NMSG, HFM, and SAS Workshop on Human Behavior Modeling for Military Training Application Toward Predicting Individual Soldier Cognitive Performance

Jonathan A. Cohen, Ph.D., Tad T. Brunyé, Ph.D.
US Army Natick Soldier Research, Development, & Engineering Center
15 Kansas Street, Natick, MA 01760
Telephone: (508) 233-5766 (Cohen); (508) 233-5997 (Brunyé)
Fax: (508) 233-6472
USA

Email: jonathan.a.cohen2@us.army.mil; thaddeus.brunye@us.army.mil

ABSTRACT

Developing predictive models of individual Soldier behavior and cognitive performance is a crucial step toward the goal of creating immersive training environments and virtual test beds designed to mitigate fatigue, task load, and errors in perceptual judgment and decision making. The Cognitive Science team at the Natick Soldier RDEC is currently developing two lines of research aimed at describing and predicting a Soldier's behavior and performance.

The first line of work investigates the deleterious effects of Nuclear, Biological, and Chemical (NBC) protective garments, and the subsequent fatigue and thermal strain they cause, on the cognitive performance of Soldiers across a variety of mission-relevant tasks. Using empirical results drawn from the NBC literature and from our own laboratory experiments, we have developed a cognitive performance model that uses as input the relative demands of a given task on a Soldier's embodied cognitive domains (e.g. motor skills, visual perception, attention, etc.) and the constraints of a Soldier's Mission Oriented Protective Posture Level (i.e. MOPP-0 to 4). Weighted input parameters are used in a non-linear model that calculates a best fit estimate of a Soldier's cognitive performance over time. Seven tasks were used to train the model's input weights, and to date the model has been used to predict performance in ten additional tasks drawn from the literature. The task database, NBC garment parameters, and algorithms used to drive the model are all accessed through a user-friendly graphical user interface (GUI). Developed for use by next-generation NBC garment designers, this line of work provides a unique approach to trade-space analyses and is a key piece in understanding the effects of thermal stress and equipment load on a Soldier's cognitive capacities. This work is conducted with the support of and objectives from the Defense Threat Reduction Agency (DTRA).

The second line of research focuses on the interactions between Soldiers and model-driven virtual characters in immersive virtual training environments. We are interested in the processes by which Soldiers perceive and understand the behaviors of civilians and potential combatants in urban environments. Specifically, we seek to describe how and which perceptual information variables available in the visual scene are used to classify behaviors in others. We are currently developing approaches to modeling and consequently generating civilian behaviors in virtual characters using non-linear behavioral dynamics. We aim to develop statistical models of behavior categorization by analyzing the ways in which Soldiers perceive and respond to the behaviors of virtual characters. The results of this line of work will benefit the modeling and simulation community and can transition to groups developing sensor technologies aimed at detecting potentially hazardous or threatening behaviors. This research is conducted with the support of a 6.1 ILIR award.

1.0 INTRODUCTION

The contemporary operating environment places the Warfighter in an increasingly dynamic and complex battlespace, confronting situations that demand a variety of adaptive and flexible behaviors. A complete understanding of how a Soldier perceives, reasons about, and reacts to his environment is critical to developing effective training paradigms and Soldier-enhancing technologies. Models of Soldier cognition and behavior serve as tools for measuring, describing, and predicting performance under a range of conditions and constraints. Researchers at the US Army Natick Soldier, Research, Development, and Engineering Center (NSRDEC) are developing two models of individual Soldier cognitive performance. The first model seeks to describe how Chemical-Biological (CB) protective equipment adversely affects cognitive and motor performance; the second approach investigates how Soldiers perceive the intentions and behaviors of other people. Empirical studies are used as the foundation for each modeling effort in order to ensure validity, robustness, and parsimony. Research conducted on CB ensemble effects on cognition has led to a software program that allows a user to interact with a computational model through a graphical-user interface. Efforts related to modeling the perception of intentional behavior, while less developed than the CB ensemble program, have led researchers to study how Soldiers reason about civilian crowd layouts in urban environments.

