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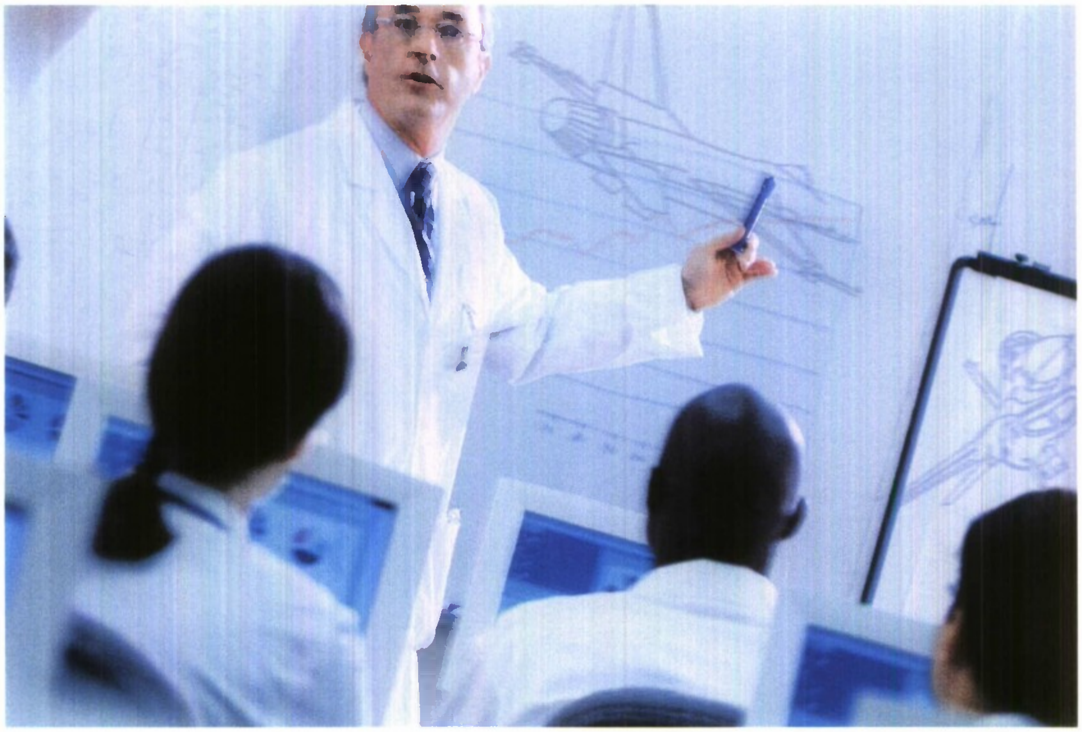
Volume XIV: Number 4 (2004)

Human Systems IAC

GATEWAY

Published by the Human Systems Information Analysis Center



The Science and Simulation of Human Performance

20081009185

MAJ James W. Ness, Ph.D.
Victoria Tepe, Ph.D.
Darren R. Ritzer, Ph.D.

The goal of human performance modeling and simulation is to represent and predict performance as precisely as possible. Over the past decade, new technologies and more flexible programming options have supported fairly dramatic improvements in the behavioral realism, artificial intelligence, and interactivity of synthetic agents who populate simulations designed to train, rehearse, and entertain.

Unfortunately, currently available simulations do a very poor job of representing or predicting the behavior of individuals and small groups. This is a problem of relevance to a variety of performance-related fields, including law enforcement, aviation, emergency management, and the military. In particular, current emphasis on Army and Joint Transformation has focused new attention on the need for tools that can measure and predict the performance of individual combatants and small, autonomous units in "close fight" scenarios (close combat, direct fire, complex terrain). This need can only be met by the advancement of research and development of models and simulations that provide valid representation of human behavior in individual and small group settings.

It has become imperative to conduct research and develop models and simulations toward the prediction of individual and small group physical, physiological, and psychological capabilities.

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http://iac.dtic.mil/hsiac

inside:

The Human Systems IAC is a United States Department of Defense Information Analysis Center administered by the Defense Technical Information Center, Fort Belvoir, Virginia, technically managed by the Air Force Research Laboratory Human Effectiveness Directorate, Wright-Patterson Air Force Base, Ohio, and operated by Booz Allen Hamilton, McLean, Virginia.

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To meet this goal, developers must rely heavily upon data gathered by behavioral and social scientists. There exists a large and growing body of research in the study of human performance, but few such studies employ methods or analyses to account for individual differences that might reasonably be expected to influence human performance. In fact, most behavioral science research is designed specifically to avoid what is generally perceived to be the problematic "noise" of individual variance. Findings that emerge from group-based studies often are not adequate to represent performance variability at the level of the individual.

