# FINAL TECHNICAL REPORT

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# BA07PRO103: Modeling Warfighter Physical and Cognitive Performance while Wearing CB Protective Equipment: A Trade-space Analysis Tool

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# 2. PROJECT AND REPORT OVERVIEW

## 1. OBJECTIVE

The objective of this project is to develop a set of human performance guidelines that relates design characteristics of chemical-biological (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.

## 2. EXECUTIVE SUMMARY

The Defense Threat Reduction Agency (DTRA) issued a call for the development of an interactive model and software suite that specifies how the landscape of Mission-Oriented Protective Posture (MOPP) chemical-biological (CB) ensembles affects Soldier cognitive, physical, and perceptual performance across a range of mission-relevant tasks. This software program will allow manufacturers of next-generation chemical-biological protective gear (i.e. the target end-users) to assess tradeoffs in developing new equipment and its potential impact on Soldier mission performance. During FY08-11, Natick Soldier Research, Development, and Engineering (NSRDEC) research psychologists conducted a research and development program focused on the cognitive and perceptual performance of Soldiers under CB ensemble constraints. A meta-analysis of the CB ensemble performance literature revealed knowledge gaps that were addressed in three empirical research studies. Each study focused on how parametric manipulations of a single component of the MOPP-4 ensemble affected cognitive performance. The first experiment manipulated the Respirator Resistance (RR) of the respirator mask/goggles. The second experiment manipulated the Moisture-Vapor Transfer Rate (MVTR) of the CB over-garment. The results of each experiment indicated that increased levels of CB protection, specifically increased RR and decreased MVTR, produced impairments in several facets of Executive Control including task-switching and behavioral inhibition. A third study manipulated the respirator's horizontal Field-of-View (FOV), and found that decreases in FOV caused impairments in peripheral vision target discrimination. In FY12 we began data collection in an experiment examining horizontal FOV effects on tasks demanding working memory and the effortful control of attention; this effort had an FY13 planned completion. The results of these studies, along with extant data and data transitioned from ARA partners, were used to define a set of heuristics that detail CB ensemble effects on cognitive and motor performance. This final report details work through FY12 and includes the first iteration of this set of heuristics designed to meet the goals outlined by DTRA. Detailed experimental methods and results are included in Appendix A, details regarding development and population of computational model are included in Appendix B, and details regarding the development and testing of the graphical user interface (GUI) are included in Appendix C.

## 3. SUMMARY OF KEY ACCOMPLISHMENTS

Below we itemize key accomplishments for the entire project duration (FY08-FY12). Each accomplishment is further detailed in the following sections.

1. Completed meta-analytic review of CB protective ensemble literature, including individual and composite CB component effects on cognitive and motor performance.
2. Completed human performance research study examining respirator resistance influences on cognitive and motor performance.
3. Completed human performance research study examining MVTR influences on cognitive and motor performance.
4. Supported FY10 demonstration planning and execution, to include statistical analyses of cognitive and motor effects.
5. Developed and populated computational model detailing independent effects of CB ensemble components on cognitive and motor performance.
    a. Publications:
        i. Augustyn, J.S., Brunyé, T., Mahoney, C. R., & Kramer, F. M. (2009). EMMA: An Agent- based Architecture for Modeling Human-environment Interactions. *Paper presented at the 53rd Annual Meeting of the Human Factors and Ergonomics Society.*
        ii. Augustyn, J.S., Brunyé, T., Mahoney, C. R., & Kramer, F. M. (2009). Modeling Situated Human Performance. *Paper presented at the 9th International Conference on Cognitive Modeling.*
        iii. Augustyn, J. S., Brunyé, T. T., Mahoney, C. R., & Kramer, F. M. (2008). Modeling the impact of chemical-biological protective gear on human performance: A situated-agent approach. *Paper presented at the Chemical-Biological Defense Physical Science and Technology Conference, New Orleans, LA.*
        iv. Augustyn, J.S., Brunyé, T., Mahoney, C. R., & Kramer, F. M. (2009). Modeling Situated Human Behavior: Insights from Evolution and Distributed Artificial Intelligence. *Paper presented at the Association for the Advancement of Artificial Intelligence Workshop on Biologically Inspired AI.*
        v. Cohen, J.A. & Brunyé, T.T. (2011). Toward Predicting Individual Soldier Cognitive Performance. *Paper presented at NATO MSG, HFM, and SAS Workshop On Human Behavior Modeling for Military Training Application, 2 December 2011*.
6. Developed, tested and delivered (FY11) initial prototype of trade-space software tool with interactive graphical user interface.
7. Completed human performance research study examining mask field of view effects on central and peripheral visual vigilance.
8. Began human performance research study examining mask field of view effects on cognitive processes related to maintaining information while controlling attention.
9. Developed protocols and materials, and obtained human use approvals for FY13 experiments examining continuous cognitive performance in CB encapsulation, and independent and interactive effects of glove thickness and mask field of view.
10. Developed and delivered (FY12) statistical relations and heuristics set using meta-analytic and experimental data to detail independent CB ensemble component effects on Soldier-relevant cognitive processes.

# 3. PROJECT BACKGROUND

The Defense Threat Reduction Agency (DTRA) issued a call for the development of an interactive model and software suite that specifies how the landscape of Mission-Oriented Protective Posture (MOPP) chemical-biological ensembles affects Soldier cognitive, physical, and perceptual performance across a range of mission-relevant tasks. This software program will allow manufacturers of next-generation chemical-biological protective gear (i.e. the target end-users) to assess tradeoffs in developing new equipment and its potential impact on Soldier mission performance. Natick Soldier Research, Development, and Engineering (NSRDEC) research psychologists, in collaboration with the Edgewood Chemical Biological Center (ECBC) and Applied Research Associates (ARA), led this effort, with specific focus on the cognitive and perceptual performance of Soldiers under CB ensemble constraints. This program required a variety of research and design approaches, including meta-analytic literature reviews, empirical laboratory studies, computational modeling, and graphical user interface (GUI) development. The effort was conducted over Fiscal Years (FY) 2009-2011. In FY12 we ceased development of the computational model and GUI and under DTRA's guidance focused our efforts on experimental work and the development of a set of heuristics (statistical guidelines) that can be used to predict CB ensemble effects on cognitive and motor performance.

# 4. PROGRESS MADE DURING THE PROJECT

## 1. LINES OF WORK

The Statement of Work outlines a series of tasks, or lines of work, to be conducted each year in support of this effort. The following sections review each task and report all generated deliverables.

## 2. FY09 TASKS

Two tasks were completed in FY09:

(1) Meta-Analytic Review of CB Protective Ensemble Literature
(2) Human Performance Research Studies: Respirator Resistance

### 2.1. Meta-Analytic Review of CB Protective Ensemble Literature

An exhaustive, meta-analytic literature search was performed on the effects the CB protection ensembles on Soldier performance. There were two goals for this task: (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. Both goals were met: The review provided a solid foundation of data on the effects of MOPP-0 (ACU) versus MOPP-4 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 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 beginning of the model's task-effect database.

### 2.2. Human Performance Research Studies: Respirator Resistance

The meta-analytic literature review indicated that research was needed that parametrically varied each component of the MOPP-4 CB ensemble along that component's performance-constraining axis. Two experiments were conducted in partnership with the Edgewood Chemical Biological Center (ECBC) to investigate the effects of respirator resistance levels on Soldiers' cognitive performance across five tasks. In Experiment 1, volunteers wore the Advanced Combat Uniform (ACU) and in Experiment 2 the CB 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 a mask possessing a different respirator resistance level (no mask; low, medium, and high inhalation pressure). Performance in two tasks provided evidence of higher-level executive control difficulties as a function of increased respirator resistance. The details of these experiments are reported in Appendix A. These studies,

and those that followed in FY10-11, were added to the model's task-effect database to improve functionality and validity.

### 2.3. FY09 Deliverables

Three presentations resulted from efforts during FY09:

Augustyn, J.S., Brunyé, T., Mahoney, C. R., & Kramer, F. M. (2009). EMMA: An Agent-based Architecture for Modeling Human-environment Interactions. *Paper presented at the 53rd Annual Meeting of the Human Factors and Ergonomics Society.*

Augustyn, J.S., Brunyé, T., Mahoney, C. R., & Kramer, F. M. (2009). Modeling Situated Human Performance. *Paper presented at the 9th International Conference on Cognitive Modeling.*

Augustyn, J. S., Brunyé, T. T., Mahoney, C. R., & Kramer, F. M. (2008). Modeling the impact of chemical-biological protective gear on human performance: A situated-agent approach. *Paper presented at the Chemical-Biological Defense Physical Science and Technology Conference, New Orleans, LA.*

## 3. FY10 TASKS

Four tasks were completed in FY10:

(1) Human Performance Research Study: Moisture-Vapor Transfer Rate
(2) Trade-off Tool Design and Prototyping
(3) Support FY10 Demonstration Planning and Execution
(4) Design and Begin Development of Computation Model

### 3.1. Human Performance Research Study: Moisture-Vapor Transfer Rate

A study was conducted to investigate the effects of the CB over-garment's moisture-vapor transfer rate (MVTR) on Soldiers' cognitive performance. Soldiers (N = 24) alternated between performing a high physical workload task and five cognitive tasks on five consecutive days, each day wearing an over-garment that possessed a different MVTR level (ACU only; low, medium, and high MVTR CB). 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. The details of this experiment are reported in Appendix A. The data from this study were added to the computational model's task-effect database.

### 3.2. Trade-Off Tool Design and Prototyping

This task provided a basis for achieving the overall objective of the program: A user-friendly software tool that supports making trade-off analyses regarding the impact of ensemble changes relative to Soldier performance, particularly related to cognitive performance. In FY10 NSRDEC researchers developed a graphical mock-up of the software tool user interface that included elements for user input (i.e. parameter adjustments) and for visualizing model outputs (i.e. graphical representations). Researchers presented the mock-up tool to representatives from ARA and DTRA in September, 2010, solicited feedback and recommendations, and gained approval for continued development of the software tool.

### 3.3. Support FY10 Demonstration Planning and Execution

A Chemical-Biological Ground Soldier System (CB-GSS) Demonstration was held in Aberdeen, MD in 4QFY10. NSRDEC researchers from the Cognitive Science and Human Factors Teams designed and developed an experimental task suite that tested Soldier visual attention performance (vigilance; orienting of attention; executive control of attention). This suite was integrated into the overall CB-GSS demonstration procedures. NSRDEC researchers submitted a proposal for data collection, were approved, and assisted in data collection during the demonstration at Aberdeen.

### 3.4. Design and Begin Development of Computational Model

This task focused on the initial design and development of the computational model that would underlie the trade-space software tool. NSRDEC researchers and Subject Matter Experts (SMEs) identified eight embodied cognitive performance taxa – vision, fine motor coordination, gross motor movement, executive functioning, working memory, long-term memory, attention, and reasoning – that could be used to describe the Soldier tasks identified in the meta-analytic literature review. For each task, SMEs estimated the degree to which each cognitive taxon was utilized.

In addition, NSRDEC received cognitive performance data from ARA researchers: cognitive taxa were estimated for the tasks performed in the ARA data set, and the data were added to the model's task-effect database.

Researchers performed a principle components analysis to reduce the taxon space from eight taxa to six: Gross motor coordination, fine motor dexterity, visual acuity/detection, memory, attention/vigilance, and multitasking/decision-making. A non-linear dynamical systems approach was developed that described Soldier performance as a function of CB ensemble, task performed, and time in the ensemble. Attention was devoted to how the model would accept and produce predictions for user-generated tasks. The computational model is described in Appendix B.

### 3.5. FY10 Deliverables

In addition to NSRDEC's participation in the CB-GSS Demonstration, the following presentation resulted from FY10 efforts:

Augustyn, J.S., Brunyé, T., Mahoney, C. R., & Kramer, F. M. (2009). Modeling Situated Human Behavior: Insights from Evolution and Distributed Artificial Intelligence. *Paper presented at the Association for the Advancement of Artificial Intelligence Workshop on Biologically Inspired AI.*

## 4. FY11 TASKS

Four tasks were completed in FY11:

(1) Human Performance Research Study: Field-of-View
(2) Populate and Develop First Version of Computational Model
(3) Develop Initial Prototype of Trade-Space Tool Software GUI
(4) Analysis and Reporting of Demonstration Performance Data

### 4.1. Human Performance Research Study: Field-of-View

An experiment was conducted by NSRDEC researchers to determine effects of protective eye-wear (mask/goggles) field-of-view (FOV) on target discrimination in central and peripheral vision. This study was designed to fill the largest knowledge gap identified by the meta-analytic literature review and to provide a systematic data set to populate the model. Researchers developed experimental scripts, secured Masks, and obtained approvals to collect data. Soldiers (N = 13) performed a target discrimination task while wearing a standard Mask, one of two restricted-view masks, or no mask. Decreased FOV resulted in performance declines, and the results were added to the model's database. The details of this experiment are found in Appendix A.

### 4.2. Populate and Develop First Version of Computational Model

A mathematical modeler was contracted to develop the first version of the computational model that underlies the trade-space tool. Working with NSRDEC researchers, the modeler determined that the current data sets did not support a dynamical systems approach, and instead settled on a simpler, non-linear equation that described performance over time. A dynamical systems model remains the long-term goal of this program; additional experiments are under development for FY13 that will result in the appropriate data sets for the second version of the model and trade-space software.

The first version of the model was populated with data from the following sources: (1) A subset of the meta-analytic literature review, (2) Data set delivered to NSRDEC by ARA researchers, (3) Results from NSRDEC's Respirator Resistance, MVTR, and FOV experiments, and (4) Butyl Glove Thickness data from Teixeira & Bensel (1990). The model was integrated with the software

GUI and presented to representatives from DTRA in September, 2011. Further details of the computational model are discussed in Appendix B.

### 4.3. Develop Initial Prototype of Trade-Space Tool Software GUI

Two computer programmers were contracted in succession to develop the first version of the trade-space software GUI, based on the initial prototype design developed by NSRDEC researchers and presented to DTRA representatives in 4QFY10. The GUI developer and computational modeler worked in tandem under the direction of NSRDEC researchers to maximize the functionality of the software tool.

The GUI was designed using C# and Microsoft Visual C#. The GUI outputs a graphical representation of Soldier cognitive performance over time, using the underlying computational model. For each run the user can specify the task and CB ensemble components that are used as input to the model. Users have access to 15 tasks in the first software iteration; more tasks will be made available for the second iteration of the program.

The GUI was presented to representatives from DTRA in September, 2011. A copy of the software tool including the integrated model and GUI, and documentation were shipped to DTRA in 1QFY12 for user comments and feedback. Further details of the computational model are discussed in Appendix C.

### 4.4. Analysis and Reporting of Demonstration Performance Data

The CB-GSS Demonstration conducted in 4QFY10 included physical and cognitive performance data collection, physiological monitoring, and mission performance assessment. Analysis and reporting of the cognitive performance data took place in FY11.

### 4.5. FY11 Deliverables

The following deliverables resulted from FY11 efforts:

Trade-Space Model and Software Tool, version 1.0

Cohen, J.A. & Brunyé, T.T. (2011*). Toward Predicting Individual Soldier Cognitive Performance. *Paper to be presented at NATO MSG, HFM, and SAS Workshop On Human Behavior Modeling for Military Training Application, 2 December 2011.*

* Paper submitted 4QFY11, accepted 1QFY12.

## 5. FY12 TASKS

Four tasks were completed in FY12:

(1) Began development of a set of heuristics using CB-Cognition statistical relations
(2) Developed experimental packages for continuous cognitive performance study (FY13 start)
(3) Obtained human use approvals for continuous cognitive performance study (FY13 start)
(4) Obtained human use approvals for investigating mask FOV and glove thickness effects
(5) Began data collection on study investigating glove thickness and mask FOV on cognition

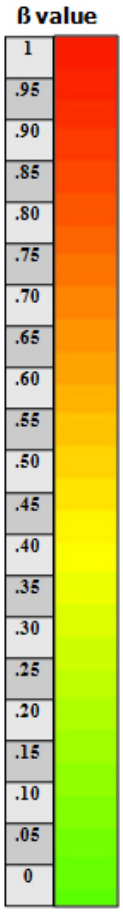
### 5.1. Began Development of Statistical Relations and Heuristics Set

FY10-11 efforts led to the development of a computational model, software tool and graphical user interface (GUI) that sought to define CB ensemble effects on cognitive and motor performance over time; the resulting v1.0 software package was delivered to DTRA at the end of FY11. Subsequent guidance from DTRA emphasized their need for a set of heuristics and underlying statistical relations, rather than a computational model. Thus, in FY12 we developed the first iteration of these statistical relationships by using effect size metrics gathered from the meta-analysis, ARA data, and NSRDEC's experimental efforts. These statistical relations are represented in a set of matrixed relationships defining the effects of individual CB parameter variations on a range of cognitive processes including vision, attention and vigilance, working memory, multi-tasking, decision-making, and gross and fine motor skills.