2.0 EFFECTS OF CHEMICAL-BIOLOGICAL EQUIPMENT ON WARFIGHTER PHYSICAL AND COGNITIVE PERFORMANCE: A TRADE-SPACE ANALYSIS TOOL

The objective of this line of research is the development of a human performance model that relates design characteristics of CB protective ensembles to Warfighter physical and cognitive performance while wearing such garments, with the goal of conducting trade-space analyses for the design of future CB protective ensembles. This work is funded by the Defense Threat Reduction Agency (DTRA), and answers a call issued for an interactive software program that models the CB ensemble-performance landscape and provides an interface for end-user interaction with the underlying model. Conducted over government fiscal year (FY) 2009-2011, this applied program integrated variety of research and design approaches, including meta-analytic literature reviews, empirical laboratory studies, computational modeling, and graphical-user interface (GUI) development. At the end of FY11, the first versions of a computational model and software program were delivered to DTRA; additional years of research and development were funded and are now underway.

The first step toward developing a model of how CB ensembles affect Soldier performance was an exhaustive, meta-analytic review of the CB ensemble literature. There were two goals for this review: (1) Identify gaps in the literature to be addressed with empirical studies, and (2) Populate a database of mission-oriented Soldier tasks to be used in the development of a computational model. The review provided a solid foundation of data on the effects of MOPP-0 (Mission-Oriented Protective Posture, Level 0; i.e. Advanced Combat Uniform – ACU) versus MOPP-4 (full ensemble) on Soldier performance; researchers identified gaps in the literature that were later addressed in laboratory experiments. Specifically, researchers found that little to no work had been conducted wherein the parameters of the MOPP-4 ensemble were independently varied along each component's (eye-wear/mask, gloves, over-garment) respective performance-constraining axis (i.e. eye-wear field-of-view, mask respirator resistance, over-garment moisture-vapor transfer rate). In addition, researchers computed the effect size of each comparison between MOPP-0 and MOPP-4 found in the literature. This meta-analysis resulted in 108 Soldier tasks and effect sizes that formed the basis of the model's task database. In addition, Subject-Matter Experts (SMEs) identified six embodied cognitive taxa that are utilized to varying degrees in each Soldier task (gross motor coordination, fine motor dexterity, visual acuity and detection, memory, attention and vigilance, and multitasking and decision-making). SMEs rated the extent to which each task relied on each of the six cognitive taxa. These ratings later formed weights to which a model's parameters were adjusted.

To address the knowledge gaps in the literature, four laboratory experiments were conducted that examined the effects of individual CB ensemble components on cognitive performance. Two experiments, conducted in partnership with the Edgewood Chemical-Biological Center (ECBC) investigated the effects of respirator resistance levels on Soldiers' cognitive and motor performance across five tasks: Attention Network Task (ANT; visual attention, vigilance, and executive control), Task-Switching (inhibitory control), Simple Reaction Time, Sustained Vigilance (visual attention and inhibitory control), and Squad Maneuver Task (spatial working memory). In Experiment 1 volunteers wore the Advanced Combat Uniform (ACU) and in Experiment 2 the JSLIST2 over-garment. In each experiment a total of 24 Soldiers were tested across five consecutive days; Soldiers alternated between performing a high physical workload task and the battery of cognitive tasks. Each day Soldiers donned an M50 mask possessing a different respirator resistance level (no mask; low, medium, and high inhalation pressure). Performance in two cognitive tasks provided evidence of higher-level executive control difficulties as a function of increased respirator resistance.

A third study was conducted to investigate the effects of the JSLIST2 over-garment's moisture-vapor transfer rate (MVTR) on Soldiers' cognitive performance. Twenty-four Soldiers alternated between performing a high physical workload task and five cognitive tasks (above) on five consecutive days, each day wearing an over-garment that possessed a different MVTR level (ACU only; low, medium, and high MVTR JSLIST2). The garment was worn without the remaining MOPP-4 ensemble components (gloves, mask, goggles). Performance on four of the five cognitive tasks provided evidence of cognitive decrements as a function of decreased MVTR. Figure 1 displays sample data from this study (Task-Switching results).

