

## PREFACE

In 1999, the U.S. Army Aeromedical Research Laboratory (USAARL), Fort Rucker, Alabama, published a book that addresses issues for the design of helmet-mounted displays (HMDs) for use in helicopters, *Helmet-Mounted Displays: Design Issues for Rotary-Wing Aircraft* (USAARL, 1999).<sup>1</sup> While primarily an engineering overview of image sources, image quality, optical design approaches, communication systems, hearing protection, and helmet head-supported mass and center-of-mass, the book also addresses such human factors issues as visual and auditory performance, head and face anthropometry, and hearing and vision protection.

In the years since the 1999 book was conceived, HMD applications have greatly expanded, not only within the military but also within the manufacturing and simulation training communities. Significant progress has been made in the development of image source technologies, especially miniature displays. This continuing image source development, coupled with advances in power source engineering - smaller size and greater efficiency, has greatly expanded the number of HMD applications. Within the U.S. Army, HMDs are being designed for use by dismounted and mounted Warfighters as well as for aviators.

As advanced technology penetrates the battlespace, the modern Warfighter is being provided with an ever-increasing stream of information. The motivation of this growing flow of information is the Army's objective to "See First, Understand First, Act First, & Finish Decisively." Whether it is a field commander or a lower echelon soldier, every Warfighter will have greater access to both tactical and strategic data and imagery. The vast majority of this information will be presented to the Warfighter in visual and auditory forms via HMDs. For this reason, the design and implementation of HMDs must be optimized to ensure optimal user performance, both visual and auditory.

Paramount in achieving this optimization is attaining a thorough understanding of the relationship between HMDs and the human concepts of perception and cognition. An excellent beginning to acquiring this understanding can be found in *Tactical Display for Soldiers-Human Factors Considerations* (National Academy Press, 1997). Presenting the results of the *Panel on Human Factors in the Design of Tactical Displays for the Individual Soldier* (established by the National Research Council at the request of the U.S. Army Natick Research, Development, and Engineering Center, Natick, Massachusetts), this book discusses critical human factors issues associated with the development of the Army's proposed Land Warrior System, an individual Warfighter monocular HMD. The overall goal of the panel was to identify critical characteristics of HMDs and the capabilities and limitations of the target user (i.e., the Warfighter). One major finding of the panel was the presence of "a lack of understanding of the impact of advanced HMD visual and auditory presentations on Warfighter workload, situational awareness and overall performance." This finding is well-known within the HMD community of researchers and often has been expressed as an important issue.

The work presented here is the second in a series of HMD books. Where the first book focused on engineering design issues, this book focuses on filling the National Research Council's identified gap in understanding the relationship between the HMD hardware design and user perception and cognition of the visual and auditory displays.

### Structure of the book

This book is divided into five parts: *Part One – Identifying the Challenges*; *Part Two – Helmet-Mounted Displays*; *Part Three – The Human Visual and Auditory Sensory Systems*; *Part Four – Perception, Cognition and Performance*; and *Part Five – Meeting the HMD Design Challenge*.

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<sup>1</sup> In 2000, SPIE Press, Bellingham, WA, republished this book under the same title.

In *Part One – Identifying the Challenge*, Chapter 1, *The Military Operational Environment*, discusses the diverse operational requirements of the modern Warfighter, to include taking on such diverse roles as combatant, peacekeeper, and disaster relief worker; operating in dissimilar physical environments where heat, cold, fog, rain, smoke, etc., degrade system and human performance; and enduring such performance stressors as fatigue, interruption of circadian rhythm, working under severe time constraints, etc. The chapter also describes the ongoing “transformation” of the U.S. Army and its effect on the individual Warfighter. Chapter 2, *The Human-Machine Interface Challenge*, examines the age-old problem of the human-machine interface, describes the visual tasks encountered by Warfighters in both training and combat; briefly introduces the visual and auditory sensory inputs and the concepts of human perception and cognition; explains the roles of stimuli, sensors and displays in HMDs; discusses future HMD systems and trends; and concludes with a statement of the challenge facing HMD designers in ensuring that newly developed systems optimize user performance by taking into consideration the performance characteristics and limitations of the human brain and visual and auditory senses.

In *Part Two – Helmet-Mounted Displays*, Chapter 3, *Introduction to Helmet-Mounted Displays*, defines an HMD; describes one method of classifying HMDs by optical approach; reviews the history of HMD development; discusses HMD applications; lists the advantages and limitations of HMDs; and provides synopses of current and future HMD programs. Chapter 4, *Visual Helmet-Mounted Displays*, addresses design considerations for *visual* HMDs, to include the importance of image quality, image source technologies, and design parameters (e.g., field-of-view, magnification, exit pupil, etc.). Chapter 5, *Audio Helmet-Mounted Displays*, provides a parallel discussion of *audio* HMD design considerations, to include noise attenuation and communication speech intelligibility.

