity of the liquid (water = 1)
ER = evaporation rate in pints per minute
n = number of occupants
MW = molecular weight (water = 18 grams/mole)
C = concentration in parts per million

Normally, Equation 9A−5 is used to calculate the airflow required to maintain the concentration of a chemical at a certain (safe) level. It can be rearranged to calculate the concentration, as follows:

$$C = \frac{403 \times 10^6 \times SG \times ER \times n}{MW \times Q} \qquad \text{(Equation 9A−6)}$$

Where:
C = concentration in parts per million
SG = specific gravity of the liquid (water = 1)
ER = evaporation rate in pints per minute
n = number of occupants
MW = molecular weight (water = 18 grams/mole)
Q = airflow in cubic feet per minute (in this case, the Q_o)

By plugging in the known variables (SG and MW) and converting units, Equation 9A−6 can be converted to calculate the change in the humidity ratio caused by the LHG:

$$\Delta HR = \frac{1601 \times ER \times n}{Q_o} \qquad \text{(Equation 9A−7)}$$

Where:
HR = humidity ratio in grains per pound of dry air
ER = evaporation rate in pints per minute
n = number of occupants
Q_o = outside airflow in cubic feet per minute

To estimate the change in T_{wb} due to the LHG, use a psychrometric chart to determine the interior humidity ratio (HR) using the known variables (e.g., adjusted T_{db} and assumed T_{wb}).

Add the change in HR calculated in Equation 9A−7 to the interior HR, and read the interior T_{wb} using the revised HR.

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APPENDIX 9C

CHAPTER 9 GLOSSARY

°C
degrees Celsius

°F
degrees Fahrenheit

ACGIH
American Conference of Governmental Industrial Hygienists

ACU
Army Combat Uniform

AL
action limit

APHC
U.S. Army Public Health Center

AR
Army Regulation

ASHRAE
American Society of Heating, Refrigeration, and Air-conditioning Engineers

ATEC
U.S. Army Test and Evaluation Command

btu/hr
British Thermal Units per hour

CAF
clothing-adjustment factor

ECU
environmental control unit

EHI
exertional heat injury

HHA
health hazard assessment

HR
humidity ratio

HS
hazard severity

HVAC
heating, ventilation, and air-conditioning

kW
kilowatt

L/min
liters per minute

LHG
latent heat gain

m/s
meters per second

MCS
microclimate cooling system

MIL−STD
Military Standard

mm Hg
millimeters mercury

MOPP
mission-oriented protective posture

MR
metabolic rate

OMS/MP
Operational Mode Summary/Mission Profile

PPE
personal protective equipment

P_w
vapor pressure of water

Q_o
outside airflow rate

Q_r
respiratory vapor release rate

Q_s
sweating rate

RH
relative humidity

SHG
sensible heat gain

T_a
dry bulb temperature (ambient)

TB MED
Technical Bulletin, Medical

T_{db}
dry bulb temperature

T_g
globe temperature

TLV
Threshold Limit Value

T_{nwb}
natural wet bulb temperature

TOP
Test Operations Procedure

TWA
time-weighted average

T_{wb}
wet bulb temperature

USARIEM
U.S. Army Research Institute of Environmental Medicine

V_{O2}
minute respiratory volume of oxygen

W
watts

W/m^2
watts per square meter

WBGT
wet bulb globe temperature

$WBGT_{eff}$
effective wet bulb globe temperature

WCT
wind chill temperature index