The result of this effort is depicted in the Figure below. Cell entries are comprised of standardized regression coefficients (β) that define the strength of the relationship between each predictor variable (CB ensemble component) and each criterion variable (cognitive process). The top row defines the aggregate effect of donning level IV MOPP gear relative to level 0; the strength of several relationships is further defined as a function of time in 15 minute increments (up to 60 minutes). The lower rows individuate each experimentally examined CB ensemble component and its effects on several cognitive processes; in the case of a grey cell, no data are available as of the end of FY12. Colored shading indicates the strength of each regression coefficient as indicated in the key. Finally, overall mean effects of each CB ensemble component across the range of cognitive and motor processes is defined in the final column.

In interpreting these data, several points are worth noting. First, whereas some CB ensemble components have clearly defined effects on cognitive performance given a range of experimental manipulations and criterion tasks, FOV effects are relatively underspecified and in certain cases not precisely examined. For instance, data defining FOV effects on decision making come from a limited number of experiments examining reaching decisions; these data thus could be more affected by estimations of motor affordances rather than purely decision making. Due to these limitations in the extant data, therefore, regression coefficients defining FOV effects on higher-order cognitive processes might be artificially inflated. Second, it is difficult to estimate task difficulty levels across examined processes and between studies. This inherent variability in methods employed leads to a degree of difficulty when attempting to make comparisons across cognitive processes. For instance, though FOV appears to affect gross motor skills more strongly than attention/vigilance, it could be the case that the gross motor skill was more difficult and therefore showed higher degradation with FOV restriction. Given this limitation we advise against direct cell-to-cell comparisons.

| | Vision | Attn/Vig | W. Memory | MulTask/DM | Gross Motor | Fine Motor | Overall |
|---|---|---|---|---|---|---|---|
| MOPP IV vs. 0 | .58 | .54 | .31 | .38 | .71 | .42 | .49 |
| | 15m 30m 45m 60m | 15m 30m 45m 60m | 15m 30m 45m 60m | 15m 30m 45m 60m | | | |
| | .33 .51 .48 .53 | .33 .49 .48 .52 | .20 .35 .33 .36 | .22 .36 .34 .36 | | | |
| Over-garment MVTR | .02 | .50 | .49 | .14 | .22 | .11 | .25 |
| Respirator Resistance | .11 | .25 | .01 | .26 | .24 | .21 | .18 |
| Mask Field of View | .71 | .53 | .06 | .69 | .89 | .56 | .67 |
| Glove Thickness | | | | | | .96 | .96 |



### 5.2. Developed experimental packages for continuous cognitive performance study

In anticipation of FY13 data collection efforts we developed the experimental methods and software packages to examine continuous cognitive performance in CB encapsulation. The experimental method included a treadmill bout of moderate-high intensity exertion in either level IV or level 0 MOPP gear for a period of time sufficient to induce moderate-high physiological strain at 1.56 m/s walking pace. Physiological measures include heart rate and respiration rate, and energy expenditure and gait activity will be monitored using the MiniSun Intelligent Device for Energy Expenditure and Activity (IDEEA) system.

During this bout of physical exertion in either level IV or 0 MOPP gear, volunteers will rate physiological strain and physical exertion using validated instruments including the Physiological Strain Index (PSI) and Borg Rating of Perceived Exertion (RPE). They will also perform two continuous cognitive tasks that challenge both low-level attention and vigilance and also the higher-order ability to effortfully control responding. During FY12, visual and auditory versions of these tasks were designed, developed and pilot tested.

### 5.3 Obtained Human Use Approvals: Continuous Cognitive Performance

In order to begin data collection on the experiment described in Section 5.2, above, we prepared an experimental protocol for submission to the human subjects research determination committee. This protocol was submitted in early FY12 and we received final approvals to begin data collection in Q4 FY12.

### 5.4 Obtained Human Use Approvals: Glove Thickness and Mask FOV

As evidenced by the grayed cells in the above Figure, no experimental work has examined the effects of glove thickness on a wide range of performance metrics. To begin addressing this issue, we proposed to conduct experimental work in FY13 designed to elucidate glove thickness effects on vision, attention/vigilance, working memory, decision making and gross motor skills. In Q4 FY12, an experimental protocol was developed and approved for data collection.

As of Q3 FY12 no data were available to define the effects of mask FOV on working memory performance. In Q4 we obtained approvals for an experiment examining how parametric restrictions of horizontal FOV affect working memory performance.

### 5.5 Began data collection investigating glove thickness and mask FOV on cognition

Glove thickness experiment: As of the time of this report, we have collected data from 2 pilot volunteers.

FOV experiment: In Q4 FY12 we began data collection on a study examining FOV effects on working memory. Regression coefficients derived from data collected from 8 pilot participants are included in the above Figure; the experimental effort and resulting data are described in Appendix A (Experiments).

### 5.6 FY12 Deliverables

The following deliverables resulted from efforts through FY12:

Version 1 of the set of statistical heuristics, as presented in Sections 5.1 and the above Figure.

## 6. SUMMARY

All FY09-12 tasks outlined in the SOW have been completed. The first version of the computational model and trade-space software tool have been developed and integrated. The four experiments conducted by NSRDEC and partners in support of the tool's development, the effects of parametric manipulation of respirator resistance (Experiment 1 ACU and Experiment 2 CB garment), MVTR, and field-of-view on cognitive performance, are detailed in Appendix A. Details regarding the computational model and GUI are found in Appendices B and C, respectively. The detailed set of statistical relations between CB ensemble components and cognitive and motor performance is depicted in the above Figure and described in Section 5.1, above.

# 5. PERFORMANCE ISSUES

None.

# 6. CONCLUSIONS

## 1. SOFTWARE PROGRAM DELIVERABLE

The work conducted for this effort over FY09-11 has resulted in an integrated software program that utilizes a meta-analytic literature review, empirical studies, a computational model, and a graphical user interface. This "first iteration" software serves as a deliverable for FY11, and also as the first step toward the long-term goal of this effort: A comprehensive interactive model and software suite that specifies the effects of MOPP ensemble components on mission-relevant task performance. However, as a first iteration piece of software, it possesses some limitations and areas for improvement. The following discusses these limitations and the approaches one can take to mitigate them and improve the model and software package.

## 2. STATISTICAL HEURISTICS DELIVERABLE

The work conducted for this effort over FY09-12 has resulted in a set of statistical heuristics that define independent effects of CB ensemble components on several components of cognitive and physical performance that underlie successful Soldier operations. The matrix presented in Section 5.1 and depicted in the above Figure is the first iteration of the heuristics, using a common measure of effect size (regression coefficients) to describe a vast array of data gathered from the extant literature and our own experimental work. The current set of heuristics is a first iteration and serves as a proof of concept that can be expanded upon in future work; indeed as delivered, the data should be interpreted with some caution (see Section 5.1 for details). That said, we view this first iteration as a concise example of how we can begin to define and predict CB ensemble component effects on cognitive and physical performance.

## 3. LIMITATIONS

The present version of the computational model and GUI represent the first step toward a more comprehensive model and visualization of Soldier cognitive performance. The computational model was originally conceived of as a set of dynamical systems. The current model is a simpler exponential equation, derived to fit the existing data. In order to derive a dynamical system, continuous cognitive performance data must first be collected.

Collecting continuous performance data will also serve to mitigate another limitation of the current work: that of paucity of effect size data in general. While the meta-analysis revealed over 100 studies investigating CB ensemble (MOPP-0 vs. MOPP-4) effects on performance, these studies each had a single effect size, thus neglecting to consider performance effects as a function of elapsed time. Additional measurements collected over a continuous period of time, would result in improved model fits. This work was proposed for FY13, contingent upon continued funding.

Currently the model and GUI can simulate performance in either MOPP-0 or MOPP-4 conditions; this is representative of the data. In order to map the entire landscape of CB ensemble effects on performance, studies must be conducted using MOPP-1, 2, and 3 ensemble conditions.

The GUI displays a slider for an Exertion parameter and an input window for ambient temperature, neither of which are functional. There are plans to improve the functionality of the software program by investigating how physical exertion and ambient temperature directly affect performance.

While the present GUI displays cognitive performance graphically and over time, it does so without a unit of measurement on the *y*-axis. There is at present no summary unit for Cognitive Performance. Therefore, further work must be conducted to determine the best way to describe and graphically represent the model's output.

Both the computational model and the heuristics set use 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. Conducting experiments that focus on the additive (linear or non-linear) effects and interactions among the ensemble components would expand the descriptive and predictive power of our approach.

## 4. PATH FORWARD

While the previous section outlined a number of limitations to the present, first iterations of our deliverables, none of these limitations is insurmountable. As of this writing one additional year (FY13) of work is proposed in order to address the above limitations and expand the capabilities of the capabilities developed to date. During this year NSRDEC researchers will conduct experiments designed to test the interactive nature of the CB ensemble components and to collect continuous cognitive performance data. Effort will be spent on formalizing the representation of Cognitive Performance with quantitative units or metrics. Finally, new versions of the statistical heuristics will be tested and submitted for review and feedback to DTRA representatives.

## 5. CONCLUSIONS

As previously stated, the objective of this effort is the development of guidelines that can serve to define the effects of CB ensemble components on cognitive and motor performance. The presented statistical heuristics are a first step toward this goal and can motivate trade-space analyses for the design of future CB protective ensembles. Reaching the ultimate goal of this effort lies in additional research, analyses, and design. However, the first, and possibly the most important, step has been successfully achieved.

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# APPENDIX A

# EXPERIMENTS AND RESULTS

## 1. OVERVIEW

The meta-analysis highlighted knowledge gaps in the CB ensemble literature. Specifically, little research had been conducted that investigated the effects of parametric changes in MOPP-4 ensemble components on Soldier cognitive performance, and prior work did not address how each component in the ensemble independently affected performance (most research compared MOPP-0 to MOPP-4 levels). To address this need, five experiments were conducted that parametrically varied the protection granted by individual pieces of the MOPP-4 ensemble: The reapirator mask/goggle's Respirator Resistance and horizontal field-of-view, and the CB over-garment's Moisture-Vapor Transfer Rate. Soldiers performed cognitive motor tasks while wearing prototype versions of the above components. The data collected from these studies directly informed the computational model of performance and the set of statistical heuristics developed for this program.

## 2. EFFECTS RESPIRATOR RESISTANCE LEVEL ON COGNITIVE PERFORMANCE

In partnership with Edgewood Chemical Biological Center (ECBC), NSRDEC conducted two experiments to determine the effects of different levels of Respirator Resistance (RR), or Inhalation Pressure Resistance, on cognitive performance across a range of tasks. The current respirator mask/goggles face protection component of the MOPP-4 ensemble (Figure 1) has a resistance level of 2.61 cm $H_2O$. Two prototype masks possessing resistance levels of 1.23 cm $H_2O$ and 4.29 cm $H_2O$ (i.e. above and below the fielded standard) were developed for this study. In Experiment 1, volunteers wore the Advanced Combat Uniform (ACU) attire, and in Experiment 2 they were subjected to increased thermal load by donning the CB garment. The results from these experiments were used to help populate the computational model's task-effect database.

Figure 1. Respirator Mask and Goggle face/eye protection.

## 2.1. Experiment 1 Method

### 2.1.1. Participants

Twenty-four Soldiers participated in this experiment.

### 2.1.2. Design

The study took place over five days of testing. On each day, Soldiers performed a battery of tests while wearing ACUs and one of three respirator masks possessing either a low (1.23 cm $H_2O$), medium (2.61 cm $H_2O$) or high (4.29 cm $H_2O$) Respirator Resistance level, or no mask.

### 2.1.3. Cognitive Tasks

Soldiers performed five cognitive tasks that assessed a range of processes:

(1) Attention Network Test (ANT), which measures lower- (basic vigilance) to higher-level (executive control) visual attention processes by combining a cued reaction time task with a flanker task designed to challenge the executive control of attention. Volunteers are presented with visual cues that may alert them to the onset of an upcoming trial, visual cues that may orient them to a particular region of the screen, and then an array of arrows. Volunteers' task is to respond to the direction of a center arrow (left/right) placed within an array of either congruent or incongruent flanking arrows (Figure 2).


Figure 2. Example of congruent and incongruent flanking arrows in the Attention Network Task.

Central cues (fixation cross) are provided one half of the trials in this test, signaling the beginning of the trial to participants. Spatial cues (top/bottom) are provided on two-thirds of the trials, signaling to participants where the arrows will appear on the screen. Performance difference scores are calculated by comparing the cue and flanker conditions. The results provide insight into the functioning of three theorized attention networks: (a) Alerting, using the central cue as an alert to the onset of an upcoming trial; higher scores indicate that a participant takes advantage of alerts to ready himself for an upcoming event, (b) Orienting, using the spatial cue an as alert to the location of an upcoming trial (i.e. whether trial will occur above or below fixation point); higher scores indicate that a participant takes advantage of the orienting cues; and (c) Executive Control, the ability to quickly detect and resolve conflict, inhibitory control (i.e. correctly responding to the left/right direction of the center arrow in the presence of conflicting flanker arrows); lower scores indicate a higher level of executive control.

In a Soldier-relevant context, the Alerting system allows a Soldier to maintain vigilance on a scene and use all available information (such as spotting enemy movement) to ready themselves for an immediate response. The extent to which Soldiers can quickly use available information to prepare themselves for a response determines the functioning of the Alerting system. The Orienting system allows a Soldier to quickly allocate their attention towards a particular area of an environment *where* they expect something to occur; for instance, seeing a muzzle flash emanate from the upper left side of a building will cue a Soldier to orient attention towards this area in the expectation of identifying important information (e.g., enemy appearance). The extent to which a Soldier can quickly use spatial cues to orient their attention to a particular location in space determines the functioning of the Orienting system. The Executive Control system allows a Soldier to withhold a response in the presence of conflicting visual information; for instance, withholding a shoot response when a civilian is the central target within a group of enemy combatants. The extent to which the presence of response-incompatible flanking arrows slows the Soldier's (shoot/don't shoot) response is a measure of failed Executive Control.

(2) Task-Switching, which measures higher-level sequential inhibition and the activation of learned stimulus-response mapping. Volunteers performed a squad strike/supply task. On a monitor they were shown a friendly and an enemy squad to the left and right of the center of the screen, and were asked to either "supply friendly squads" or "strike enemy squads." Figure 3 provides an example of the abstract squad displays.

Figure 3. Enemy (red) and friendly (blue) squads in Task-Switching task.

The action of supplying or striking periodically switched throughout the course of this task. Task-Switching performance costs are typically seen as increases in reaction time (RT); RT increases more when runs alternate between strike/supply (e.g., strike, supply, or supply, strike compared to non-alternating runs (e.g. strike, strike, or supply, supply, etc.). This task tests volunteers' ability to inhibit a learned response set and temporarily activate an alternative set.

(3) Simple Response Time Task that measures lower-level visual attention. Volunteers responded to target silhouettes that appear on a display at one of four distances. Participants were instructed to press the spacebar as quickly as possible after they observed a silhouette. This task tests basic stimulus-response RT, much like the Alerting function of the ANT above, as well as hit-rate accuracy (i.e. proportion of silhouettes to which volunteers responded).

(4) Sustained Vigilance Task, which measures lower-level visual attention with added higher-level inhibitory control (i.e. shoot/don't shoot). Volunteers observed a cluttered scene (Figure 4), in which enemies and civilians appeared successively in various locations. Volunteers were instructed to press the spacebar as quickly as possible in response to the appearance of an enemy, but not to press the spacebar when a civilian appears. An enemy appears on one-half of the trials, and a civilian appears on the remaining half. There were three dependent measures in this task: hit rate, response time, and false alarm (FA; responding to civilian as if it were an enemy) rate.

Figure 4. Environment in Sustained Vigilance Task.

(5) Squad Maneuver Task, which measures spatial working memory as Soldiers must monitor and update virtual squad locations. Volunteers observed a 6x6 square grid in which 1-3 squad icons appeared; volunteers were instructed to learn the squad locations. Between 1-3 squad movement commands were then presented, and the squad locations would then change. Volunteers were asked to respond yes or no to whether the new squad locations corresponded to the commands presented. Figure 5 shows an example of the Squad Maneuver Task. Accuracy (hit rate), false alarm rate, and RT were measured, and corrected recognition, or sensitivity *(d')* was calculated (z-scored hits minus z-scored false alarms).