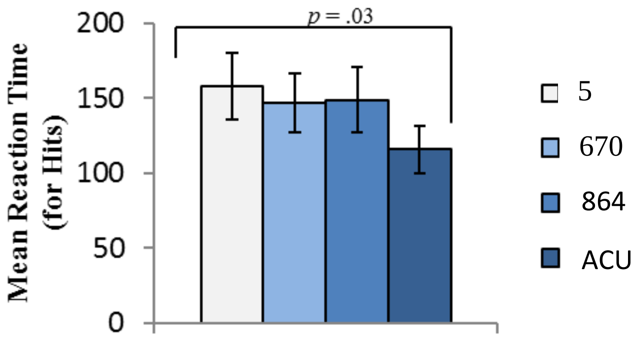


Figure 1. Sample data: Task-switching, MVTR experiment. Reaction time increases as MVTR decreases.

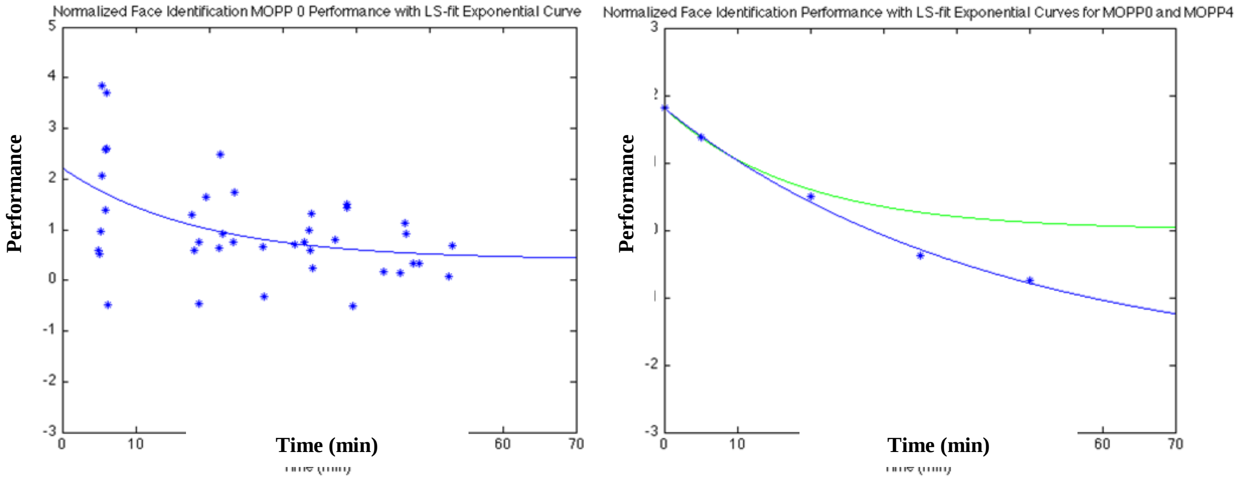
Experiment 4 determined the effects of protective eye-wear (M50 Mask/Goggles) field-of-view (FOV) on target discrimination in central and peripheral vision. Thirteen soldiers performed a target discrimination task while wearing a standard M50 Mask, one of two restricted-view masks, or no mask. Decreased FOV resulted in performance declines.