Sponsored by the U.S. Army Medical and Materiel Command, *The Science and Simulation of Human Performance* has been written and assembled in an effort to bridge the gap between performance research and simulation. Specifically, this edited volume addresses the need to identify, quantify, and represent specific aspects of human performance for use in models and simulations of individual and small group behavior in a variety of operational and combat settings. The goal of this book is to document the state of the art and to imagine the "state of the possible" in human performance research, assessment, and simulation.

We intend this book to serve as a useful reference for those who seek to understand the strengths and weaknesses of currently available datasets, methods, models, and simulations. Each chapter is grounded in rigorous research, with emphasis on its usefulness to the development of simulations that are relevant and applicable to a variety of real-world operations and settings.

As well as responding to the need for finer resolution in human performance simulations, this effort recognizes the need for improved communication among modelers, scientists, and experts in government and military agencies and services. In 1996, the National Research Council established a panel to review the status of human behavior representation in military simulations. In its final report (1), the panel explicitly recognized the need for interdisciplinary teamwork and "intensive collaboration" between behavioral scientists and simulation experts. The challenge of modeling human behavior is made more difficult when scientists and developers fail to understand, appreciate, or support each other's needs and priorities.

A central intent of *The Science and Simulation of Human Performance* is to provide guidance to researchers, analysts, and developers, and to build a bridge of common communication for experts in these communities. To that end, the volume represents a diverse and interdisciplinary team of contributors from within academe, industry, and military science. Project advisors, authors, and editors include recognized researchers and developers from within the fields of behavioral and social science, physiology, human engineering, military medicine, and modeling and simulation. The result is a thorough and credible presentation of knowledge, experience, and perspectives converging upon a specific problem of common interest and relevance. It is hoped that the success of this uniquely collaborative effort will inspire and facilitate additional productive cooperation and interaction among human systems researchers and engineers in relevant professional domains and disciplines.

This special edition of the *Gateway* contains articles written by several of our contributing authors to feature scientific, analytical, and applied themes that are critical to understanding and improving the current state of the art in human performance modeling and simulation.

The Science and Simulation of Human Performance is divided into four sections. The first section of the book provides an introduction to the history and current status of human performance research, training, and assessment. This includes a comprehensive overview of how military scientists train and assess human performance. A second section provides critical theoretical, methodological, and specific disciplinary insights toward the development of standardized operational definitions, methods, and metrics. The objective is to support the gathering of datasets that are informative and useful to modeling and simulation. Specific content areas include human cognition, health and physiology, and social factors. This section concludes with a chapter that integrates these critical aspects of human performance within a single, neurochemical framework.

A third section considers current and available techniques to support the analysis and simulation of human performance data. Chapters in this section provide critical analysis of existing models and offer specific recommendations to improve their relevance and predictive value. This section concludes with a chapter that identifies emergent themes from within the volume as a whole, offer-

continued on page 4...

From Outcome Assessment to Prediction

MAJ James W. Ness, Ph.D.
COL Karl E. Friedl, Ph.D.

The U.S. Army Medical Research and Materiel Command (USAMRMC) often leverages the resources and expertise of the Department of Defense's Human Systems Information and Analysis Center (HSIAC) to evaluate the state of the art in specific and timely areas of medical research and development. HSIAC has unique technical expertise and charter to perform the necessary comprehensive and deliberative review and analysis of all relevant technical reports, published manuscripts, and unpublished records.

In keeping with the current shift from "threat-based" to "capabilities-based" military strategy and emphasis, interest and attention has turned toward the need for analytical tools that can explore the space of performance possibilities of Objective Force (Rumsfeld, 2001) combatants. There is a pressing need for individual human performance research, models, and high-fidelity simulations that can accurately represent and predict human behavior in individual and small unit settings, and thereby be used to sustain and enhance performance in a "capabilities-based" force structure.

In response to this need, the USAMRMC Military Operational Medicine Research Directorate initiated production of a State of the Art Report (SOAR) on "The Science and Simulation of Human Performance." The SOAR explores relevant issues concerning the metrics, methods, and presuppositions of scientific inquiry in all aspects of human performance, with specific focus on individual and small unit performance. Its objective is to bridge the gap between outcome assessment and prediction in military performance literature, and thus to advance the utility and development of individual human performance research, modeling, and simulation.