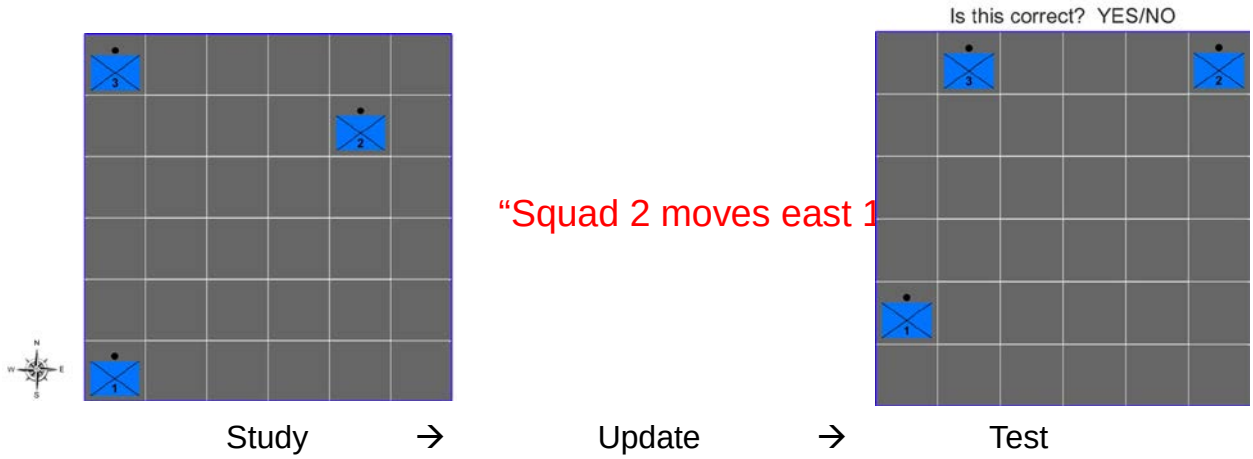


Figure 5. Example of the Squad Maneuver Task.

### 2.1.4. Physical Tasks

In addition to the cognitive tasks, volunteers performed two physical tasks designed to test gross and fine motor coordination. The first was a Bennett Hand Tool Task, wherein Soldiers used common hand tools (two open-ended wrenches, one adjustable wrench, one screwdriver) to loosen, relocate, and tighten nut/bolt/screw hardware assemblies from one location to another (Figure 6). Time to completion was the dependent measurement.

Figure 6. Bennett Hand Tool Task

The second physical task required Soldiers to move boxes filled with sand across a laboratory floor, one box at a time. Boxes were either light (10 kg), moderate (15 kg) or heavy (20 kg) weights. Soldiers were required to step on designated floor targets; this constrained their walking path.

Dependent measures included the number of boxes moved over a period of ten minutes, and the number of floor targets missed.

#### 2.1.5. Procedure

The study took place over five consecutive days. The first day was devoted to instruction and training. On days 2-5 volunteers were placed in one of four conditions: no mask, low, medium, or high Respirator Resistance (RR). Volunteers then cognitive tasks described above. Following the cognitive tasks, volunteers performed the two physical tasks.

## 2.2. Experiment 1 Results

#### 2.2.1. Attention Network Test

Figure 7 displays the results of the Attention Network Test. A repeated-measures Analysis of Variance (ANOVA) performed on Alerting data indicates that there was no effect of RR on response time ($F$ (3, 69) = .72, $p$ = .54) or accuracy ($F$ (3, 69) = .75, $p$ = .52). A repeated-measures ANOVA was performed on the Orienting data and revealed no effect of RR on response time ($F$ (3, 69) = .23, $p$ = .88) or accuracy ($F$ (3, 69) = 1.07, $p$ = .37). A repeated-measures ANOVA was performed on the Executive Control scores: There was a main effect of RR on response time (F (3, 69) = 3.19, $p$ = .03) but no effect on accuracy ($F$ (3, 69) = .296, $p$ = .83). Pairwise comparisons performed on the response time data revealed that response times in the no mask condition were significantly lower than the 2.61 and 4.29 cm $H_2O$ conditions ($p < .025$), and response times in the 1.23 cm $H_2O$ condition were lower than in the 4.29 cm $H_2O$ condition ($p < .05$). These results indicate that overall as RR increased, Executive Control of attention became increasingly impaired.

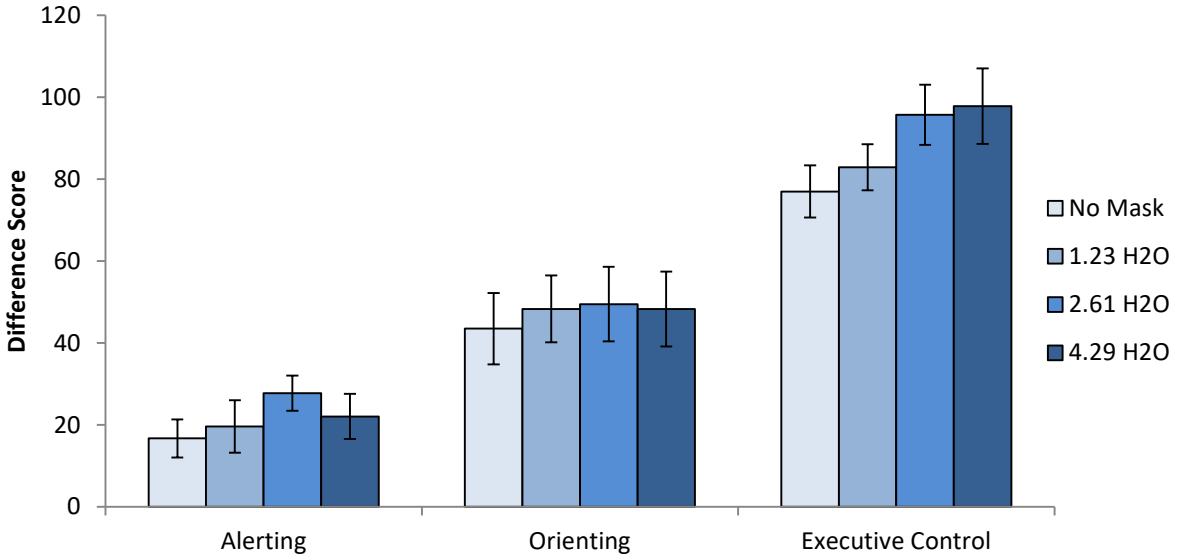


Figure 7. Attention Network Test results for Respirator Resistance Experiment 1.

### 2.2.2. Task-Switching

Figure 8 displays the results of the Task-Switching cognitive task. A repeated-measures ANOVA revealed that there was a response time cost effect on alternating runs, with a diminishing cost over the length of the set (from switch to switch + 3 runs), $F$ (3,66) = 26.99, $p < .01$. There was also an interaction with inhalation pressure: In the 4.29 cm $H_2O$ condition, a switch did not differ from a "switch + 1 run" with respect to response time, $t$ (23) = 1.28, $p < .05$. This effect did not appear when analyzing non-alternating runs. These results suggest that there is a prolonged recovery from task set switches as a function of increased RR.

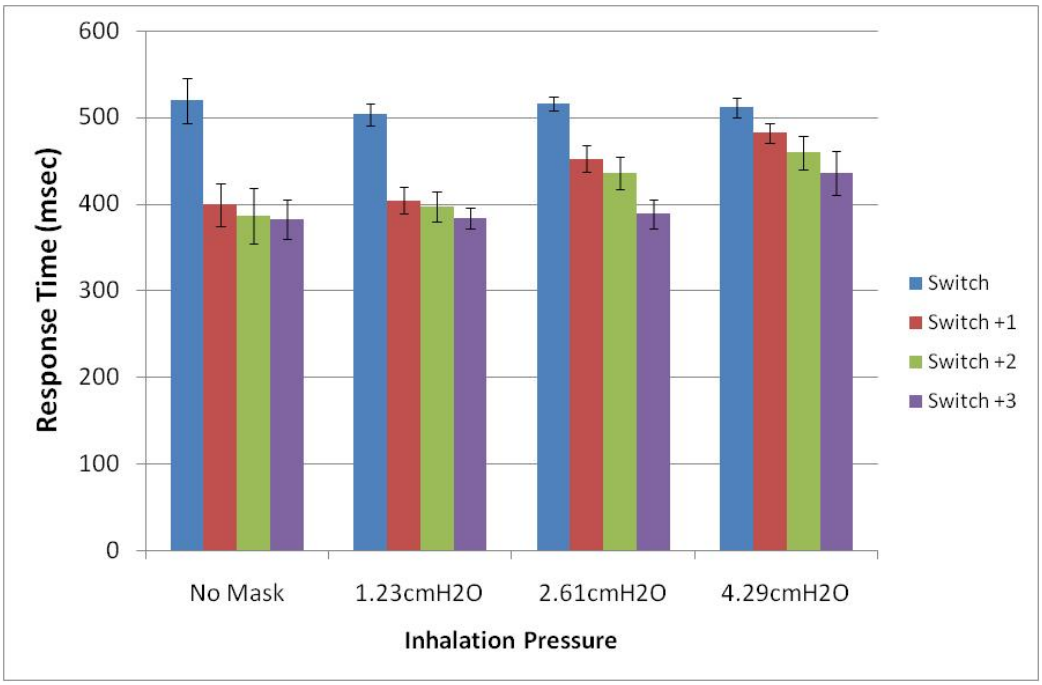


Figure 8. Task-Switching results for Respirator Resistance Experiment 1.

### 2.2.3. Simple Response Time

Table 1 displays the results of the Simple Response Time task. There was no effect of RR on hit rate, which was at ceiling levels in all RR conditions, $F$ (3, 69) = 1.41, $p$ = .25. In addition, there was no effect of RR on response time, $F$ (3, 69) = 1.77, $p$ = .16.

| Respirator Resistance | Hit Rate | Response Time |
|---|---|---|
| **No Mask** | .997 | 487.2 |
| **1.23cm$H_2O$** | 1.00 | 491.9 |
| **2.61cm$H_2O$** | .986 | 490.9 |
| **4.29cm$H_2O$** | .986 | 524.6 |

Table 1. Simple Response Time results for Respirator Resistance Experiment 1.

### 2.2.4. Sustained Vigilance

Table 2 displays the results of the Sustained Vigilance task. There was no effect of RR on hit rate, which was at ceiling levels in all RR conditions, $F$ (3, 69) = 1.391, $p$ = .25. In addition, there was no effect of RR on response time, $F$ (3, 69) = 1.08, $p$ = .36. There was a marginal effect of RR on false alarm rate, $F$ (3, 69) = 2.63, $p$ = .057. A repeated-measures ANOVA performed on *d'* sensitivity levels (i.e. z-scored false alarms subtracted from z-scored hits) revealed a main effect of RR, $F$ (3, 69) = 2.97, $p$ = .04. Overall, the results suggest that as RR increased, Executive Control functioning became impaired; these results converge with those in the ANT and Task-Switching tasks above.

| **Respirator Resistance** | **Hit Rate** | **Response Time** | **False Alarm Rate** | ***d'* Sensitivity** |
|---|---|---|---|---|
| **No Mask** | .984 | 695.3 | .015 | 4.23 |
| **1.23 cm $H_2O$** | .979 | 704.3 | .022 | 4.07 |
| **2.61 cm $H_2O$** | .971 | 722.5 | .032 | 3.95 |
| **4.29 cm $H_2O$** | .967 | 721.4 | .034 | 3.83 |

Table 2. Sustained Vigilance results for Respirator Resistance Experiment 1.

### 2.2.5. Squad Maneuver

Figure 9 shows the results of the Squad Maneuver Task. Overall, volunteers experienced increased difficulty as the number of squads and movement commands increased. There were main effects of squad and movement numbers. There were no main or interactive effects of RR on any measure, including sensitivity (as assessed using *d'*).

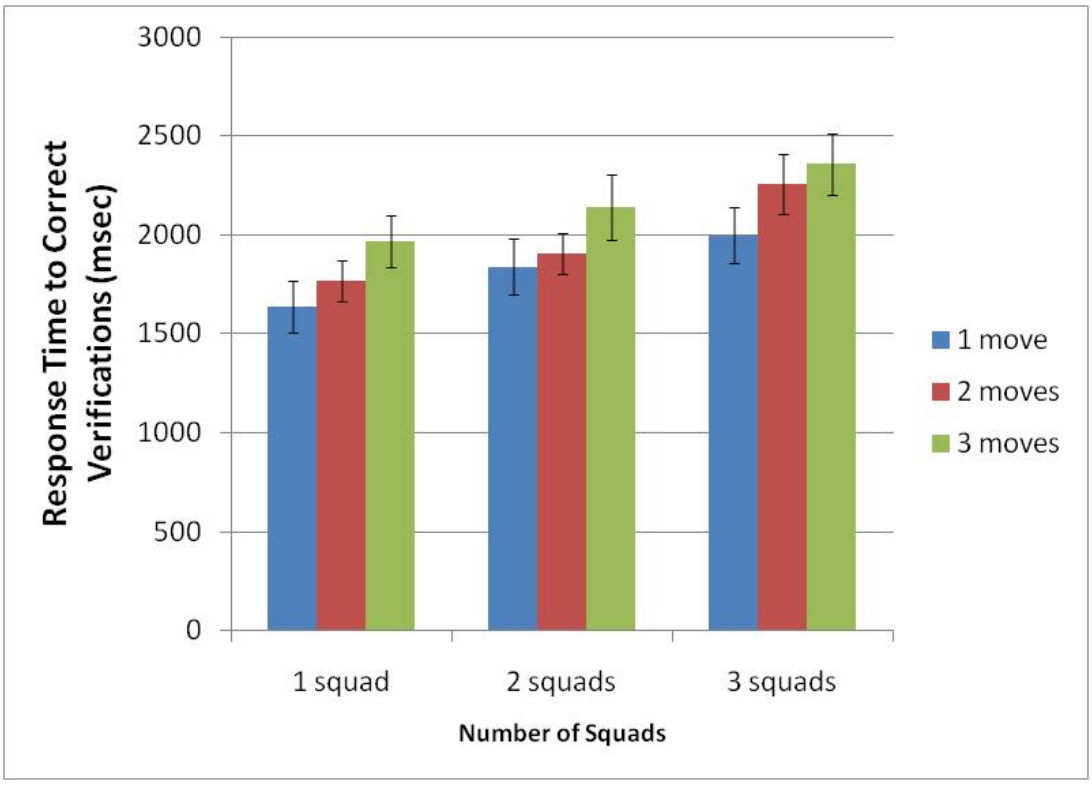


Figure 9. Squad Maneuver task results for Respirator Resistance Experiment 1.

### 2.2.6. Bennett Hand Tool Task

Table 3 displays the results of the Bennett Hand Tool Task. Overall, performance on this task did not vary as a function of RR.

| Test Condition | Task Time (s) | Performance Rating (%) |
|---|---|---|
| No Mask | 358 ± 9 | n/a |
| 1.23 cm $H_2O$ | 358 ± 8 | 99.6 |
| 2.61 cm $H_2O$ | 362 ± 10 | 98.6 |
| 4.29 cm $H_2O$ | 362 ± 9 | 98.4 |

Table 3. Bennett Hand Tool Task results for Respirator Resistance Experiment 1.

### 2.2.7. Box Movement

Figure 10 displays the results of the Box Movement task. As RR increased, volunteers' gross motor performance became degraded. This effect was present for all three levels of box weight, suggesting that gross motor performance is affected regardless of the extent to which volunteers were physically taxed.

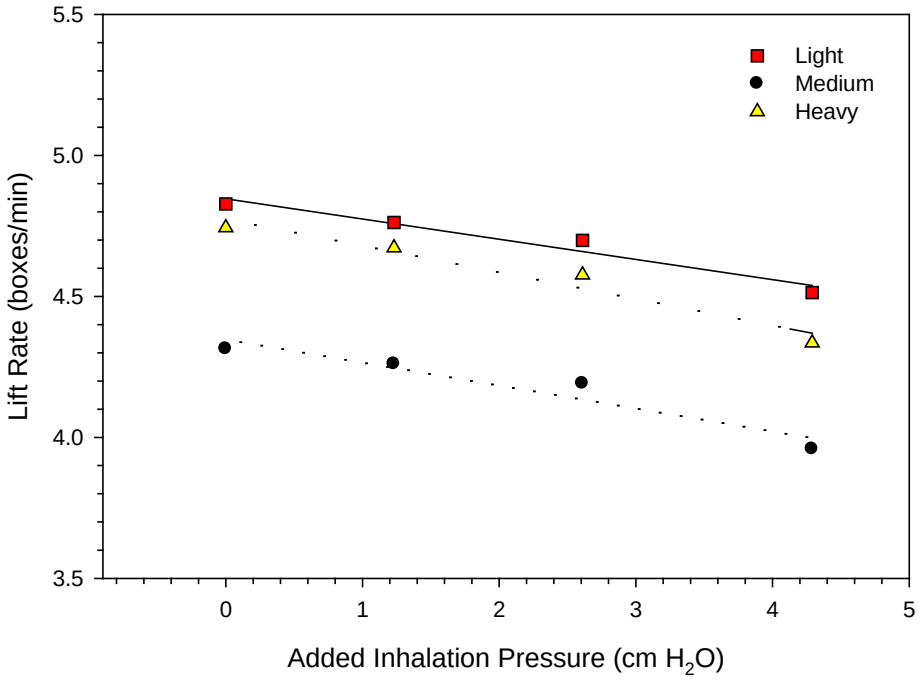


Figure 10. Box Movement task results, Respirator Resistance Experiment 1.