The task information and data from all four studies were added to a database consisting of tasks and effect sizes identified in the literature review (e.g. Teixeira & Bensel, 1990) and results transitioned to NSRDEC by partners at Applied Research Associates (ARA). Fifteen tasks were selected for the first iteration of a computational model and software program. A non-linear exponential curve with four coefficients (a_0, b_0, c_0, and d_0) that described cognitive performance over time was fit to MOPP-0 performance data and taxa rating parameters from seven tasks (Figure 2A). The equation is given as:

$$CP_0(\vec{r},t) = a_0(\vec{r})exp^{\left(-b_0(\vec{r})t+c_0(\vec{r})\right)} + d_0(\vec{r})$$

The model's coefficients are a function of a given task's cognitive taxa ratings $\vec{r}$. The remaining Soldier tasks were fit to the existing curves using a similarity comparison between cognitive taxa ratings. Effect size data (η^2) for each task were used to derive MOPP-4 comparison curves (Figure 2B):

$$CP_4(\vec{r},\eta^2,t) = a_4(\vec{r})exp^{\left(-b_4(\vec{r})t+c_4(\vec{r})\right)} + d_4(\eta^2)$$



A B

Figure 2. (A) Fit of MOPP-0 equation to taxa parameters and data for Face Identification task, (B) MOPP-0 (green) and MOPP-4 (blue) performance curves for Face Identification task.

To incorporate data collected on the effects of individual equipment parameters on performance, $\vec{r}$ was modified to $\vec{r}_s = \vec{r} + g(\vec{s})$, where g is a function defined by the cognitive taxa weights associated with the tasks performed in the four experiments described above, and $\vec{s}$ is the vector of specific equipment parameters that the user has selected. If $\vec{s}$ is the default MOPP-4 parameter values (i.e. each component in the software program is set to the currently fielded level), then $g(\vec{s}) = 0$, and $\vec{r}_s = \vec{r}$.

A graphical-user interface (GUI) was developed that allows a user to simulate cognitive performance for a specific task and set of equipment parameters (MOPP-0, MOPP-4, or custom ensemble). A screenshot of the GUI is shown in Figure 3. In addition to choosing from a list of fifteen tasks, users can also create custom tasks by altering the cognitive taxa weights on existing tasks.