In the Spring of 2001, the HSIAC under the direction of USAMRMC Military Operational Medicine Directorate convened an advisory panel of senior DoD researchers and strategists. The panel charged the HSIAC to report on the state of the art and to advance the state of the possible by providing direction in the use of research methods, metrics, and paradigms useful and appropriate to model and simulation development. The assertion was that rather than force the universal term "human performance" to accommodate an ever-expanding family of observations that happen to occur under similar paradigms, the researcher should focus instead on the need to refine and define "human performance" in terms of behavioral data upon which specific outcomes (e.g., task completion, mission accomplishment) are contingent. To this end, this SOAR advocates a problem-oriented strategy in which experimental methods and procedures are selected not only to confirm performance aspects and outcomes, but also to reveal fundamental contingencies of performance at the level of the individual. This approach advances the state of the possible through meeting the immediate requirements of the researcher to address an hypothesis, the requirements of the modeler to organize individual research findings into meaningful representations of performance, and the goals of the developer to incorporate models into simulations that reliably predict performance.

We are pleased for the opportunity to partner with the HSIAC on this project. We are grateful to the advisory panel for the course set as timely and essential contribution to performance-related research in the military. Most of all, we are indebted to contributing authors

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for their perspective, dedication, and commitment to advancing the state of the possible in performance-related research in the military. ■

1. Equipped and well-trained in all tasks across the full spectrum of operations, Objective Force soldiers will be versatile and prepared to fight independently in small units (brigade and below). This will require maximum preparation and protection at the individual level (Rumsfeld, 2001; The United States Army, 2001).

...continued from Ness, Tepe, Ritzer article page 2

ing specific conclusions and recommendations for how the current state of the art may be used to shape the state of the possible. A fourth and final section provides key information resources, including a comprehensive overview of human performance research as it is currently conducted in defense laboratories across all branches of the armed services. The book concludes with an overview of currently available human performance models and simulations.

Contributors to this effort hope and anticipate that military and non-military scientists alike will recognize the importance of this effort to the U.S. military and to the scientific community in general. For more information about the book and its content, please visit our project website at http://www.hsiacsoar.com. ■

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Project Advisory Committee

In February 2001, project sponsors and HSIAC team members hosted a meeting with members of the "Methods and Metrics State of the Art Report" project Advisory Committee, whose members offered specific recommendations as to the content of this volume. HSIAC would like to thank the following Advisory Committee members for their helpful recommendations, interest, and guidance to this effort:

- CDR Stephen T. Ahlers, Ph.D., Office of Naval Research
- LTC Paul Bartone, Ph.D., National Defense University
- Kenneth R. Boff, Ph.D., Air Force Research Laboratory
- MG (Ret.) Carl Ernst, Booz Allen Hamilton
- Robert E. Foster, Ph.D., Director, Bio Systems, Director of Defense Research & Engineering (OSD)
- LTC Karl E. Friedl, Ph.D., U.S. Army Research Institute of Environmental Medicine
- COL Robert Fulcher, Chief of Staff 7th Army Training Command
- CAPT Michael Lilienthal, Ph.D., Defense Modeling and Simulation Office
- Joe McDaniel, Ph.D., Air Force Research Laboratory
- MAJ James W. Ness, Ph.D., United States Military Academy
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The Study and Measurement of Human Performance in Military Laboratories

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Since World War I, the U.S. military has been at the forefront of human performance science, operational testing, and application of cutting-edge procedural and technical developments that support human performance under the most demanding conditions. The military has a rich and productive history of scientific and applied accomplishment in personnel selection, training, and human factors engineering. Today, the DoD supports an extensive range of research, testing, and development in human performance as it relates to warfighter health and readiness, performance under stress, and the operational impact of complex weapon systems, advanced technical equipment, and protective clothing and devices. Specific areas of research include the study of physical, perceptual, social and cognitive variables that may influence warfighter readiness and performance in combat (See Table 1 on page 7).

Over the past decade, a large and collaborative network of DoD research laboratories has evolved to provide technical expertise for the military services. These laboratories support the full cycle of discovery and basic research through development, deployment, and ongoing support of complex equipment and systems. Each branch of the military has its own system and unique laboratory structure to develop products in support of its particular service missions, practices, and methods of systems acquisition.

Although the various service branches differ in their systems and procedures, all are able to train and assess human performance in naturalistic settings (see Figure 1 on page 6). Battle laboratories support large-scale battle experiments to investigate new technological advances and determine their potential for rapid deployment in the field. Researchers at these labs also consider and test new applications for existing systems and off-the-shelf equipment. The U.S. Army has eight Training and Doctrine Command (TRADOC) battle laboratories that specialize in different areas of testing. The U.S. Air Force operates seven battle laboratories. The U.S. Marines and Navy operate three battle laboratories. When the Navy and Marine Corps need to perform large-scale battle experiments, they conduct Fleet Battle Experiments (FBEs) at sea.