## 2.3. Experiment 2 Method

### 2.3.1. Participants

Twenty-four Soldiers participated in Experiment 2.

### 2.3.2. Design

The study took place over six days of testing. On each day, Soldiers performed a battery of tests while wearing the CB garment attire and one of three respirator masks possessing either a low (1.23 cm $H_2O$), medium (2.61 cm $H_2O$) or high (4.29 cm $H_2O$) Respirator Resistance level, or no mask. In a final session, volunteers wore the medium respirator mask and a helmet.

### 2.3.3. Tasks

Soldiers performed the same five cognitive and two physical tasks used in Experiment 1: the Attention Network Test, Task-Switching, Simple Response Time, Sustained Vigilance, Squad Maneuver, Bennett Hand Tool, and Box Lifting tasks.

### 2.3.4. Procedure

The study took place over six consecutive days. The first day was devoted to instruction and training. On days 2-5 volunteers were placed in one of four conditions: no mask, low, medium, or high Respirator Resistance (RR). On the final day, volunteers donned the medium resistance respriator mask and a helmet. Volunteers then performed cognitive tasks described above in section 2.1.3. Following the cognitive tasks, volunteers performed the two physical tasks described above in section 2.1.4.

## 2.4. Experiment 2 Results

### 2.4.1. Attention Network Test

Figure 11 displays the results of the Attention Network Test. A repeated-measures Analysis of Variance (ANOVA) performed on Alerting data indicates that there was no effect of RR on response time ($F$ (3, 66) = .05, $p$ = .99) or accuracy ($F$ (3, 69) = .53, $p$ = .66). A repeated-measures ANOVA was performed on the Orienting data and revealed no effect of RR on response time ($F$ (3, 66) = .46, $p$ = .71) or accuracy ($F$ (3, 69) = .25, $p$ = .86). A repeated-measures ANOVA was performed on the Executive Control scores: There was a main effect of RR on response time (F (3, 66) = 3.0, $p$ = .04) but no effect on accuracy ($F$ (3, 69) = .53, $p$ = .67). Pairwise comparisons performed on the response time data revealed that response times in the no mask condition were significantly lower than the 2.61 and 4.29 cm $H_2O$ conditions ($p$ < .034). These results indicate that overall as RR increased, Executive Control of attention became increasingly impaired.

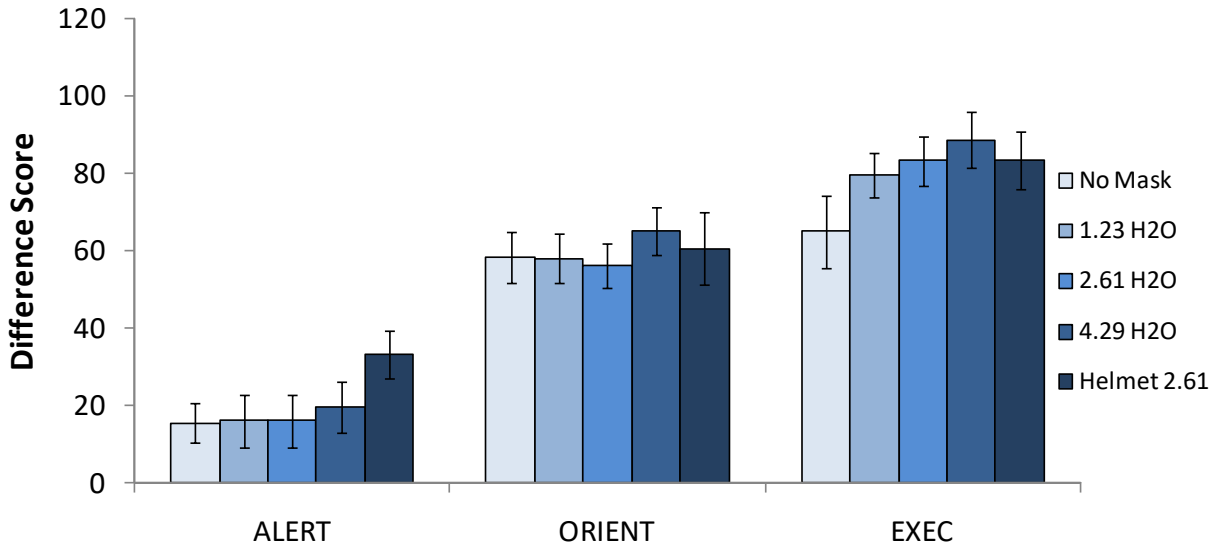


Figure 11. Attention Network Test results for Respirator Resistance Experiment 2.

### 2.4.2. Task-Switching

Figure 12 displays the results of the Task-Switching cognitive task. A repeated-measures ANOVA revealed that there was a response time cost effect on alternating runs, with a diminishing cost over the length of the set (from switch to switch + 3 runs), $F$ (3,66) = 23.08, $p < .01$. There was also an interaction with inhalation pressure: In the 4.29 cm $H_2O$ condition, a switch did not differ from a "switch + 1 run" with respect to response time, $t$ (23) = 1.29, $p > .05$. This effect did not appear when analyzing non-alternating runs. These results suggest that there is a prolonged recovery from task set switches as a function of increased RR.

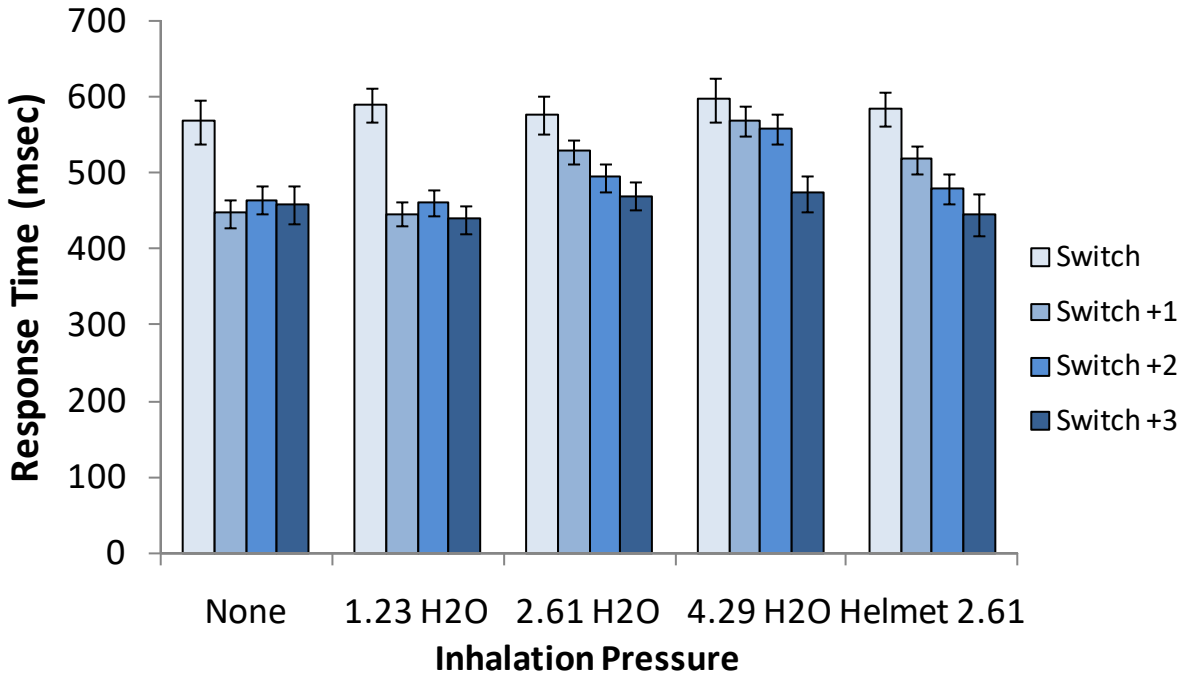


Figure 12. Task-Switching results for Respirator Resistance Experiment 2.

2.4.3. Simple Response Time

Table 4 displays the results of the Simple Response Time task. There was no effect of RR on hit rate, which was at ceiling levels in all RR conditions, $F$ (3, 63) = .66, $p$ = .58. In addition, there was no effect of RR on response time, $F$ (3, 60) = 2.16, $p$ = .11.

| Respirator Resistance | Hit Rate | Response Time |
|---|---|---|
| **No Mask** | 1.00 | 646.9 |
| **1.23cm$H_2O$** | .999 | 695.9 |
| **2.61cm$H_2O$** | .999 | 657.9 |
| **4.29cm$H_2O$** | 1.00 | 669.1 |
| **Helmet + 2.61** | .998 | 683.2 |

Table 4. Simple Response Time results for Respirator Resistance Experiment 2.

### 2.4.4. Sustained Vigilance

Table 5 displays the results of the Sustained Vigilance task. There was no effect of RR on hit rate, which was at ceiling levels in all RR conditions, $F$ (3, 66) = .22, $p$ = .89. In addition, there was no effect of RR on response time, $F$ (3, 66) = .12, $p$ = .95. There was a significant effect of RR on false alarm rate, $F$ (3, 66) = 3.14, $p$ = .031. A repeated-measures ANOVA performed on *d'* sensitivity levels (i.e. z-scored false alarms subtracted from z-scored hits) revealed a main effect of RR, $F$ (3, 66) = 2.45, $p$ = .07. Overall, the results suggest that as RR increased, Executive Control functioning became impaired; these results converge with those in the ANT and Task-Switching tasks above.

| **Respirator Resistance** | **Hit Rate** | **Response Time** | **False Alarm Rate** | ***d'* Sensitivity** |
|---|---|---|---|---|
| **No Mask** | .971 | 723.8 | .025 | 3.50 |
| **1.23 cm $H_2O$** | .977 | 727.3 | .052 | 3.36 |
| **2.61 cm $H_2O$** | .971 | 728.5 | .077 | 3.24 |
| **4.29 cm $H_2O$** | .971 | 732.8 | .085 | 3.22 |
| **Helmet + 2.61** | .975 | 731.4 | .074 | 3.31 |

Table 5. Sustained Vigilance results for Respirator Resistance Experiment 2.

### 2.4.5. Squad Maneuver

Figure 13 shows the results of the Squad Maneuver Task. Overall, volunteers experienced increased difficulty as the number of squads and movement commands increased. There were main effects of squad and movement numbers. There were no main or interactive effects of RR on any measure, including sensitivity (as assessed using *d'*).

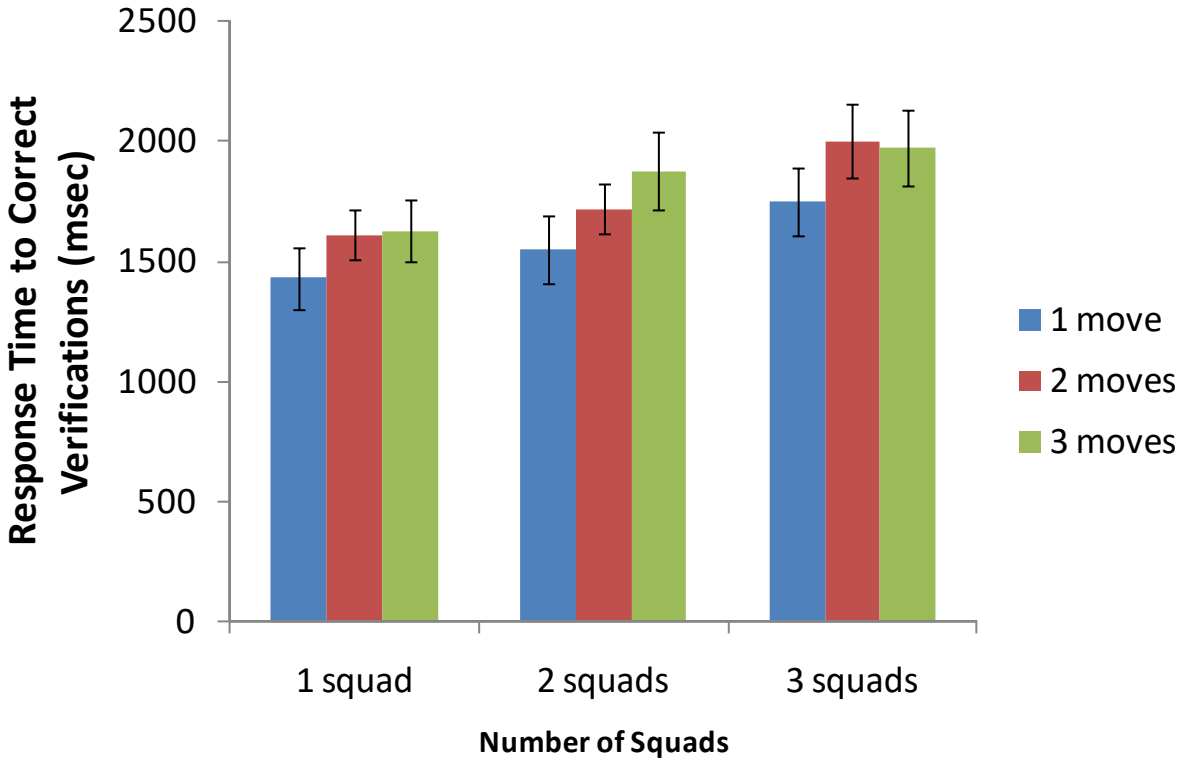


Figure 13. Squad Maneuver task results for Respirator Resistance Experiment 2.

### 2.4.6. Bennett Hand Tool Task

Table 6 displays the results of the Bennett Hand Tool Task. Overall, performance on this task did not vary as a function of RR, $F$ (4, 84) = .78, $p$ = .54.

| Test Condition | Task Time (s) |
|---|---|
| No Mask | 438 ± 22 |
| 1.23 cm $H_2O$ | 429 ± 15 |
| 2.61 cm $H_2O$ | 439 ± 15 |
| 4.29 cm $H_2O$ | 440 ± 14 |
| Helmet + 2.61 cm $H_2O$ | 405 ± 23 |

Table 6. Bennett Hand Tool Task results for Respirator Resistance Experiment 2.

### 2.4.7. Box Movement

Figure 14 displays the results of the Box Movement task. There were no significant effects of box weight, $F$ (2, 38) = .56, $p$ = .58, or RR level, $F$ (4, 76) = .999, $p$ = .4, nor was there a significant interaction, $F$ (8, 152) = 1.39, $p$ = .2.

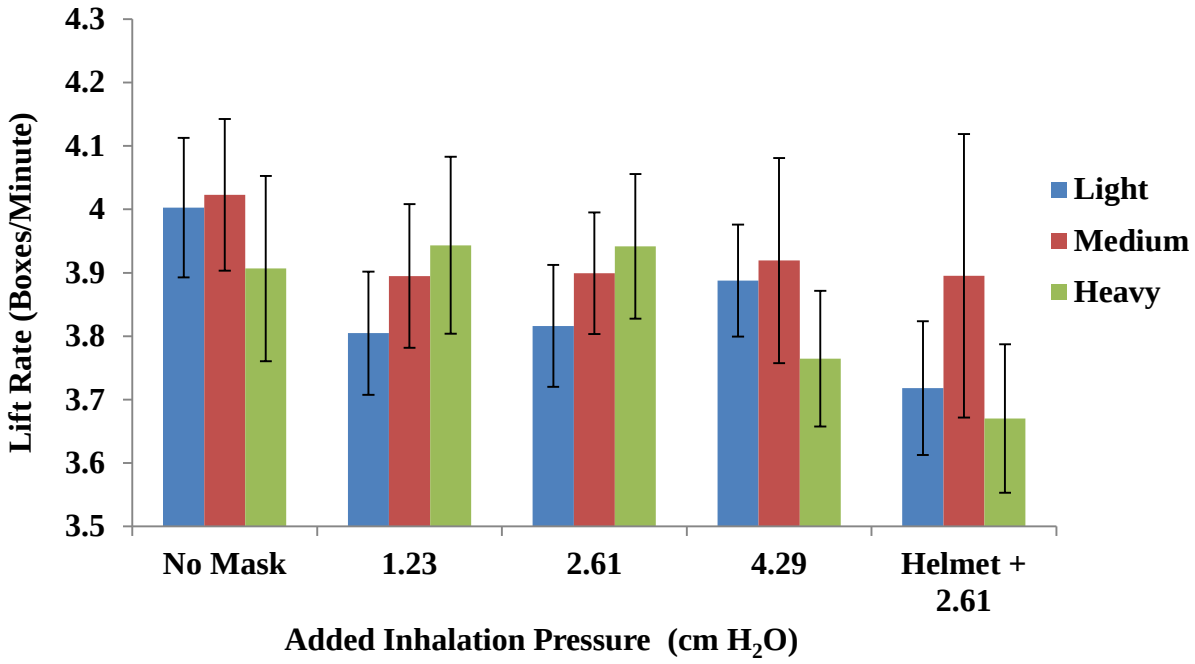


Figure 14. Box Movement task results, Respirator Resistance Experiment 2.