*Part Three – The Human Visual and Auditory Sensory Systems* - introduces the human sense organs for vision and audition. Chapters 6, *Basic Anatomy and Physiology of the Human Eye*, and 8, *Basic Anatomy of the Hearing System*, review the basic anatomy, structure, and physiology of the human eye and ear, respectively. These chapters are intended to provide the reader with a fundamental understanding of these two critical sensory systems. Chapter 7, *Visual Function*, discusses the vision process, starting with light originating from an object or source and the formation of an image on the retina. This chapter continues with explanations of various visual functions, e.g., color vision, accommodation, the ocular-motor function, etc. In an analogous manner, Chapter 9, *Auditory Function*, discusses the hearing process, starting with the production of sound by stimuli and continues with explanations of theories of hearing, neural coding and the processing of sound in the brain.

Having discussed vision and audition from a sensory perspective, *Part Four – Perception, Cognition and Performance* – addresses the major impetus of this book – perceptual and cognitive issues associated with HMD design. Chapters 10, *Visual Perception and Cognitive Performance*, and 11, *Auditory Perception and Cognitive Performance*, discuss visual and auditory perception and performance, respectively. Visual factors discussed include brightness perception, pattern recognition, motion and depth perception, and 2- vs. 3-dimensional presentations. Auditory factors include loudness and pitch perception, speech recognition, sound localization, and hearing deficits. Chapters 12, *Visual Perceptual Conflicts and Illusions*, and 13, *Auditory Conflicts and Illusions*, describe perceptual conflicts and illusions (visual and auditory, respectively) that Warfighters may encounter and must overcome. Visual conflicts and illusions discussed include static and dynamic illusions, masking, binocular rivalry, spatial disorientation, and special issues such as hyperstereopsis and luning. Auditory conflicts and illusions discussed include masking, spatial hearing, binaural rivalry and the issue of auditory channel capacity. In Chapter 14, *Auditory-Visual Interactions*, the issues of multisensory perception, including synergy, redundancy and synchrony are explored. The cognitive factors of attention, memory and decision making are discussed in Chapter 15, *Cognitive Factors*. This section concludes with an in-depth overview of performance effects in the presence of mechanical, physiological, sensory, and cognitive adverse operational factors in Chapter 16, *Performance Effects Due to Adverse Operational Factors*. Such factors include vibration, fatigue, stress, workload level, and extreme environmental conditions.

The book concludes with *Part Five – Meeting the HMD Design Challenge*. The first chapter, Chapter 17, *Guidelines for HMD Design*, provides summary guidelines and recommendations for creating an optimal design

for an HMD for a defined application based upon the various optical/visual, acoustic/auditory, perceptual/cognitive, and user adjustment topics and concerns discussed in earlier chapters. It discusses tradeoffs in design parameter values and the impact of such tradeoffs on system and user performance. Included in this chapter is a brief, but essential, reminder of other design issues not covered in previous chapters, e.g., the biodynamic issues of head-supported weight and center-of-mass offsets. Chapter 18, *Exploring the Tactile Modality for HMDs*, goes beyond current optical and acoustic HMD designs and explores the potential of adding a haptic modality to HMD designs by introducing tactile information flow and force feedback. The final chapter, Chapter 19, *The Potential of an Interactive HMD*, looks further to the future of HMDs. The concept of the HMD as an interactive system is explored through the implementation of neuro-physiological monitoring technologies, such as electro-cortical, evoked potentials, and ocular-motor measures.

## Limitations of the book

This book is intended to address the issues of HMDs as they pertain to the processes of human sensation, perception and cognition. However, the enormous scope of these subject areas precludes this work from being all-inclusive. The emphasis is placed on the military environment. Nonmilitary HMD applications, especially in the fields of virtual reality and simulation, are not explored to their fullest extent. While the authors liberally draw upon data derived from research supporting such applications, the data are presented in a military context, and even then with greater emphasis on Army applications. This is an unapologetic consequence of the areas of experience and expertise of most of the book's contributors. Fortunately, this does not preclude the information presented here from being useful in tri-service military and nonmilitary applications. While not explicit, much of the technical data is derived from research and development from around the world. Indeed, many nations have contributed and to continue to contribute (and many cases, lead) to the design, production and fielding experience of HMDs.

In addition, the material in Chapter 17 only superficially discusses the equally important biodynamic design issues that remind us that the HMD is not a stand-alone component, but instead is an integrated part of the Warfighter, vehicle or aircraft system.

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