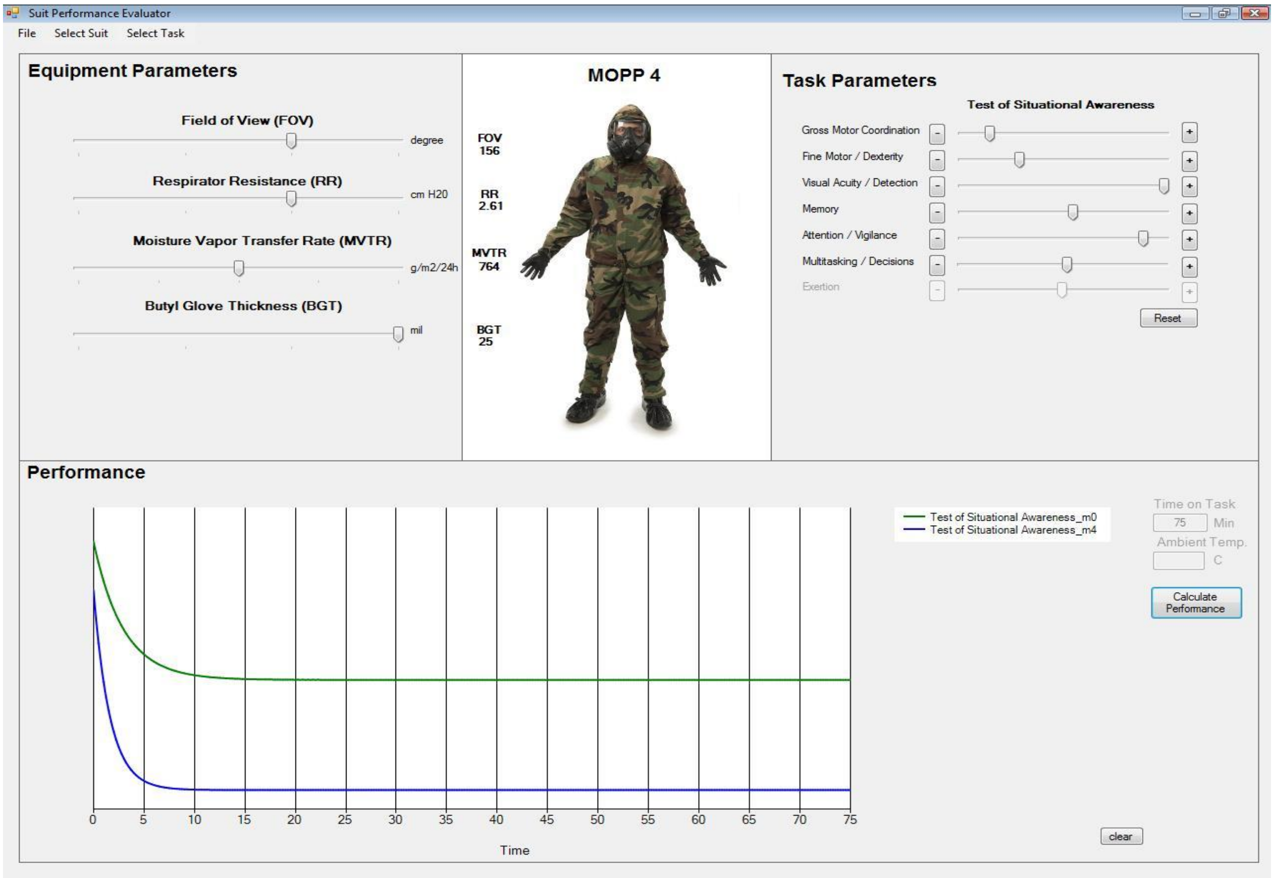


Figure 3. Screenshot of the first version of the CB ensemble trade-space software GUI.

The result of this effort is the first iteration of an interactive software program for modeling Soldier cognitive performance across a range of mission-relevant tasks. The model is currently limited by the discrete and punctuated nature of the existing data; further research involving continuous measurements of cognitive processing will mitigate this limitation and improve both the validity and robustness of the model. In addition, the model and GUI presently lack a unit of measure for cognitive performance. The GUI displays performance over time in an abstract space; relative performance comparisons can be made between tasks and between MOPP levels. Approaches to overcome this limitation are currently under investigation. Finally, the current work contains a simple effects model of how CB ensemble components affect performance; each ensemble component was manipulated individually, with the assumption that each component independently affects cognitive performance. This assumption is most likely incorrect. Future work will focus on the additive (linear or non-linear) effects and interactions among the ensemble components to expand the functionality and descriptive and predictive power of the software program.

3.0 PERCEIVING AGENT BEHAVIOR AND THREATS TO CROWDS

A second line of research aimed at modeling Soldier cognitive performance focuses on how Soldiers identify behaviors and intentions in others. Soldiers tasked with preserving order and peace in crowded urban spaces have the unique problem of observing crowds of local civilians while maintaining sustained vigilance (e.g. Parasuraman, de Visser, Clarke, McGarry, Hussey, Shaw, & Thompson, 2009) for threatening individuals, including active shooters and suicide bombers. Furthermore, Soldiers are often performing multiple tasks at a time while maintaining vigilance, which can further divide their perceptual and cognitive resources.The problem of identifying specific intentional actions in other agents has a long history in psychology. Heider and Simmel (1944) demonstrated that observers can consistently attribute intentional behaviors to moving geometric shapes, and Michotte's (1963) stimuli depicting physical causal events between multiple objects has spawned a large literature focusing on the perception of causal and intentional actions (e.g. Scholl & Tremoulet, 2000). Researchers in the areas of computer vision, surveillance automaticity, and decision modeling have investigated methods for identifying individuals carrying potentially harmful objects (e.g. Barrouil, Castel, Fabiani, Mampey, Secchi, & Tessier, 1998; BenAbdelkader & Davis, 2002; Kaplan & Kress, 2005; Lombardo, Knudson, Rutz, Pattison, Stratton, & Wiborg, 2010). However, little research has been conducted on the information that may be perceptually available to Soldiers who are directly observing individuals that may pose a threat. This information may be embedded in the motion patterns of people moving about a space (e.g. Basilli, 1976; Gao, Newman, & Scholl, 2009), and may also include variables such as head and eye fixation (e.g. Nummenmaa, Hyona, & Hietanen, 2009). In addition, environmental constraints and factors may also contribute to the successful or unsuccessful identification of behaviors or threats.