Military labs are often concerned with human performance as an essential component of complex human-machine interaction (see Figure 2 on page 6). Aircraft, ships, and tanks are obvious examples of large systems whose successful operation depends not only upon machine component function, but also upon the skills, characteristics, and performance of their human operators. Human performance factors such as fatigue, motivation, and situation awareness can have life-or-death consequences for the warfighter who operates complex systems in combat. Performance in combat is made all the more complex by the need to work with team and multi-team systems that require effective coordination and may impose additional levels of uncertainty in planning, communication, and decision making.

The relatively recent development of advanced decision support systems that interpose agent-based "operators" and sophisticated multi-layered, multi-modal information displays provides new opportunities for researchers to study the effects of individual and small team behavior on military mission performance. As simulation-based acquisition becomes standard, and as technology enables more advanced and cost-effective simulation-based

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platforms, there is a rapidly growing emphasis on the need to advance human performance research toward modeling and prediction. Ideally, predictive behavioral models will ultimately and accurately represent individual and small unit capabilities, coordination among units, and mission-level system performance.

As authors contributing to *The Science and Simulation of Human Performance*, researchers from the U.S. Army, Air Force, and Navy have combined their expertise to offer a comprehensive overview of military and government laboratories that conduct human performance research and testing. Authors Elizabeth Redden (U.S. Army Research Laboratory), James Sheehy (Naval Air Warfare Center) and COL Eileen Bjorkman (Aeronautical Systems Center Air Force) present a detailed compendium of military and government laboratories and organizations, identify their respective research missions, and provide resources and contact information to facilitate communication and exchange among scientists and developers who seek additional information or guidance. The authors also provide a thorough overview of individual and small unit performance issues, interests, and metrics as are employed by each laboratory and service branch. Information is summarized in table form to provide a quick reference guide and resource map for investigators, modelers and manufacturers who wish to locate relevant findings and programs within the DoD. ■

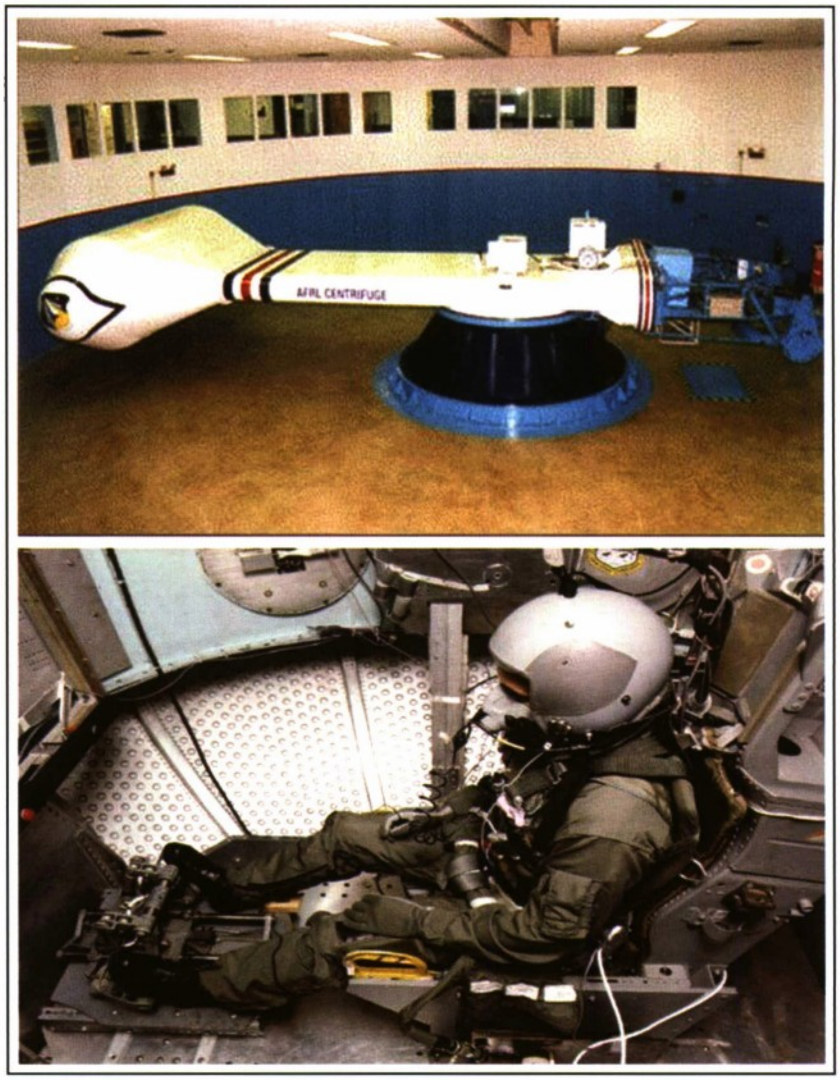

Figure 2. Top: Air Force flight simulator centrifuge at Brooks City-Base, Texas. Bottom: Inside the centrifuge. Researchers monitor a pilot's response to simulated maneuvers.