## 2.5. Respirator Resistance Experiments 1-2 Discussion

The quantitative performance decrements found in this study were used to develop components of the computational model.

Results from both Experiment 1 and Experiment 2 provide consistent, convergent evidence of higher-level Executive Control difficulties as a function of increased Respirator Resistance: The ANT - Executive Control network of visual attention displayed impairment primarily in the 2.61 and 4.29 cm $H_2O$ conditions, and performance in the Task-Switching task displayed Executive Control difficulties in general. In addition, there was a marginal decrease in Executive Control in the Sustained Vigilance task (i.e., the inhibition of a prepotent "shoot" response). In contrast, the relatively lower-level tasks, as well as the spatial working memory (Squad Maneuver) task showed no evidence of impairment as a function of Respirator Resistance.

Executive Control impairment can be explained as a result of decreased oxygen consumption due to increased RR. Research has shown that oxyhemoglobin desaturation/hypoxemia has resulted in reductions in Executive Control (Naismith, Winger, Gotsopoulos, Hickie, & Cistulli, 2004; Sagaspe, Philip, & Schwartz, 2007). Moreover, decreases in oxygen consumption can also explain the reductions in gross motor performance in the Box Movement task.

# 3. EFFECTS OF MOISTURE-VAPOR TRANSFER RATE ON COGNITIVE PERFORMANCE

NSRDEC researchers conducted an experiment to determine the effects of different levels of CB over-garment Moisture-Vapor Transfer Rate (MVTR) on cognitive performance across a range of tasks. The current CB over-garment, a component of the MOPP-4 ensemble, has an MVTR level of 764 $g/m^2/24$ hrs. Three prototype garments possessing MVTR levels of 5, 670, and 864 $g/m^2/24$ hrs were developed for this study. The results from this experiment were used to help populate the computational model's task-effect database.

## 3.1. Method

### 3.1.1. Participants

Twenty-four Soldiers participated in this experiment.

### 3.1.2. Design

The study took place over five days of testing. On each day, Soldiers performed a battery of tests while wearing either ACUs, which possess an MVTR of 915 $g/m^2/24$ hrs, or one of three CB over-garments possessing either a low (5 $g/m^2/24$ hrs), medium (670 $g/m^2/24$ hrs) or high (864

g/m$^2$/24 hrs) MVTR. The standard CB over-garment (764 g/m$^2$/24 hrs) was not worn in this experiment.

#### 3.1.3. Tasks

Volunteers in the MVTR study performed the five cognitive tasks (ANT, Task-Switching, Simple Response Time, Sustained Vigilance, and Squad Maneuver) and two physical tasks (Bennett Hand Tool Task and Box Movement) that were performed in the RR experiments.

#### 3.1.4. Procedure

The procedure in the MVTR study was identical to the procedure in the RR study. The study took place over five consecutive days: Day 1 was devoted to practice, and on days 2-5 volunteers wore either ACUs (915 g/m$^2$/24 hrs) or one of the three modified CB overgarments (5, 670, 864 g/ m$^2$/24 hrs).

### 3.2. Results

#### 3.2.1. Attention Network Test

Figure 15 displays the results of the Attention Network Test. There was no effect of MVTR on response time ($F$ (3, 69) = .83, $p$ = .48) or accuracy ($F$ (3, 69) = .97, $p$ = .40), in repeated-measures ANOVAs; none of the three networks were affected by MVTR.

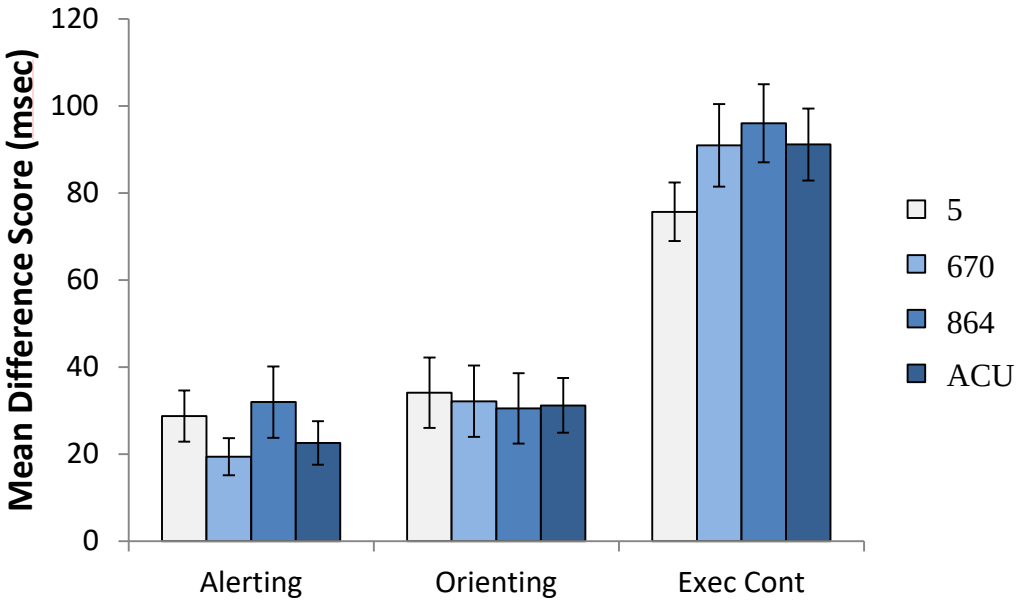


Figure 15. Attention Network Test results for MVTR study.

### 3.2.2. Task-Switching

Figure 16 displays the results of the Task-Switching cognitive task. Depicted are the alternating run reaction times (RTs). The commonplace switch cost effect was present in the data; there were higher RTs on alternating runs than on non-alternating runs. There was no main effect of MVTR, $F$ (3, 69) = 1.5, $p$ = .22 (repeated-measures ANOVA). However, a paired $t$ test revealed a significant different between the 5 g/m$^2$/24 hrs MVTR condition and the ACU (915 g/m$^2$/24 hrs) condition, $p$ = .03 (shown on Figure 12). The results suggest a prolonged recovery from task set switches as a function of decreased MVTR.

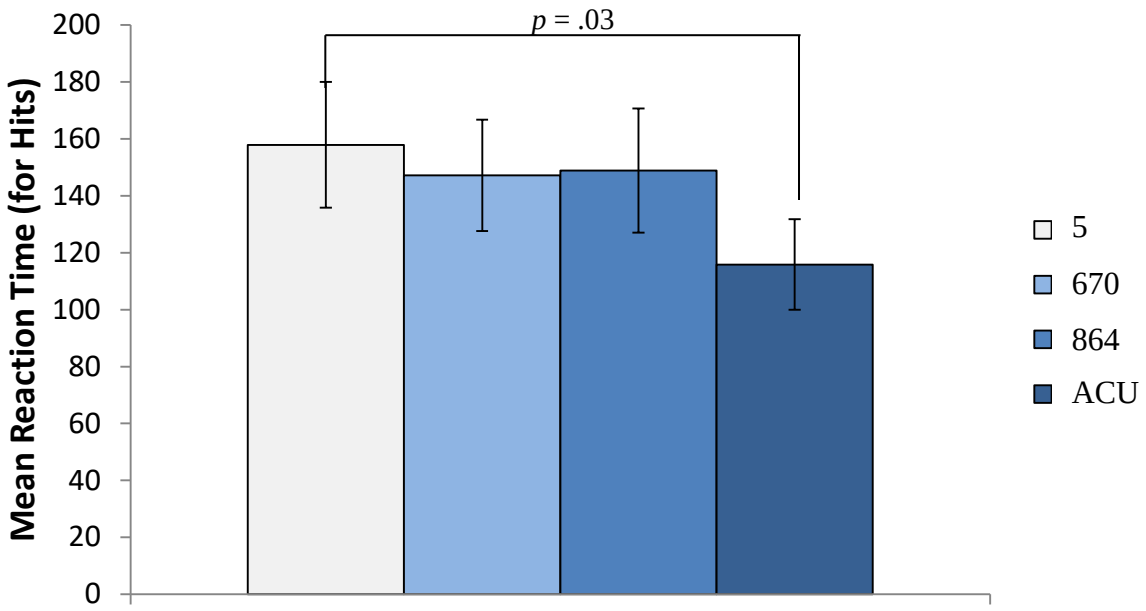


Figure 16. Task-Switching results for MVTR study.

### 3.2.3. Simple Response Time

Figure 17 displays the results of the Simple Response Time task. There was a main effect of MVTR, $F$ (3, 69) = 4.50, $p < .01$, suggesting that lower MVTR impaired volunteers' ability to quickly respond to visual stimuli. The results of paired comparison t-tests are depicted in the figure.

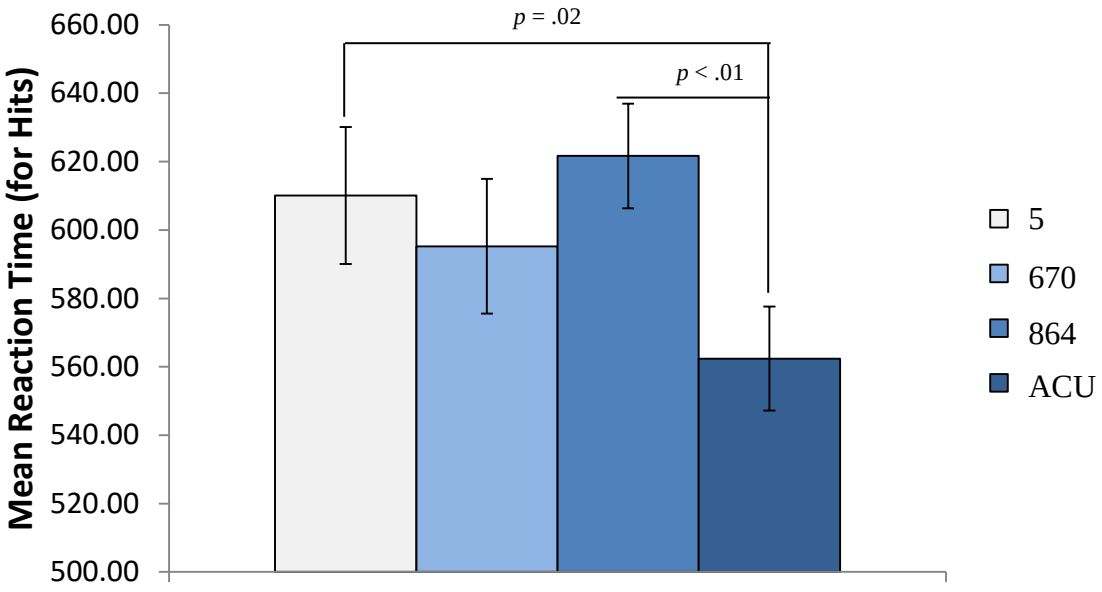


Figure 17. Simple Response Time results in MVTR study.

### 3.2.4. Sustained Vigilance

Figure 18 displays the results of the Sustained Vigilance task. There was a main effect (trend) of MVTR on false alarm rates, $F$ (3, 69) = 2.26, $p$ = .09. This result suggests that the ability to withhold a response in a "shoot/don't shoot" situation is reduced with lower MVTR levels. The results of paired comparison t-tests are depicted in the figure.

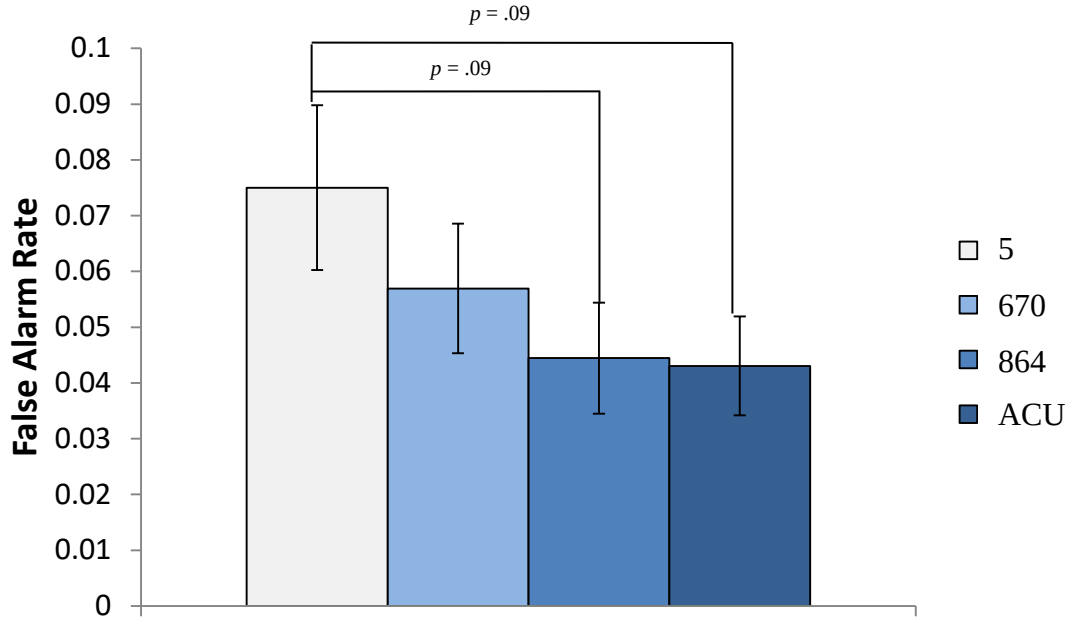


Figure 18. Sustained Vigilance results in MVTR study.

### 3.2.5. Squad Maneuver

Figure 19 shows the results of the Squad Maneuver Task. There was a main effect of MVTR on accuracy during trials with multiple squads and multiple movement commands (i.e. high workload), $F$ (3, 69) = 2.89, $p$ = .04. This suggests that spatial working memory capacity is impaired at lower MVTR levels. The results of paired comparison t-tests are depicted in the figure.

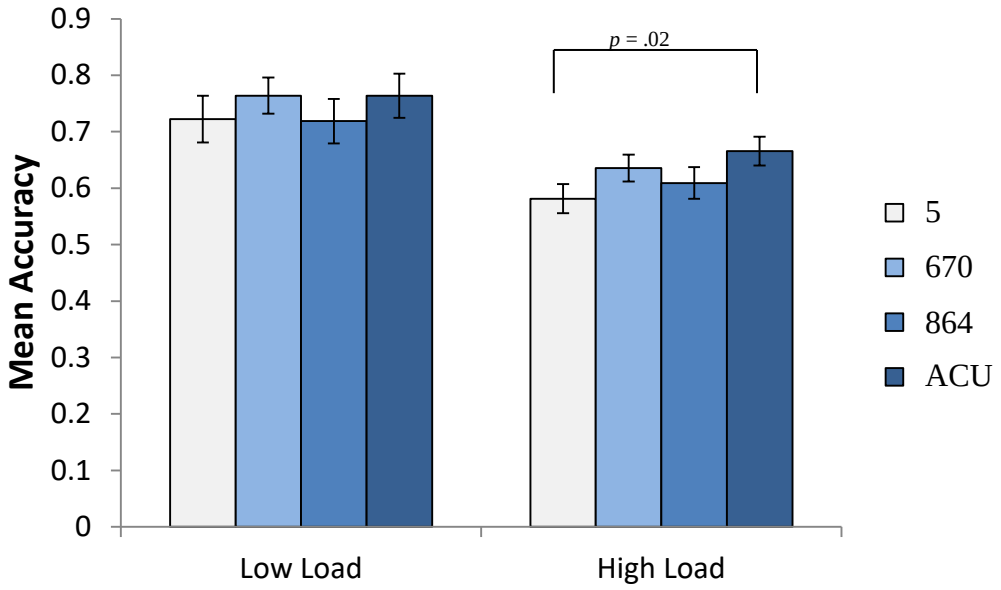


Figure 19. Squad Maneuver task results in MVTR study.

### 3.2.6. Bennett Hand Tool Task

There was no impact of MVTR on performance in the Bennett Hand Tool Task.

### 3.2.7. Box Movement

Figure 20 displays the results of the Box Movement task. Volunteers' gross motor performance (i.e. lift rate) declined when they donned the CB over-garments, but there were no differences between MVTR levels. In addition, performance became degraded with heavier box weights.

