Two different concerns have led to an increased interest in developing methods by which commanders can monitor the status of combat service members in the field during military operations. The first is to avoid performance degradation in combat service members and the second is the need to maintain both mental and physical capabilities in highly stressful situations.

The ability to monitor combat member status would allow commanders to determine when individuals need to rest, eat, or consume fluids, and to determine whether their condition has deteriorated to the point that they need to be replaced rather than risk combat injury. Physiology and psychology training for service members thus becomes an important part of their education. Similarly, in the civilian sector, it is necessary to be able to monitor the physiological and cognitive status of individuals involved in situations such as sustained fire-fighting operations, chemical and other hazardous materials clean-ups, and for emergency medical personnel working extended shifts.

This report examines appropriate biological markers, monitoring technologies currently available and in need of development, and appropriate algorithms to interpret the data in order to provide information for command decisions relative to the physiological and psychological "readiness" of each combat service member.

The most promising biomarkers for prediction of performance deterioration are listed below. As noted, some biomarkers are ready to be used in the field whereas others are impractical or still need field validation.

- Overall physical status: Overall physical status can be evaluated by taking physiological objective measurements, such as energy...
expenditure or vital signs, or subjective measurements, such as ratings of perceived exertion. Field-validation, though, is still needed before they are implemented.

- **Bone health:** Bone mineral density is the most predictive measure of risk of fractures but it is a slow process and more valuable in initial training than in the field. There are no groups of intermediate markers of bone health that can provide prediction of risk of fractures. Other markers should include bone density, sensation of bone pain, menstrual status, and mental state as related to cortisol responsiveness. The role of cortisol in bone health during military exercises, however, may be transient and not have long-term effects on bone health.

- **Muscle fatigue:** Protein turnover and urinary 3-methylhistididine may be good objective indicators of muscle fatigue, but there is insufficient evidence to specifically correlate these biomarkers with actual decrements in muscle performance. Subjective measures, although generally less desirable, seem promising but also present limitations and need to be validated in the field.

- **Anaerobic glucose metabolism:** Potential biomarkers are Borg's 6-20 scale of perceived exertion; muscle soreness; tissue levels of lactate measured by near-infrared spectroscopy (NIRS); muscle biopsy for glycogen, cytokines, and enzymes; actigraphy; electroencephalography; heart-rate variability; profile of mood state; and visual analog scale. All these biomarkers need validation before implementation in the field.

- **Hydration status and renal function:** One of the most sensitive indicators of hydration status is short-term changes in body weight and a practical measurement method for use in the field should be developed. The military should consider training personnel in the use of urine dipstick-type test strips that could be used in the field and would provide information on levels of urine protein (a marker for potential renal damage), ketones and glucose (potential markers for energy metabolism), and leukocyte esterase and nitrates (indicators of urinary tract infections) as indicators of muscle damage and hydration.

- **Cognitive readiness:** The most promising techniques are actigraphy, electroencephalography, and heart-rate variability. Significant progress has already been made in developing and validating high-impedance sensors that could soon be mounted in helmets and clothing. Self-reported data can be influenced by peer pressure but should also be considered.

- **Activity and total energy expenditure:** Self-selected pace, foot-strike devices, and activity monitors that integrate pulse, temperature, and movement could serve as estimates, may be useful in the field, and should be developed.

- **Stress and immune responses:** A full evaluation of the effects of activation of stress response systems on immune function requires measures of multiple functional and molecular biomarkers at multiple time points. Indicators currently in use and in development include cortisol levels and heart-rate variability as measured with high-impedance electrocardiogram electrodes.

The committee addressed the questions of monitoring technologies needed to predict intermediate targets in critical metabolic pathways, recommending that future monitoring technologies consist of an integrated system incorporating noninvasive or minimally invasive sensor technology, communication interface and integration, data analysis tools, and local area networks. The committee also explored algorithms that
might provide specific predictions from combined sensor signals, concluding that although new variables made possible by new technologies may be predictive using simpler algorithms, a parallel initiative to explore presently available physiological measurements with more nonlinear complex models seems appropriate.

The committee emphasized concerns regarding the design and interpretation of biological research. Specifically, the committee recommends the use of research frameworks that address the various concerns such as the importance of differentiating intra- and inter-individual variability and of considering interactions with the environment and time factors. In fact, a full description of human responses requires an observation of a certain individual at a time and place. Such research frameworks, therefore, should be multivariate and consider persons, occasions, and variables as sources of variance. Statistical techniques that allow for that type of analysis already exist and should be used.

The research investments that may lead to revolutionary advances, according to the committee, include the development of new cognitive measurement approaches; optimization of markers to monitor stress and immune function; the use of odors as biomarkers and human tears as sources of biomarkers; the development of new algorithms to integrate complex biological information; understanding the impact of unexpected hazards on biomarkers of health; and further developments in metabolomics.

OTHER SELECTED RECOMMENDATIONS

- To develop databases of individual combat service members, as the committee believes that simple protocol data based on group averages may be imprecise.
- To develop new algorithms that employ currently measurable biomarkers and nonlinear modeling techniques.
- To develop patterns in rates of changes and resiliency. For example, research is needed to elucidate individual patterns of rates of change of stress hormones.
- To conduct research to evaluate and validate available biomarkers in the field, such as ratings of perceived exertion, immune function markers, and muscle fatigue physiological markers.
- To develop non- and minimally invasive technologies.
- To continue research on the use of NIRS to monitor muscle function and skin hydration status concurrently.

COMMITTEE ON METABOLIC MONITORING FOR MILITARY FIELD APPLICATIONS

JOHN E. VANDERVEEN (chair), San Antonio, Texas
BRUCE R. BISTRIAN, Clinical Nutrition, Beth Israel Deaconess Medical Center, Boston, Massachusetts
JOHN A. CALDWELL, Air Force Research Laboratory, Brooks City Air Force Base, San Antonio, Texas
JOHANNA T. DWYER, Office of Dietary Supplements, National Institutes of Health, Bethesda, Maryland and Tufts University and New England Medical Center, Boston, Massachusetts
JOHN W. ERDMAN, Department of Food Science and Human Nutrition, University of Illinois at Urbana-Champaign
HELEN W. LANE, Habitability, Environmental Factors, and Bioastronautics Office, NASA Johnson Space Center, Houston, Texas
MELINDA M. MANORE, Department of Nutrition and Food Management, Oregon State University, Corvallis
WILLIAM P. MORGAN, Exercise Psychology Laboratory, University of Wisconsin, Madison
PATRICK M. O’NEIL, Weight Management Center, Medical University of South Carolina, Charleston
ESTHER M. STERNBERG, Section on Neuroendocrine Immunology and Behavior, National Institute of Mental Health, Bethesda, Maryland
BEVERLY J. TEPPER, Department of Food Science, Rutgers University, New Brunswick, New Jersey
JULIAN THAYER, Gerontology Research Center, National Institute on Aging, Baltimore, Maryland

Staff
MARIA ORIA, Study Director
MARY I. POOS, Study Director (through November 2003)
LESLIE J. VOGELSANG, Research Assistant
SANAIT B. TESFAGIORGIS, Senior Project Assistant
HARLEEN K. SETHI, Senior Project Assistant (through August 2003)

For More Information...
Copies of the report, Metabolic Monitoring, are available for sale from the National Academies Press at (800) 624-6242 or (202) 334-3313 (in the Washington, D.C. metropolitan area) or via the NAP homepage at www.nap.edu. Full text of the report is also available at www.nap.edu. This study was funded by the U.S. Army Medical Research and Materiel Command. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect those of the funding agency.

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