Figure 1. Left: Soldiers train at the Military Operations in Urban Terrain (MOUT) facility (Fort Benning, Georgia). Right: Soldiers conduct a search for suspected Taliban and weapons compound in the city of Naray, Afghanistan (January 2003).

I. Individual Performance
Perception Metrics
Visual
Target
Detection
Classification
Identification
Indirect viewing
Target recognition
Accurancy of target engagement
Impact of background clutter
Auditory
Aural detectability
Spech intelligibility
Detectability in high noise environment
Haptic or tactile
Detectability in high workload environment
Accuracy—haptic navigation aid
Gross motor skills
Portability of equipment (load carriage)
Individual movement techniques (IMT) with equipment
MOUT maneuverability with equipment (load/config assessment)
Fine motor tasks
Mounting weapon devices (sights, pointers)
Weapon maintanence (disassembly/cleaning/inspection/assembly)
Weapons loading
Piloting aircraft in different phases of flight
Using on-board controllers (cursor control, buttons, etc.)
Target tracking
Tactility and dexterity tests
Skills and Task Performance
Land or air navigation
Number of times off-course
Distance off-course
Time to complete navigation course
Time required to complete navigation course
RMS error
Driving and piloting times and errors
Cross-country course
Cone course
Aviation course
Mounting weapon devices
Weapon maintenance
Skills and Task Performance, cont'd
Accuracy
Static target engagement
Dynamic target engagement
Air-to-surface engagement
Instrument approach performance
Simulator based engagements
Cognitive Performance Metrics
Situation Awareness (SA)
Objective measures
Subjective measures
Stress
Objective measures
Subjective measures
Overload and workload
Objective measures
Subjective measures
Attention and vigilance
Performance Degradation
NBC
Heat
Task overload
High G's
High Noise
Load carriage
Performance Moderators
Measures of fear
Illness and injury
Leadership
Motivation
Fatigue
II. Small Unit or Team Measures
Skills and Task Performance
Team communication
Time for a squad to clear a room
Aircraft formation (flight, element)
Cognitive Performance
Team SA
Team cognitive performance measure
Social Processes
Other team performance measures

Table 1. Summary of Human Performance Metrics

calendar

jan

Reno, NV, USA. January 5–8, 2004
42nd AIAA Aerospace Sciences Meeting and Exhibit
Contact: AIAA, 1801 Alexander Bell Drive, Suite 500, Reston, VA 20191–4344
• Tel: 703/264–7500 or 800/637–AIAA • Fax: 703/264–7551 • E-mail: custserv@aiaa.org
URL: http://www.aiaa.org

mar

Orlando, FL, USA. March 8–11, 2004
7th Annual Applied Ergonomics Conference
Contact: Tom Miller, Institute of Industrial Engineers
• Tel: 770/449–0461, ext. 127 • E-mail: tmiller@iienet.org
URL: http://www.iienet.org

Daytona Beach, FL, USA. March 22–25, 2004
Human Performance Situation Awareness and Automation Technology Conference II
Contact: Dennis A.Vincenzi
• Tel: 386/226–7035 • E-mail: dennis.vincenzi@aero.edu
URL: http://faculty.erau.edu/hpsaa

Alexandria, VA, USA. March 29–April 1, 2004
DTIC Annual Users Meeting and Training Conference
Register online after January 5, 2004
Contact: DTIC's Conference Coordinator
• Tel: 703/767–8236 • E-mail: confinfo@dtic.mil
URL: http://www.dtic.mil/dtic/annualconf/

apr

Chicago, IL, USA. April 2–4, 2004
Society for Industrial and Organizational Psychology Inc.
URL: http://www.siop.org/Conferences/Confer.htm

Tampa, FL, USA. April 20–23, 2004
42nd Annual International Performance Improvement Conference and Expo
Contact: International Society for Performance Improvement
1400 Spring Street, Suite 260, Silver Spring, MD 20910
• Tel: 301/587–8570 • Fax: 301/587–8573
URL: http://www.ispi.org

San Antonio, TX, USA. April 26–29, 2004
ITS America 2004 Annual Meeting
URL: http://www.itsa.org/annualmeeting.html

# of events

may

Atlantic City, NJ, USA. May 10–13, 2004
Department of Defense Human Factors Engineering Technical Advisory Group
Contact: Ms. Sheryl Cosing, 10822 Crippen Vale Court, Reston, VA 20194
• Tel: 703/925–9791 • Fax: 703/925–9694• E-mail: scosing@comcast.net
URL: http://hfetag.dtic.mil/meetschl.html