To investigate the latter source of information, an experiment is being conducted that investigates how the perception of a threat to a crowd in an urban setting (suicide bomb attack) is influenced by the layout of the crowd (i.e. environmental factors). Soldiers are shown top-down images of abstract urban spaces and crowds (Figure 4) and are asked to judge how likely a suicide bomb attack would take place among the crowd, how many casualties would result, and where the attack would occur. The size and density of the crowd are manipulated in a repeated-measures design. Researchers predict that crowd size and density will interact non-linearly in determining the pattern of results for perceived threat probability estimations. Data will indicate whether Soldiers perceive threats to crowds in a manner consistent with predictions made by models of IED casualty estimation (Kress, 2004).

The results of this study will inform the design of virtual environments containing crowds of avatars, enabling researchers to control the influence of a crowd's layout on an observer's perception of avatar behavior. Avatar movement will be driven by dynamic models of locomotor behavior developed from existing data sets (e.g. Fajen & Warren, 2003) and supplemental performance-capture studies. Researchers will investigate the conditions under which threatening and suspicious patterns of movement are either easy or difficult to detect (Gao, Newman, & Scholl, 2009), identifying the informational variables and model parameters that underscore each percept. Finally, researchers will conduct studies to determine the roles that non-motion sources of information (e.g. observer knowledge, avatar head/eye fixation, multiple perspectives, etc.) play in perceiving threats within a crowd.

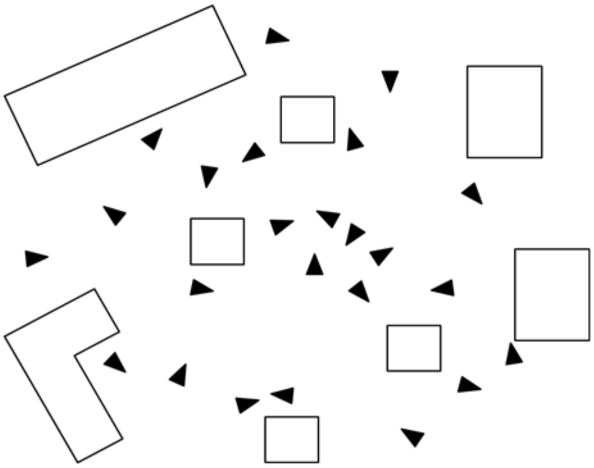


Figure 4. Sample trial image. Filled triangles represent individual agents, while rectangular objects represent buildings and other environmental clutter.

4.0 DISCUSSION

The successful modeling of Soldier cognitive performance requires a combination of research approaches and disciplines. At the core of a robust model is a data set that accurately describes the behaviors or cognitive processes in question. Acquiring the data set is often the largest hurdle in human modeling. If literature reviews reveal gaps, as was seen in the CB ensemble effort, one must design and conduct empirical studies to fill in the missing data pieces. The nature of the data can often dictate or constrain aspects of a model. The discrete data collected under the CB program limited the predictive capabilities of the model. Future work will develop the program through additional experiments and measurement of continuous cognitive processes, as well as through the parallel development of continuous, dynamical models of cognition.