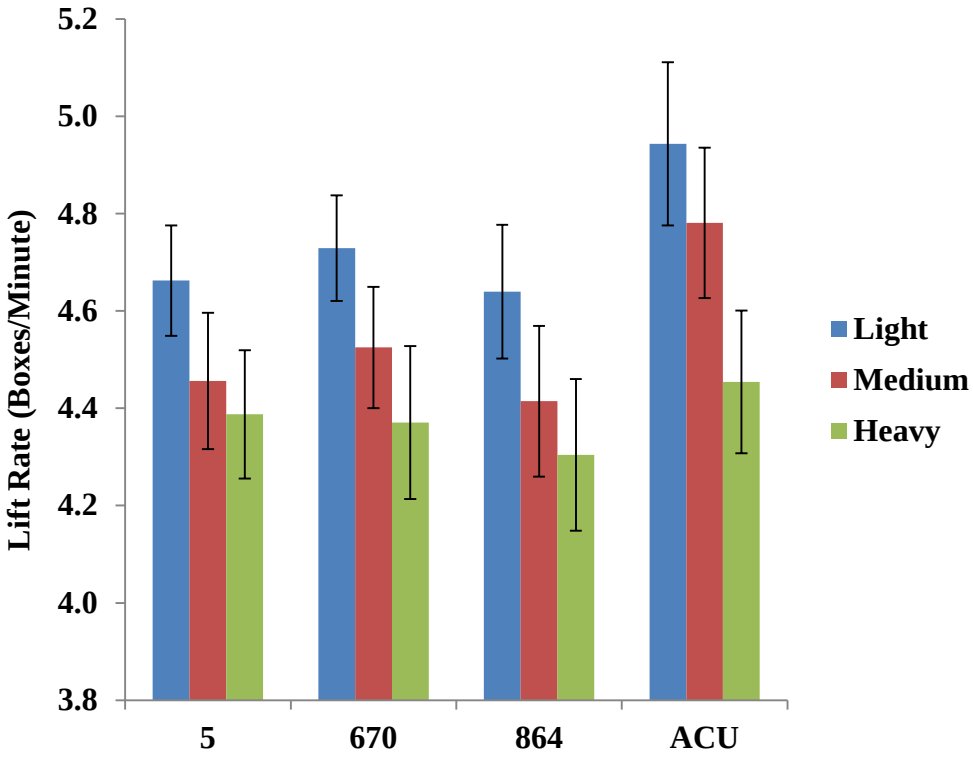


Figure 20. Box Movement task results, MVTR study.

### 3.3. Discussion

The quantitative performance decrements found in this study were used to develop components of the computational model.

Performance in four of the five cognitive tasks showed evidence of cognitive decrements as a function of decreased MVTR: Task-Switching, Simple Response Time, Sustained Vigilance, and Squad Maneuver tasks. These results overall suggest broad-based cognitive performance impairments due to decreased MVTR, indicating that MVTR affects a wide spectrum of tasks with regards to both speed and accuracy. Gross motor performance differences between ACUs and CB over-garments indicate that the presence of the over-garment impairs tasks that require exertion. Fine motor control was unaffected by the over-garments. This was unsurprising as participants did not wear gloves during the experiment.

## 4. EFFECT OF FIELD-OF-VIEW ON PERIPHERAL TARGET DISCRIMINATION

NSRDEC researchers conducted an experiment to determine how the horizontal field-of-view (FOV) of the respirator mask/goggles affected peripheral vision target discrimination. The current respirator mask/goggles face protection component of the MOPP-4 ensemble (Figure 1) has a horizontal FOV of 156 degrees. Researchers created modified respirators with horizontal fields-of-view of 132

and 108 degrees. Researchers predicted that a decreased horizontal FOV would impair one's ability to discriminate between targets (lower accuracy rates and greater reaction times) that appeared in the peripheral visual field, but not the central visual field. The results from this experiment were used to help populate the computational model's task-effect database.

## 4.1. Method

### 4.1.1 Participants

Thirteen Soldiers participated in this experiment.

### 4.1.2. Stimuli

The visual targets in this study were ten 200 x 200 pixel images of capital and lower-case letters. Only letters that had visually distinct capital and lower-case forms were used (e.g. A/a, G/g, not O/o, V/v).

### 4.1.3. Design

Data were collected during a single study session. Volunteers performed a target discrimination task while wearing three different M50s (156, 132, 108 degree horizontal FOV) or no mask (i.e. four blocks). The order in which volunteers donned each mask was counterbalanced across participants. The visual target letters were presented on a 55-inch monitor at a distance of 10 inches from the volunteer. On each trial a single letter appeared for 250 ms, with an interstimulus interval (ISI) of 500 ms. Letters appeared in 48 locations on the monitor, at *x*-coordinates of 0, 90, 180, 270, 360, 450, 540, 630, 720, 810, 900, 990, 1080, 1260, and 1350 pixels, and at *y*-coordinates of 300, 400, and 500 pixels. These positions were binned into four columns (far left, mid left, mid right, far right) and three rows (top, center, bottom) for purposes of analysis and visualization. Each capital and lower case letter appeared once at each location, for a total of 960 trials per block, and 3840 trials total. Accuracy and reaction time were measured.

### 4.1.4. Task

On each trial volunteers were instructed to determine as quickly as possible whether the target was a capital or lower case letter. Volunteers entered their response on a keyboard (F = capital, J = lower case; neither F nor J appeared as stimuli).

#### 4.1.5. Procedure

Volunteers were given verbal instructions, and were fitted with either a small, medium, or large set of M50s. Volunteers performed 240 practice trials, after which the experimenters answered any questions the volunteers had that would not invalidate the results of the study. Volunteers then proceeded with the four blocks of trials described above. In each block volunteers wore either no mask or a mask with a horizontal FOV of 156, 132, or 108 degrees.

## 4.2. Results

#### 4.2.1. Accuracy

Figure 20 displays the accuracy results by binned column position and FOV. There were no differences between the three binned rows; vertical FOV was unchanged across the respirator's conditions. For analysis the data were collapsed across left/right columns (i.e. far left and far right were collapsed, as were mid left and mid right). A repeated-measures ANOVA revealed no main effect of FOV on accuracy, $F$ (3, 36) = 1.8, $p$ = .16. There was, however, a main effect of location (far vs. mid), $F$ (1, 12) = 18.3, $p$ = .001, and a significant interaction (FOV x location), $F$ (3, 36) = 5.4, $p$ = .004. In the 108 and 132 degree FOV conditions, performance was poorer in the far column locations than in the mid column locations. This result supports the prediction that decreases in horizontal FOV would negatively affect target discrimination in the periphery, while leaving the center of the visual field unimpaired. Critically, no differences were found between the No Mask condition and the FOV afforded by the currently fielded respirator mask.

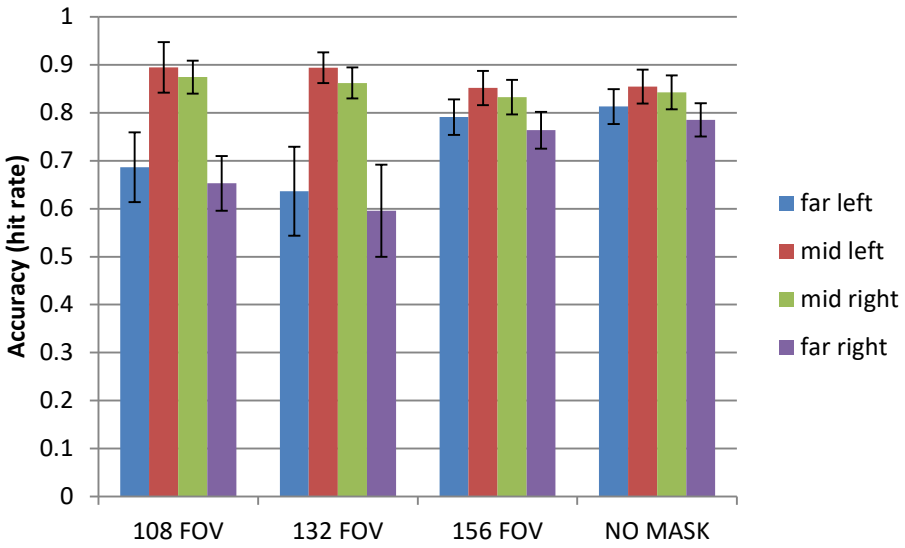


Figure 21. FOV study accuracy results by column and FOV.

### 4.2.2. Reaction Time

Figure 21 displays the accuracy results for correct trials by binned column position and FOV; data were collapsed across rows. As with the accuracy data above, the far left/right and mid left/right column data were collapsed for analysis. A repeated-measures ANOVA revealed a main effect of FOV, $F$ (3, 33) = 4.32, $p < .05$, and a main effect of location (far vs. mid), $F$ (1, 11) = 9.2, $p < .05$, but no significant interaction, $F$ (3, 33) = 2.07, $p = .123$; degrees of freedom were different than in the accuracy analyses because one participant had no correct responses in a condition, and therefore no correct RT data. Overall, RT increased as FOV decreased, and RT was greater for far targets than mid targets. These results converge with the accuracy data and indicate that a decreased horizontal FOV impairs peripheral target discrimination and response time. Critically, no differences were found between the No Mask condition and the FOV afforded by the currently fielded respirator mask.

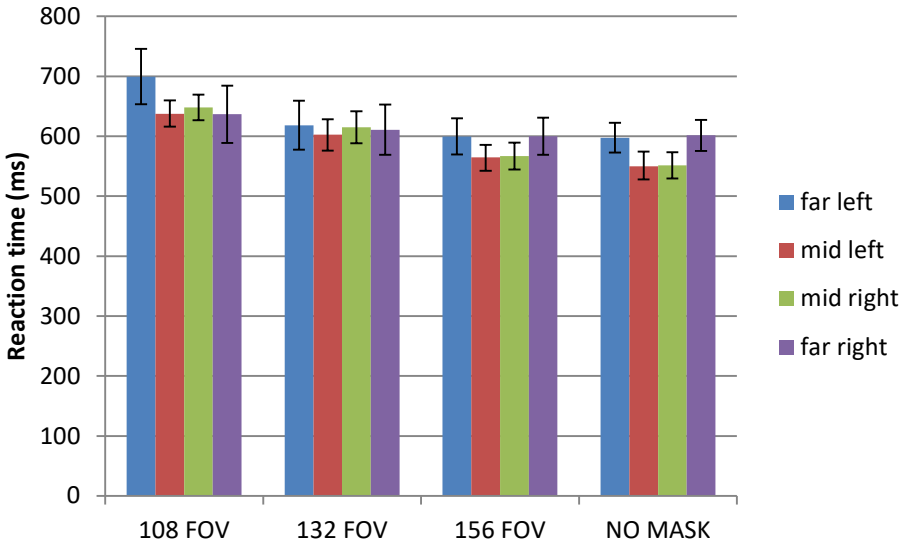


Figure 22. FOV study reaction time (correct trials) results by column and FOV.

## 4.3. Discussion

The quantitative performance decrements found in this study were used to develop components of the computational model.

Performance in a peripheral vision target discrimination task was impaired as a result of decreases in horizontal FOV. In general, volunteers had lower accuracy rates when responding to targets that appeared in their peripheral vision compared to targets that appeared in the central visual field. Low horizontal FOV (i.e. 108 and 132 degree conditions) exacerbated this difference in accuracy. Reaction times were generally slower for smaller FOV and for peripheral targets. The data from this experiment demonstrated that changes to the respirator mask/goggles produced decrements in

Soldiers' visual perception. They also demonstrate that, at least in this visual discrimination task, the No Mask and currently fielded respirator conditions were comparable in performance.

# 5. EFFECT OF FIELD-OF-VIEW ON WORKING MEMORY

NSRDEC researchers conducted an experiment to determine how the horizontal field-of-view (FOV) of the respirator mask/goggles affected the ability to maintain information in working memory while effortfully controlling attention. The current respirator mask/goggles face protection component of the MOPP-4 ensemble (Figure 1) has a horizontal FOV of 156 degrees. Researchers created modified respirators with horizontal fields-of-view of 132 and 108 degrees. Researchers predicted that a decreased horizontal FOV would show limited effects on one's ability to maintain information in working memory. The results from this experiment were used to help populate the set of statistical heuristics (Figure 1).

## 5.1. Method

### 5.1.1 Participants

Eight volunteers comprised of both Soldiers and Civilians participated in this experiment.

### 5.1.2. Stimuli

We used a highly reliable and well-validated measure of working memory capacity, the operation span task (OSPAN), developed by Turner and Engle (1989). In this task, volunteers solve a series of simple arithmetic operations while simultaneously attempting to remember a set of unrelated words. After learning a set of 4, 5 or 6 words, the volunteer attempts to recall the words in their original order. Higher performance on this task is indicative of the ability to maintain information in working memory while simultaneously controlling attention and focusing on rehearsing the words rather than solving the arithmetic problems. To ensure there was no direct visual interference, we presented task stimuli in the center of a computer monitor at a visual angle much smaller (4°) than that afforded by the highly restricted FOV (108°).

### 5.1.3. Design

Data were collected during a single study session. Volunteers performed the OSPAN once for each of the three horizontal FOV conditions. Each OSPAN version used unique stimuli and the order in which volunteers donned each mask was fully counterbalanced across participants. The visual target letters were presented on a 55-inch monitor at a distance of 10 inches from the volunteer. On each trial a single word appeared for 1000 ms and volunteers were provided with up to 6 sec to solve each intervening arithmetic problem. Three set sizes were used (4, 5, 6) each containing either 4, 5 or 6 (respectively) to-be-remembered words and to-be-solved arithmetic problems. For each FOV, volunteers performed 3 trials for each of the three set sizes. Proportion words accurately recalled (in correct order) was measured.

### 5.1.4. Task

On each trial volunteers were instructed to memorize the words as well as possibly while quickly solving the intervening arithmetic operations. Volunteers entered responses on a keyboard.

#### 5.1.5. Procedure

Volunteers were given verbal instructions, and were fitted with either a small, medium, or large set of M50s. Volunteers performed 240 practice trials, after which the experimenters answered any questions the volunteers had that would not invalidate the results of the study. Volunteers then proceeded with the four blocks of trials described above. In each block volunteers wore either no mask or a mask with a horizontal FOV of 156, 132, or 108 degrees.

### 5.2. Results

#### 5.2.1. Arithmetic accuracy

In all FOV conditions, and across each of the three task set levels (4, 5, 6), volunteers maintained arithmetic task accuracy greater than or equal to an 80% criterion. Overall, arithmetic accuracy was lower in the higher task set levels (94%, 93%, 88%, respectively). No numerical or statistical patterns emerged from these data as a function of FOV condition.

#### 5.2.2 Recall accuracy

Figure 24 depicts proportion recalled data as a function of both FOV condition and task set level (4, 5, 6 items). A repeated-measures ANOVA revealed an effect of task set level, $F$ (2, 10) = 5.89, $p$ = .02, indicating increased difficult as a function of task set (90%, 76%, 69%, respectively). The ANOVA did not reveal an effect of FOV, $F$ (2, 10) = 1.24, $p$ = .33, or an interaction between task set level and FOV, $F$ (4, 20) = .09, $p$ = .99. This result supports the prediction that decreases in horizontal FOV would not affect working memory performance, so long as task stimuli were clearly visible within the restricted FOV conditions.

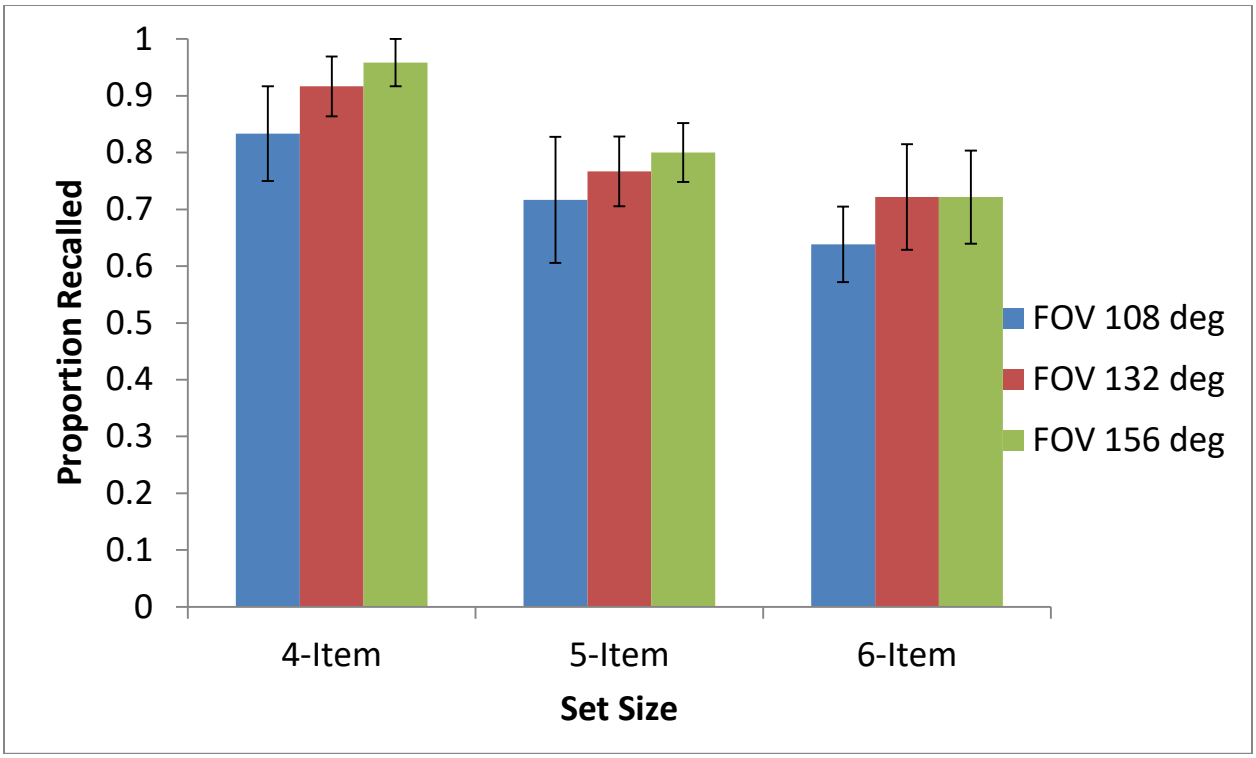


Figure 23. Mean proportion recall data from Experiment 5 examining FOV effects on working memory performance.