Boston, MA, USA. May 28–June 1, 2004
Association for Behavioral Analysis 30th Annual Convention
Contact: Association for Behavioral Analysis, 1219 South Park Street, Kalamazoo, MI 49001
• Tel: 269/492–9310 • Fax: 269/492–9316 • E-mail: mail@abainternational.org
URL: http://www.abainternational.org

jun

Rochester, MI, USA. June 15–17, 2004
2004 Digital Human Modeling Conference
Contact: Becky Wiley/SAE
• Tel: 724/772–7116 • E-mail: beckyf@sae.org
URL: http://www.sae.org/congress

sep

New Orleans, LA, USA. September 20–24, 2004
48th Annual Human Factors and Ergonomics Society Meeting
Contact: human Factors and Ergonomics Society, P.O. Box 1369, Santa Monica, CA 90406–1369
• Tel: 310/394–1811 • Fax: 301/394–2410 • E-mail: info@hfes.org
URL: http://www.hfes.org

dec

Orlando, FL, USA. December 6–9, 2004
Interservice/Industry Training, Simulation and Education Conference (I/ITSEC)
URL: http://www.iitsec.org

Statistics and the Art of Model Construction

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Statistical methods contribute to reliable knowledge when they promote principled argument. At its best, the process of model construction is exactly that, supported by theory validation as its ultimate objective. Theories involve claims about causal patterns. The intended endpoint of most behavioral research is to develop a model of causal processes. Reliable knowledge is achieved when there is a consensus that a model encompasses the available evidence and is superior to alternative models.

Constructing and evaluating behavioral science models is a complex process, but can be generally described as a natural progression from exploration to confirmation. Pure exploratory models impose no a priori constraints on either the number of constructs to be included in the model or the values of the parameters linking the model components. Pure confirmatory models specify fixed values for both elements of the model. The maturation of a field of study, therefore, can be seen in terms of the number of constraints that can be imposed while maintaining accuracy in reproducing the data.

Measurement is a prerequisite for tests of substantive theory. Measurement models quantify constructs and so are the first necessary step in pursuing a line of research. Data analysis methods in this phase include factor analysis, multidimensional scaling, latent class analysis, cluster analysis, and taxometrics. Each of these methods uses the pattern of relationships among indicator variables to determine whether the data are consistent with the existence of a hypothesized construct. Recent developments in cluster analysis (Fraley & Raftery, 2002) and taxometrics (Waller & Meehl, 1998) provide the basis for confirmatory categorical measurement models.

Substantive models describe relationships among constructs. These can involve combinations of categorical and continuous variables as hypothesized causal influences on categorical and continuous outcome variables. Useful procedures include common regression methods to more complex structural equation modeling, loglinear analysis, and survival analysis. Recent developments support improved flexibility. For example, linking functions can be used to transform loglinear, survival, and probit analyses into familiar linear regression models (Long, 1997). Hierarchical linear models also make it possible to combine intra-individual, inter-individual, and group levels of theory into a single model (Raudenbush & Bryk, 2003).

The model construction process is naturally vulnerable to preconceptions and assumptions about specific constructs and their relationships. Whenever possible, underlying assumptions should be identified and challenged. Qualitative data analysis and exploratory data analysis can help the investigator to identify patterns in the data that otherwise might simply be subsumed into a single number (e.g., residual sum of squares, chi-square). These methods involve the researcher in an iterative examination of the data to identify areas of fit and misfit between the data and the model under construction. Direct examination of graphic representations of the data is usually a key element of this process.

Once a model has been constructed, it must be appraised. Model appraisal is the critical process of deciding what model parameters should be retained, whether and where new parameters should be added, and whether the model in question is preferable to alternative models. Historically, these decisions have been based primarily on tests for statistical significance. Current trends indicate that greater emphasis should be placed on the importance of explanatory power (effect size). This trend is accompanied by improved methods to identify and compare competing and equivalent models on the basis of parsimony. For example, graph theory provides one framework for the search for alternative models (Scheines, Spirtes, Glymour, Meek, & Richardson, 1998). Recent insights into the problem of how to define equivalent models (Raykov & Penev, 1999) should foster growth in this line of development.