The programs described in the present work both seek to model a Soldier's cognitive mechanisms and processes. The CB ensemble program approaches cognition in an embodied fashion, constructing an output metric that aggregates over a number of cognitive processes (i.e. taxa ratings). The crowd behavior program, alternatively, seeks to model the interaction between specific perceptual and cognitive processes and the information available to those systems in the environment. Each approach has merit, and like most models has been selected to fit a need or achieve a goal. The CB program is designed with an end-user in mind, one who need not know the specifics of the model that drives the GUI. Given this goal and constraint, a model that individually describes how each of the cognitive taxa is affected by CB ensembles is not sensible. However, in attempting to create a single metric, researchers discovered the new problem of describing the abstract landscape of cognitive performance that is displayed in the GUI. The truth that the two modeling approaches described above highlight is that no one model can describe or predict the whole of performance or behavior.

While a model can be evaluated by its predictive power or robustness, it can also be measured by how it is transitioned or applied to other problems. The Army looks to researchers and modelers for inspiration and data that form the basis of new technologies and training regimens. It is important that these goals be kept in mind when developing research and modeling programs. The programs presented in this work seek to answer current and critical Army needs, and both have methods for transitioning models to those who can develop outputs into technologies. The result is an iterative design approach to modeling human behavior and cognition that benefits the researchers designing the models and the end-users who provide feedback on products.

5.0 REFERENCES

[1] Barrouil, C., Castel, C., Fabiani, P., Mampey, R., Secchi, P., & Tessier, C. (1998). A perception strategy for a surveillance system. *Proceedings of the 13th European Conference on Artificial Intelligence*, 627-631.

[2] Bassili, J. (1976). Temporal and spatial contingencies in the perception of social events. *Journal of Personality and Social Psychology, 33 (6),* 680-685.

[3] BenAbdelkader, C. & Davis, L. (2002). Detection of people carrying objects: A motion-based recognition approach. *Proceedings of the IEEE International Conference on Automatic Face and Gesture Recognition*, 378-383.

[4] Fajen, B.R. & Warren, W.H. (2003). Behavioral dynamics of steering, obstacle avoidance, and route selection. *Journal of Experimental Psychology: Human Perception and Performance, 29 (2),* 343-362

[5] Gao, T., Newman, G. E., & Scholl, B. J. (2009). The psychophysics of chasing: A case study in the perception of animacy. *Cognitive Psychology*, *59,* 154-179.

[6] Heider, F. & Simmell, M. (1944). An experimental study of apparent behavior. *American Journal of Psychology, 57,* 243-259.

[7] Kaplan, E.H., & Kress, M. (2005). Operational effectiveness of suicide-bomber-detector schemes: A best-case analysis. *Proceedings of the National Academy of Sciences, 102 (29),* 10399-10404.

[8] Kress, M. (2004). The effect of crowd density on the expected number of causalities in a suicide attack. *Naval Research Logistics, 52 (1),* 22-29.

[9] Lombardo, N.J., Knudson, C.K., Rutz, F.C., Pattison, K.J., Stratton, R.C., & Wiborg, J.C. (2010). Considerations for developing technologies for an integrated person-borne IED countermeasure architecture. *Proceedings of SPIE Defense, Security, and Sensing Conference, April 5*-9.

[10] Michotte, A. (1963). *The perception of causality* (trans. T.R. Miles & E. Miles). New York: Basic Books.

[11] Nummenmaa, L., Hyona, J., & Hietanen, J.K. (2009). I'll walk this way: Eyes reveal the direction of locomotion and make passersby look and go the other way. *Psychological Science, 20 (12),* 1454-1458.

[12] Parasuraman, R., de Visser, E., Clarke, E., McGarry, W.R., Hussey, E., Shaw, T., & Thompson, J.C. (2009). Detecting threat-related intentional actions of others: Effects of image quality, response mode, and target cueing on vigilance. *Journal of Experimental Psychology: Applied, 15 (4),* 275-290.

[13] Scholl, B.J., & Tremoulet, P.D. (2000). Perceptual causality and animacy. *Trends in Cognitive Science, 4 (8),* 299-309.

[14] Teixeira, R.A. & Bensel, C.K. (1990). The effects of chemical protective gloves and glove liners on manual dexterity (U). US Army Natick Research, Development, and Engineering Center, Natick, Massachusetts, NATICK/TR/91/002.