## 6. SUMMARY

Five laboratory experiments were conducted in order to fill in gaps in the CB ensemble literature and to determine how parametric changes in the properties of MOPP-4 ensemble components independently affect Soldier performance. Manipulations in the respirator mask/goggle's Respirator Resistance and in the CB over-garment's Moisture-Vapor Transfer Rate resulted in broad decrements in cognitive functioning, primarily in areas of Executive Control. Decreasing the horizontal field-of-view of the respirator mask/goggles resulted in perceptual impairments when discriminating between visual target categories, but did not produce measurable effects on working memory performance. The results of experiments 1-4 were added to the computational model's database of tasks and effect sizes, described in Appendix B, which underlies the software program and graphical-user interface, which are described in Appendix C. The results of experiments 1-5 were included in the set of statistical heuristics depicted in Figure 1.

# APPENDIX B

# COMPUTATIONAL MODEL

## 1. OVERVIEW

The computational model that drives the software package developed in this program uses data gathered from the meta-analytic literature review, the experimental data described in Appendix A, and data collected by partners at Applied Research Associates (ARA). Initially conceived of as a set of dynamical systems, the computational model was reduced in complexity due to the limited temporal resolution of the data currently available. The model is a non-linear exponential equation that describes a Soldier's cognitive performance decrement over time, taking as inputs the degrees to which aspects of embodied cognition are taxed in a given task, as well as the parameters of the CB ensemble worn by the simulated Soldier-agent. The model uses a task-effect database comprised of a series of Soldier-relevant tasks, cognitive taxa weights, and effect size measurements. A user interacts with the model via a graphical user interface, described in Appendix C. The following sections summarize the work conducted toward the development of the task-effect database and the model's equations.

## 2. TASK-EFFECT DATABASE

The computational model developed for this effort uses as its input a database of Soldier-relevant tasks. The tasks that appear in the database are an amalgam of those found in the meta-analytic literature review, the experiments conducted by NSRDEC and ECBC, and in a study conducted by ARA. There are over 100 tasks in total. The first iteration of the model and software program described in the present report use 15 of these 100 tasks. The model uses as input an array of cognitive taxa weights and effect sizes associated with each task.

### 2.1. Embodied Cognitive Taxa

NSRDEC researchers and Subject Matter Experts (SMEs) identified eight embodied cognitive performance taxa that are employed in Soldier-relevant tasks: Vision, fine motor coordination, gross motor movement, executive functioning, working memory, long-term memory, attention, and reasoning. For each task used by the model, SMEs rated from 0-7 the degree to which taxon was used (0 = not at all, 7 = extensively used/required). The space of eight taxa was reduced to six via principal components analysis resulting in the taxa gross motor coordination, fine motor dexterity, visual acuity/detection, memory, attention/vigilance, and multitasking/decision-making. In addition, the weights were normalized to values ranging from 0-1 and used to fit the model's parameters (see below).

### 2.2 Effect Sizes

In order to use data from studies with disparate designs, volunteer numbers, and metrics, effect size measurements were calculated for the tasks used by the model. Effect sizes were computed for comparisons made between MOPP-0 and MOPP-4 performance found in the ARA data set, literature review, and for the CB component comparisons made in Teixeira and Bensel's (1990) work on effects of butyl glove thickness on performance and in the research conducted by NSRDEC on the respirator mask/goggles and CB over-garment. The effect sizes are used as additional inputs to the model. The effect size $\eta^2$ (eta-squared) is used in tables below; an $\eta^2$ value of .01 is considered a "small" effect size, a value of .04 a "medium" effect size, and a value of .1 and higher a "large" effect size.

## 2.3. Butyl Glove Thickness

NSRDEC conducted four experiments that parametrically manipulated aspects of the MOPP-4 ensemble: Respirator Resistance, Moisture-Vapor Transfer Rate, and field-of-view. To complement these data, results from Teixeira and Bensel's (1990) research on the effects of butyl glove thickness on manual dexterity were added to the task-effect database. Teixeira and Bensel found that as the thickness of the butyl gloves increased, performance on three manual dexterity tasks decreased.

## 2.4. First Iteration Tasks and Parameters

The first iteration of the model uses a database of 15 tasks. Seven tasks are provided by the data set collected by partners at ARA, and eight of the tasks are drawn from the literature; the tasks performed by in the NSRDEC/ECBC research and in Teixeira and Bensel's (1990) research do not appear as available tasks in the software program, but instead act as a set of equipment-based parameters that modulate the 15 tasks' weights.

### 2.4.1. ARA Task Parameters

The seven ARA tasks and their normalized cognitive taxa weights are shown in Table 7.

| Task | Gross Motor Coordination | Fine Motor Dexterity | Visual Acuity/ Detection | Memory | Attention/ Vigilance | Multitasking/ Decision-making |
|---|---|---|---|---|---|---|
| **Executive Control (Stroop Test)** | 0.1667 | 0.2083 | 0.7500 | 0.4583 | 0.7500 | 0.5625 |
| **Serial Memory Span** | 0.1667 | 0.2083 | 0.5000 | 0.6667 | 0.7083 | 0.4792 |
| **Face Identification** | 0.1250 | 0.2083 | 0.7917 | 0.6458 | 0.7500 | 0.5208 |
| **Test of Vigilance** | 0.2500 | 0.3333 | 0.7083 | 0.4583 | 0.8750 | 0.5625 |
| **Situational Awareness** | 0.1250 | 0.2500 | 0.8750 | 0.4792 | 0.7917 | 0.4583 |
| **Object Search** | 0.3333 | 0.2917 | 0.7917 | 0.5000 | 0.7500 | 0.5208 |
| **Navigation (Traveling Salesman Problem)** | 0.2083 | 0.2917 | 0.7083 | 0.5625 | 0.6667 | 0.6667 |

Table 7. Tasks and cognitive taxa weights from ARA data set.

These seven tasks were used to fit the MOPP-0 model parameters (described below); unlike the tasks found in the literature, for which a single effect size measurement was computed, the performance in the ARA study was sampled multiple times over a period of 60 minutes, resulting in multiple effect size measures. The ARA task effect sizes ($\eta^2$) for MOPP-0 vs. MOPP-4 comparisons are shown in Table 8. Where effect sizes are shown to increase across collection cycles, the differences between performance in MOPP-0 and MOPP-4 increase; MOPP-4 performance is poorer than MOPP-0 performance. Cases where the final effect size in cycle 4 is smaller than cycle 3 show evidence of learning or adaptation; the gap between MOPP-0 and MOPP-4 is reduced.

| Task | Collection Cycle 1 ($\eta^2$) | Collection Cycle 2 ($\eta^2$) | Collection Cycle 3 ($\eta^2$) | Collection Cycle 4 ($\eta^2$) |
|---|---|---|---|---|
| **Executive Control (Stroop Test)** | 0.0019 | 0.0006 | 0.0099 | N/A |
| **Serial Memory Span** | 0.0355 | 0.0571 | 0.0367 | 0.0184 |
| **Face Identification** | 0.0002 | 0.0002 | 0.0181 | 0.0150 |
| **Test of Vigilance** | 0.0155 | 0.0150 | 0.0132 | 0.0343 |
| **Situational Awareness** | 0.0195 | 0.0915 | 0.0234 | 0.0767 |
| **Object Search** | 0.0520 | 0.0189 | 0.0248 | 0.1340 |
| **Navigation (Traveling Salesman Problem)** | 0.0033 | 0.0372 | 0.0086 | 0.0075 |

Table 8. Tasks and MOPP-0 vs. MOPP-4 comparison effect sizes from ARA data set.

### 2.4.2. Literature Task Parameters

The eight tasks drawn from the literature that appear in the first iteration of the software program are shown in Table 9 with their respective cognitive taxa weights and effect sizes ($\eta^2$). The effect sizes of these tasks are used by the model to estimate each task's MOPP-0 and MOPP-4 performance curves.

| Task | Gross Motor Coord. | Fine Motor Dexterity | Visual Acuity/ Detection | Memory | Attention/ Vigilance | Multi-tasking / Decision-making | Effect Size ($\eta^2$) |
|---|---|---|---|---|---|---|---|
| **Aircraft ID** | 0.429 | 0.333 | 0.952 | 0.714 | 0.857 | 0.762 | 0.0016 |
| **Assault Course** | 0.952 | 0.619 | 0.857 | 0.643 | 0.810 | 0.643 | 0.0058 |
| **Construct Whip Antenna** | 0.619 | 0.857 | 0.810 | 0.762 | 0.762 | 0.714 | 0.0519 |
| **Erect Camouflage Net** | 0.857 | 0.714 | 0.810 | 0.643 | 0.714 | 0.619 | 0.1274 |
| **Night Combat Engagement** | 0.810 | 0.667 | 0.905 | 0.762 | 0.905 | 0.738 | 0.0544 |
| **Route Reconn-aissance** | 0.952 | 0.429 | 0.905 | 0.738 | 0.857 | 0.738 | 0.007 |
| **Target Detection** | 0.381 | 0.333 | 0.857 | 0.595 | 0.762 | 0.643 | 0.272 |
| **Target Engagement** | 0.429 | 0.476 | 0.857 | 0.619 | 0.952 | 0.857 | 0.0615 |

Table 9. Tasks, cognitive taxa weights, and MOPP-0 vs. MOPP-4 comparison effect sizes from literature data set.

### 2.4.3. Equipment Parameters

The four CB ensemble parameters (Respirator Resistance, Moisture-Vapor Transfer Rate, Field-of-View, and Glove Thickness) are used in the model to differentially weight the task parameters defined above; these Equipment Parameters act as a hidden layer in the model. In the CB ensemble experiments conducted by NSRDEC/ECBC and in Teixeira and Bensel (1990), participants

performed tasks that used the six cognitive taxa to varying degrees. Therefore weights were determined for these tasks. The average weights for the tasks in the RR/MVTR studies, and the weights for the FOV and Teixeira and Bensel's Glove Thickness study are shown in Table 10. The effect sizes for comparisons between levels for each ensemble component are shown in Table 11. The effect sizes determine the degree to which the Equipment Parameters modify a given task's Task Parameters; the cognitive taxa weights determine how the effect sizes are applied to the Task Parameters.

| Equipment Parameter | Gross Motor Coord. | Fine Motor Dexterity | Visual Acuity/ Detection | Memory | Attention/ Vigilance | Multi-tasking / Decision-making |
|---|---|---|---|---|---|---|
| **Respirator Resistance (ANT, et al.)** | 0.197 | 0.401 | 0.667 | 0.388 | 0.878 | 0.551 |
| **Moisture-Vapor Transfer Rate (ANT, et al.)** | 0.197 | 0.401 | 0.667 | 0.388 | 0.878 | 0.551 |
| **Field-of-View (Peripheral Targets)** | 0.000 | 0.300 | 1.000 | 0.000 | 0.850 | 0.850 |
| **Glove Thickness (Manual Dexterity)** | 0.000 | 1.000 | 0.000 | 0.000 | 0.000 | 0.000 |

Table 10. Equipment Parameter cognitive taxa weights.

| **Respirator Resistance Comparison** | **Effect Size ($\eta^2$)** |
|---|---|
| None-1.23 cm $H_2O$ | 0.0059 |
| 1.23 – 2.61cm $H_2O$ | 0.0244 |
| 2.61 - 4.29 cm $H_2O$ | 0.0131 |

**A**

| **Moisture-Vapor Transfer Rate Comparison** | **Effect Size ($\eta^2$)** |
|---|---|
| 5 -670 $g/m^2$/24 hrs | 0.0162 |
| 670 – 864 $g/m^2$/24 hrs | 0.0105 |
| 864 – 915 $g/m^2$/24 hrs | 0.0391 |

**B**

| Field-of-View Comparison | Effect Size ($\eta^2$) |
|---|---|
| 108-132 deg | 0.105 |
| 132-156 deg | 0.216 |
| 156 deg- No Mask | 0.135 |

**C**

| Glove Thickness Comparison | Effect Size ($\eta^2$) |
|---|---|
| No Glove – 7 mil | 0.262 |
| 7 – 14 mil | 0.144 |
| 14 – 25 mil | 0.362 |

**D**

Table 11. Equipment Parameter level comparison effect sizes: (A) Respirator Resistance, (B) Moisture-Vapor Transfer Rate, (C) Field-of-View, (D) Glove Thickness.

## 3. MODEL EQUATIONS

The computational model contains two equations, one for MOPP-0 and one for MOPP-4 performance. Both equations are based on the following assumptions:

(1) Cognitive performance decreases over time;
(2) There exists a minimum level of performance; and

(3) Cognitive performance is determined by the cognitive taxa Task Parameters and Equipment Parameters.

### 3.1 MOPP-0 Model

A function that describes Cognitive Performance (CP) over time under MOPP-0 conditions (i.e. ACUs), that satisfies Assumptions (1) and (2) above, is the negative exponential equation:

$$CP_0(t) = a_0 exp^{(-b_0 t + c_0)} + d_0 \qquad (1)$$

The parameters $a_0$, $b_0, c_0$, and $d_0$ were fit to each ARA task's Task Parameters using a least-squares method. An example of one such fit is shown in Figure 22.

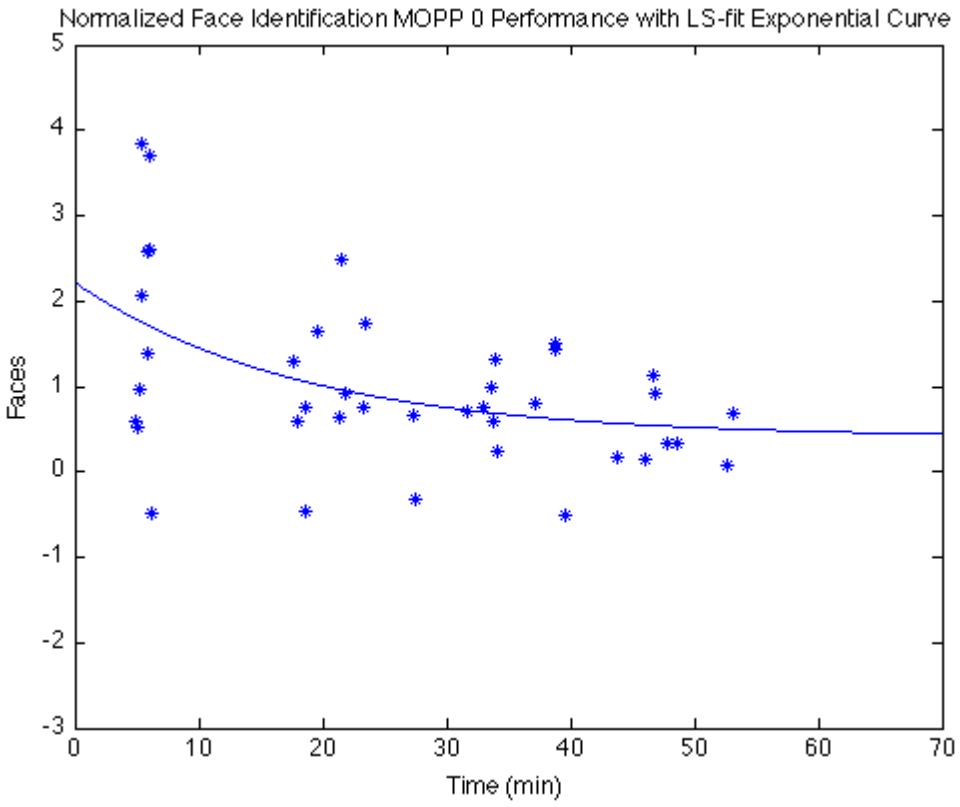


Figure 23. Fit of MOPP-0 equation (1) to Face Identification Task Parameters.

Because each of the model's coefficients are a function of a given task's cognitive taxa Task Ratings, it was determined that $a_0$, $b_0, c_0$, and $d_0$must be functions of the task ratings $\vec{r}$ in order to satisfy Assumption (3) above. This results in the model equation:

$$CP_0(\vec{r},t) = a_0(\vec{r})exp^{(-b_0(\vec{r})t+c_0(\vec{r}))} + d_0(\vec{r}) \qquad (2)$$

It was determined that the coefficient $d_0(\vec{r})$ had little explanatory value: $d_0(\vec{r})$ functions as an asymptotic value, but as the current iteration of the software program does not employ a unit of measure for Cognitive Performance, but rather an abstract visual space, there is no need for a discrete asymptote to the curve. Therefore $d_0(\vec{r}) = 0$.