Computer programs are now available to implement all of the most recent advances in data analysis. Wider use of these tools will enable the investigator to more fully appreciate and address the weaknesses of traditional analyses, and will sensitize investigators to the fact that judgment is as important to data analysis as to any other aspect of experimental design and execution. Effective use of newer methods directly supports improved behavioral models by increasing the magnitude of their parameter values and by improving their articulation, generalizability, interest value, and credibility. Abelson (1997) refers to this combination of attributes as MAGIC, and argues that this end is the product of principled argument. Recent advances in statistical methods provide tools to support sharper comparisons and contrasts between alternative models and to incorporate cumulative evidence to forge reliable knowledge. ■

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Toward Realism in the Simulation of Human Performance

A chapter in *The Science and Simulation of Human Performance*:

In an innovative chapter devoted to the science of human performance simulation, Dr. Barry Silverman and his colleagues from the University of Pennsylvania consider challenges to improving the realism of socially intelligent software agents. The authors focus specific attention to the impact of values, emotion, physiology and stress upon individual and group decision making. They assess the current state of the art and argue for the need to make better use of human performance moderator functions (PMFs) currently available in the literature of behavioral science. Asymmetric warfare and civil unrest case studies are presented to highlight issues and concerns that affect PMF implementation. Considered application issues include verification, validation, and interoperability with existing simulators, artificial life emulators, and artificial intelligence components.

The chapter includes an illustrative framework for integrating PMF theories and models of physiology and stress, cognition and emotion, individual differences, and group behavior. As an instructive demonstration, the authors describe a simulation interoperability experiment using original and innovative PMF software to drive the behavior of characters in a popular 3-D video game. The purpose of this experiment was to examine how decisions made by individuals can lead to the emergence of group behavior ("equilibrium tipping"). The result is summarized in video clips that are now available for viewing at http://www.seas.upenn.edu/~barryg/HBMR.html.

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An Integrated Neurochemical Perspective on Warfighter Performance

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The study of warfighter performance offers a unique opportunity to consider human performance in extreme environments and conditions. The urgency, uncertainty, and life-or-death consequences of combat creates very high levels of arousal and stress, physiological pressures ranging from fatigue to hypothermia, and cognitive demands for rapid, parallel processing. Combined, these forces may push the warfighter to the brink of psychological and physiological exhaustion. However, the potentially debilitating effects of physiological and psychological stress can be overcome by certain personality styles and social structures that exert a positive influence on coping, motivation, and unit cohesion.

Although arousal theory may be helpful to account for environmental and other influences that increase arousal (e.g., hypothermia, incentive, noise), complex interactions among stressor and support variables cannot be accounted for simply in terms of arousal. Explanations in terms of arousal are also limited for both definitional reasons (e.g., how can arousal be defined independently of performance) and in terms of generalizability (ability to predict immunocompetence, mood, effects of personality, etc.) (Hockey, 1986).

Hence, it is necessary to seek a more fundamental common denominator for measuring the interactions of various influences on warfighter performance, as with almost all other normal and clinical behavior (Previc, 1999). The value of using a neurochemical model is that the interaction of different influences on various measures of warfighter health and performance can be understood by the roles of four key neurotransmitters in physiology and behavior. Specifically, the interaction of four neurotransmitters—dopamine (DA), norepinephrine (noradrenaline) (NE), acetylcholine (ACh), and serotonin or 5-hydroxytrypamine (5-HT)—appear to be most crucial for understanding behavior. Dopamine and ACh both exert a parasympathetic influence to reduce cardiac output and temperature. Conversely, NE and 5-HT exert a sympathetic influence to elevate cardiac output and temperature during arousal. Norepinephrine and 5-HT are activated during arousal-producing events, but are depleted by fatigue and arousal reduction. They are also elevated as a consequence of social and emotional support, and have mostly inhibitory interactions with dopamine and acetylcholine, which tend to reduce (or at least channel) the arousal response.

In terms of warfighter health and performance, the catecholamines NE and DA and the indoleamine 5-HT all appear to be beneficial, though in different ways. All three neurotransmitters boost immune function, help manage pain and inflammation, and maintain arousal. Norepinephrine may help to improve vigilance, dampen the stress response, and contribute to memory formation during arousal-producing events. Serotonin's action is mainly to increase psychological arousal and, along with norepinephrine, to elevate mood during adaptation to stress. Dopamine maintains active coping and strategic thinking during what is perceived as controllable stress (Anisman & Zacharko, 1986). The "dopaminergic personality" is one that exhibits high achievement motivation and a high internal locus-of-control (perception of control over one's own destiny), but exhibits relatively less empathy and emotional attachment to others (Farde, Gustavsonn, & Jonsson, 1997). Adequate reserves of NE and DA are particularly related to what is termed "toughness" or "hardiness" (Dienstbier, 1989).

Conversely, over-activation of cholinergic systems may actually exert a suppressive effect on active coping, mood, and immune function and is believed to underlie at least some of the constellation of symptoms known as Gulf War Syndrome (Davis, 2000). Cholinergic systems may play a positive role in some cognitive functioning, however.