In addition, as the ARA data contained four sampling cycles, and the literature data contained only one, the cognitive taxa weight space was reduced from six to four: Visual acuity was combined with attention/vigilance, and memory was combined with multitasking/decision-making in a hidden computational layer (unbeknownst to the user). This process reduced the parameter space $R$ from $R = [0,1]^6$ to $R = [0,1]^4$.

Using Task Rating similarity, the literature tasks were fit to the curves established by the ARA data fits.

### 3.2. MOPP-4 Model

The ARA task data and effect sizes were used to compute estimates for the MOPP-4 model coefficients $a_4,\ b_4, c_4,$ and $d_4$. The coefficient $d_4$ was determined by the last collection cycle's effect size (see Table 8). This was done because in all but the ARA tasks, only one effect size exists; for the literature tasks it was assumed that the effect size represented the end of the task's data collection period time-wise. The resulting equation is given as:

$$CP_4(t) = a_4exp^{(-b_4t+c_4)} + d_4 \qquad (3)$$

Because $a_4,\ b_4, c_4,$ and $d_4$are functions of the task ratings $\vec{r}$ and $d_4$ is a function of the effect size $\eta^2$, equation (3) becomes:

$$CP_4(\vec{r},\eta^2,t) = a_4(\vec{r})exp^{(-b_4(\vec{r})t+c_4(\vec{r}))} + d_4(\eta^2) \qquad (4)$$

Figure 23 shows both the MOPP-0 curve and MOPP-4 curve derived with equation (4) for the same task.

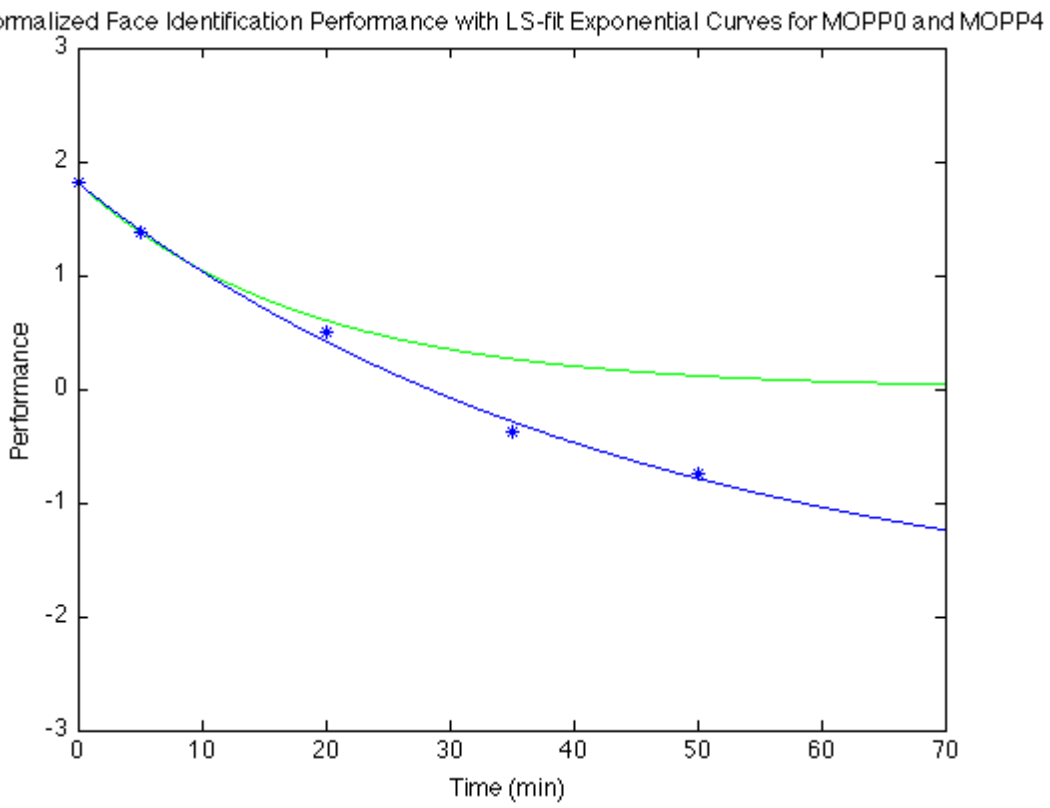


Figure 24. MOPP-0 (green) and MOPP-4 (blue) performance curves for Face Identification task.

To incorporate the CB ensemble Equipment Parameters, the Task Parameters are then modified according to:

$$\vec{r}_s = \vec{r} + g(\vec{s}) \qquad (5)$$

where $g$ is a function defined by the cognitive taxa weights associated with the Equipment Parameters (see Table X) and $\vec{s}$ is the vector of 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), $g(\vec{s}) = 0$ so $\vec{r}_s = \vec{r}$.

## 4. SUMMARY

The MOPP-0 and MOPP-4 computational models take the form of negative exponential equations. Each contains coefficients that are fit to Task Parameters. In addition, the MOPP-4 model uses effect sizes and CB ensemble Equipment Parameters to further define its performance curve. Parameters and effect sizes are stored in a task-effect database. There are presently 15 tasks in the

database, along with their respective cognitive taxa weights (i.e. Task Parameters) and effect sizes (MOPP-0 vs. MOPP-4 performance difference). The Equipment Parameters are derived from the experiments conducted by NSRDEC/ECBC, described in Appendix A, as well as research conducted by Teixeira and Bensel (1990) on the effects of butyl glove thickness on manual dexterity performance. The model is accessed by the user via a graphical user interface (GUI), described in Appendix C.

# APPENDIX C

# GRAPHICAL USER INTERFACE

## 1. OVERVIEW

The graphical user interface (GUI) is the top-most level of the software program developed for DTRA. The GUI, as its name suggests, is the piece of software with which the end-user interacts. The computational model described in Appendix B sits "beneath" the GUI; the GUI sends input to the model and displays the model's output, and the GUI, titled the Suit Performance Evaluator, allows a user to simulate the effects of CB ensemble components and task demands on a Soldier's cognitive performance over a period of 75 minutes. The user specifies the a Soldier-relevant task and its respective Task Parameters – the cognitive taxa described elsewhere in this report – as well as the Equipment Parameters: The Respirator Resistance and field-of-view of the respirator mask/goggles, the Moisture-Vapor Transfer Rate of the CB over-garment, and the thickness of CB butyl gloves. Performance is graphically depicted, and the user can save the output of a given run. The primary goal of the GUI is to provide a user-friendly interface to visualize differences in cognitive performance due to changes in task constraints or CB ensemble parameters. The following sections provide a description and "walk-through" of the GUI.

## 2. SUIT PERFORMANCE EVALUATOR

The Suit Performance Evaluator (SPE) is the name given to the first iteration of the software program and GUI. The program was written in *C#,* and compiled using Microsoft Visual *C#* 2010 Express. A screenshot of the GUI is shown in Figure 24.

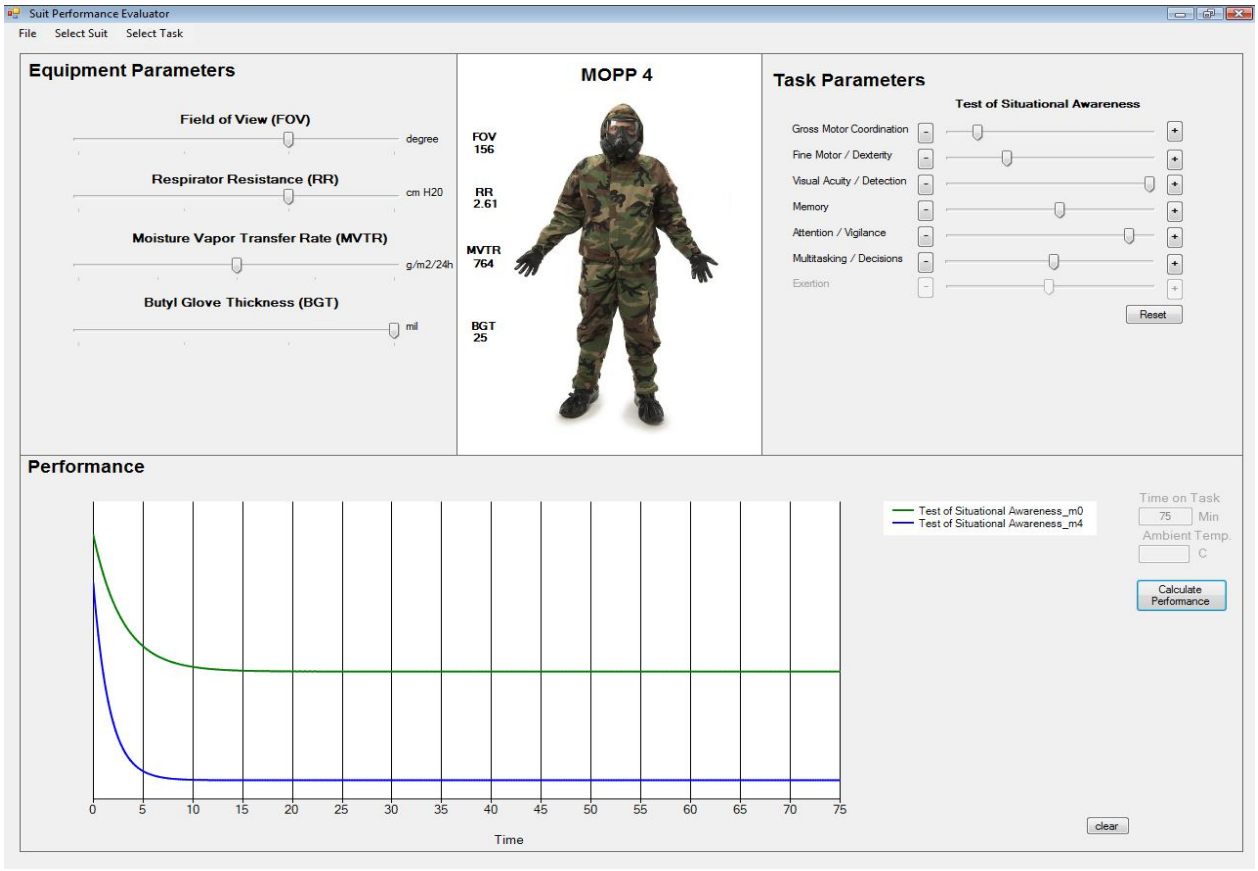


Figure 25. Screenshot of the Suit Performance Evaluator trade-space software tool, version 1.

## 3. GUI TUTORIAL

The following sections provide a “walk-through” of the software GUI’s capabilities.

### 3.1. Select a CB Ensemble “Suit”

Click on *Select Suit* from the menu in the top left corner of the screen (see Figure 25).
If MOPP-0 is selected, the Equipment Parameter sliders will be inaccessible. If MOPP-4 is selected, all four Equipment Parameters will be accessible for customization.

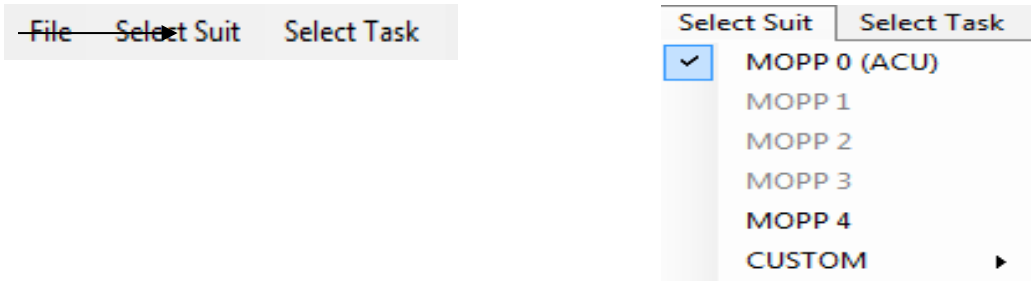


Figure 26. CB Ensemble "suit" selection.

### 3.2. Create a Custom Ensemble

Select MOPP-4 from the *Select Suit* menu option.
Move the Equipment Parameter sliders to the desired settings (see Figure 26).
Select *File* → *Save* → *Suit*
Enter a name for the custom ensemble and click *Save*.
The custom ensemble can then be accessed under the *Select Suit* → *Custom* menu.

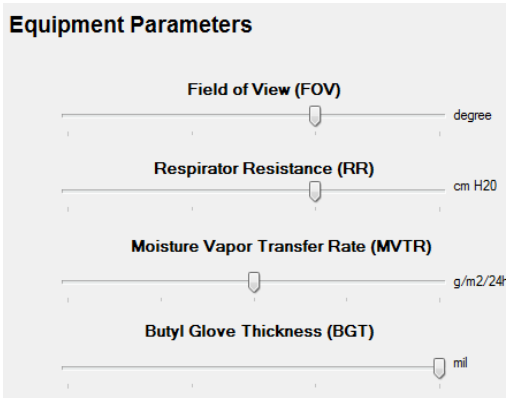


Figure 27. Equipment Parameter sliders.

### 3.3. Select a Task

Click on *Select Task* from the menu in the top left corner of the screen.
A drop-down menu will appear listing all available tasks. Click on any task to load it. The Task Parameter sliders (Figure 27) will adjust automatically to reflect the selected task.

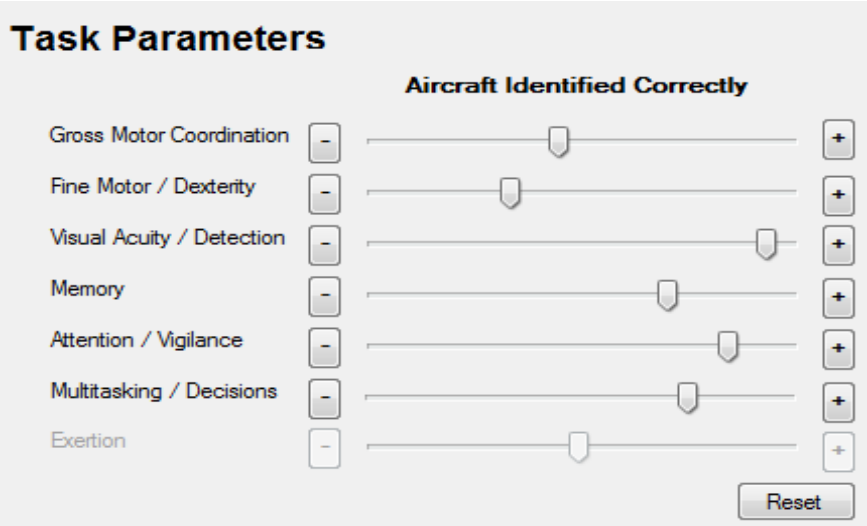


Figure 28. Task Parameter sliders, adjusted to reflect the selection of the task "Aircraft Identified Correctly."

### 3.4. Create a Custom Task

Select any task from the list of available tasks (as above).
After a task has been selected, adjust the Task Parameter sliders until a desired setting is reached. Clicking the '+' symbol or dragging a slider to the right indicates that the Embodied Cognitive Taxon is utilized to a greater degree, while clicking on the '–' symbol or dragging the slider to the left indicates that the Taxon is utilized to a lesser degree by the custom task. Once a task has been edited by the user an asterisk (*) will appear next to the name of the task to indicate that its parameters have been altered.
Select *File* → *Save* → *Task*
Enter a name for the task and click *Save*.
The custom task can then be accessed under the *Select Task* menu.

### 3.5. Plot Performance Curve

Select an ensemble and task.
Click the *Calculate Performance* (Figure 28) button located in the bottom right corner of the screen.
A performance-over-time curve will appear in the Performance window.
Up to ten lines can be plotted in the same window. To clear the window, click *Clear*.

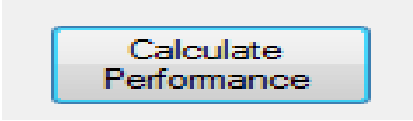


Figure 29. Calculate Performance button.

### 3.6. Save Output

After plotting a performance curve, select *Save Output* from the *File* menu.
Select a file directory and name, and click *Save.*
A text file (*.txt) will be generated and saved to the location the user has specified. The text file will contain the name of the ensemble and task, and the *x* and *y* coordinates of the plotted curve.

### 3.7. Resetting the GUI

To reset the Equipment Parameters to the default MOPP-4 settings, select MOPP-4 under the *Select Suit* menu.
To reset the Task Parameter sliders, click *Reset*. This action will reset the selected task to the first task in the available list (currently Aircraft Identified Correctly).

### 3.8. Hotkeys

There are two shortcut hotkeys:
Pressing R will iterate through the standard CB ensembles (MOPP-0, MOPP-4; no custom ensembles).
Pressing E will iterate through all available tasks, including custom tasks.