One can qualitatively predict the net initial effects of major stressors and coping mechanisms on the four major neurotransmitters by the arrow directions shown in Figure 1. For example, motion sickness diminishes the relative influence of NE and compounds the effects of hypothermia and sleep deprivation, both of which also decrease NE in the brain. Conversely, high psychic stress, noise, exercise, and stimulant drugs may temporarily increase NE activity to counter the effects of sleep deprivation, which depletes brain levels of NE. Social support, which boosts both NE and 5-HT, can help to overcome many stressors and improve morale and may explain the continued functioning of some military units even as they face overwhelming stress and probable defeat. It should be noted, however, that the initial effects of a stressor or coping mechanism may differ from its long-term effects; for example, psychosocial stress may temporarily increase both NE and 5-HT, but these same substances may become depleted after a long-term exposure.

Although most neurochemical measures must be made indirectly, it is possible to evaluate the functioning of major neurochemical systems non-invasively. For example, direct measures are available from saliva. It is also possible to assess specific neurochemical systems indirectly by reference to cardiac response, body temperature, voice stress, and various ocular effects (e.g., blink rate, pupillary reflexes, and saccadic velocity). Underlying individual neurochemical predispositions might also be indicated by performance on specific cognitive tasks (e.g., working memory, which critically requires DA), by the non-invasive recording of brain wave activity (e.g., the theta rhythm, which involves both ACh and DA), and by results from personality inventories (e.g., internal locus of control may predict underlying DA reserves. As new and more well-defined links are established to explain and predict human performance as a function of neurochemistry, we can develop more precise models of warfighter health and performance. ■

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Stressor	NE	5-HT	DA	ACh
Motion	↓			↑
Noise	↑			
Psychosocial	↑	↑		
Sleep deprivation	↓	↓	↑	↑
Thermal (hyper)			↑	↑
Thermal (hypo)	↑	↑		
Vibration	↕			

Coping Mechanism	NE	5-HT	DA	ACh
Drug (Depressants)	↓	↓	↓	↑
Drugs (Stimulants)	↑		↑	
Exercise	↑	↑	↑	
Incentives			↑	
Personality (coping)	↑		↑	
Social support	↑	↑	↓	

Figure 1. The temporary effects of various stressors and coping mechanisms on the activity of dopamine, norepinephrine, serotonin, and acetylcholine.

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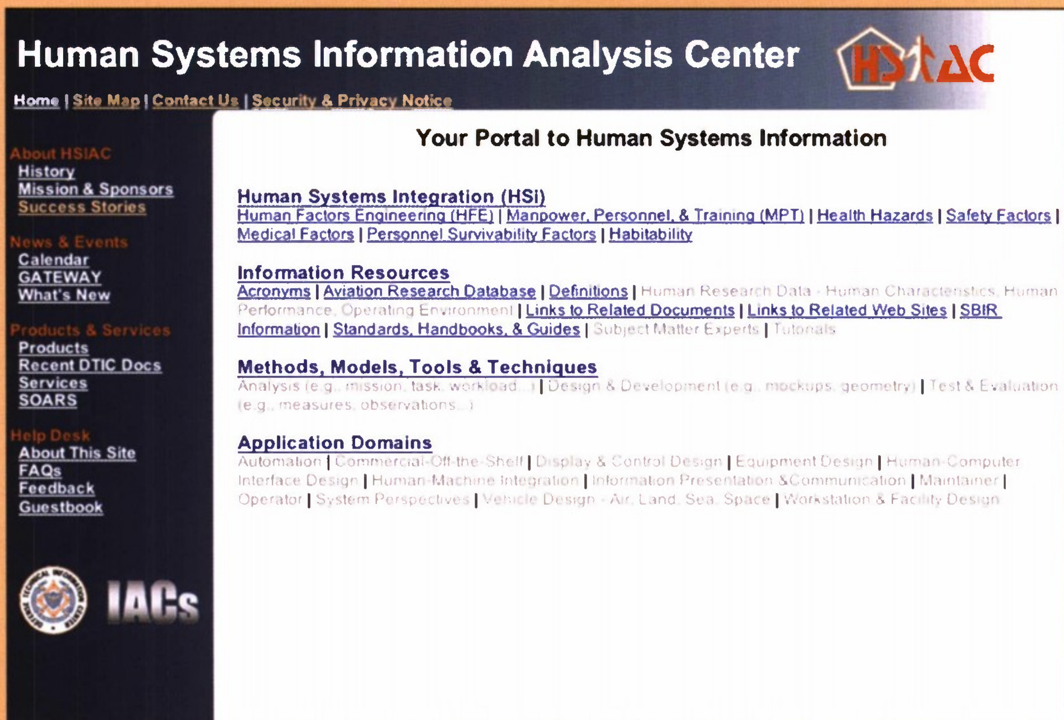

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