Dorneich, M.C., Whitlow, S.D., Mathan, S., Carciofini, J., and Ververs, P.M. (2005). "The Communications Scheduler: A Task Scheduling Mitigation For A Closed Loop Adaptive System", *Foundations of Augmented Cognition* (D.D. Schmorrow, Ed.). Mahwah, NJ: Lawrence Erlbaum Associates. pp. 132-141.

The Communications Scheduler: A Task Scheduling Mitigation For A Closed Loop Adaptive System

Michael C. Dorneich, Stephen D. Whitlow, Santosh Mathan, Jim Carciofini, Patricia May Ververs

Honeywell Laboratories
3660 Technology Drive; Minneapolis, MN 55418
michael.dorneich@honeywell.com

Abstract

This paper describes the Communications Scheduler, an adaptive system mitigation designed to scheduler incoming messages to improve message comprehension and situation awareness. The U.S. Army is currently defining the roles of the 2010-era Future Force Warrior (FFW) program, which seeks to push information exchange requirements to the lowest levels and posits that with enhanced capabilities a squad can cover the battlefield in the same way that a platoon now does. Among other capabilities, the application of a full range of netted communications and collaborative situational awareness will afford the FFW unparalleled knowledge and expand the effect of the Future Force three dimensionally. It is expected that in a highly networked environment the sheer magnitude of communication traffic could overwhelm the individual soldier. The Honeywell Augmented Cognition team has developed the Communications Scheduler, a task scheduling mitigation driven by real-time neurophysiological and physiological measurements of human cognitive state, which is used to augment the work environment to improve human-automation joint performance. Evaluations have shown over at least a 100% improvement in message comprehension an situation awareness.

1 Introduction

Task analysis interviews with existing military operations identified factors that negatively impact communications efficacy. In one example, in the first few minutes of any intense mission, radio communications are a suboptimal method of communications because everybody is intensely focused on their tasks at hand. In one famous raid, for example, the commander did not hear the radio communications informing him that the plan had changed until he was physically grabbed by the ground force commander and given this critical information. The commander responded by radioing his own troops, who also did not respond. The implications of these kinds of situations are many, but, first and foremost, mission critical information must be reliably communicated. What aspects of the communication method can be altered to improve the chances that a message will be received and understood? Does it require a multi-modal, physical alert? Should communications be limited to only critical messages during high workload situations?

The U.S. Army is currently defining the roles of the 2010-era Future Force Warrior (FFW). The FFW program seeks to push information exchange requirements to the lowest levels and posits that with enhanced capabilities a squad can cover the battlefield in the same way that a platoon now does. Among other capabilities, the application of a full range of netted communications and collaborative situational awareness will afford the FFW unparalleled knowledge and expand the effect of the Future Force three dimensionally.

An approach was adopted that considers the joint human-computer system when identifying bottlenecks to improve system performance. The Honeywell team is focusing primarily on the Attention Bottleneck. The appropriate allocation of attention is important to FFW because it directly affects two cornerstone technology thrusts within the FFW program: netted communications and collaborative situation awareness. The Honeywell team has developed a set of cognitive gauges based on real-time neurophysiological and physiological measurements of the human operator. The capability to assess cognitive state to determine allocation of attention provides the opportunity to adapt the soldier's current task environment. Cognitive assessment can drive adaptive strategies to mitigate the specific information processing bottlenecks.

With the aid of our proposed adaptive system we hope to increase the soldier's situation awareness, survivability, performance, and information intake by improving their ability to comprehend and act on available information. The results of this work will benefit soldiers by creating a system that alters task presentation based on an analysis of that soldier's cognitive state. It is hypothesized that this adaptation of the soldier's workspace will lead to greater joint human-automation performance in dismounted soldier operations. Honeywell has developed the Communications Scheduler to manage the incoming information by scheduling the communications to be received by the soldier at the most optimal period, offloading tasks or portions of tasks to automation when the soldier is overwhelmed, and providing information in multiple modalities (audio, visual, tactile) to ensure comprehension. A high task load condition will prompt the automation to defer all but the highest priority messages, offload tasks, or change the modality of information presentation; a low load condition would indicate an appropriate time for interruption and higher levels of soldier participation in on-going tasks. Without these augmentations the soldier can become overloaded with information having to decide when and where to focus this attention among the myriad of high priority communications and high priority tasks.

Section 2 describes the architecture of the Augmented Cognition Systems. Section 3 describes the Communications Scheduler in detail. Section 4 describes the results of two evaluations to test aspects of the Communications Scheduler's logic and ability to improve performance when driven correctly from the cognitive gauges.

2 Augmented Cognition System Design

2.1 Architecture

This section briefly describes the system architecture of the Honeywell Closed Loop Integrated Prototype (CLIP). (see Figure 1). The architecture is made up of the following components:

- *Cognitive State Assessor* (CSA) combines measures of cognitive state to produces the cognitive state profile (CSP).
- *Augmentation Manager* (AM), adapts the work environment to optimize joint human-automation cognitive abilities for specific domain tasks. The AM is comprised of three components:
  - *Interface Manager*, responsible for realizing a dynamic interaction design in the HMI
  - *Automation Manager*, responsible for the level and type of automation
  - *Context Manager*, responsible for tracking tasks, goals, and performance
- *Human-Machine Interface*, where the human interacts with the system.
- *Automation*, where tasks can be partially or wholly automated.
- *Virtual Environment* (not shown) is a simulated approximation of the real world.
- *Experimenter's Interface* give the experimenter both insight and control over events within the system.

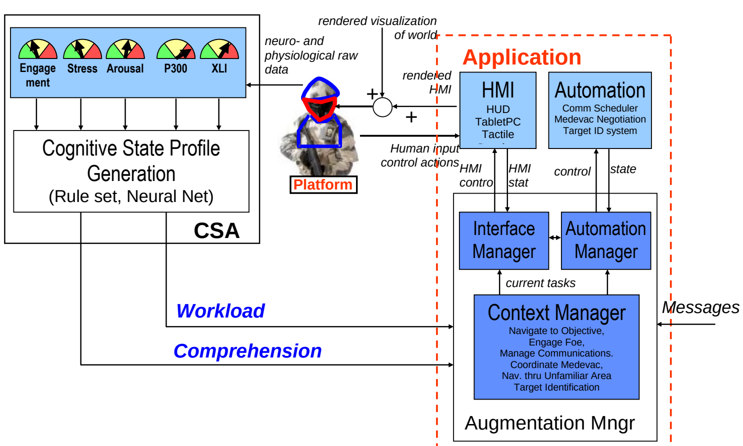

Figure 1. Honeywell Augmented Cognition system architecture.

2.2 Cognitive State Assessor

The Honeywell AugCog team has developed a comprehensive suite of sensors (including EEG, pupilometry, physiological measures such as EDR, and ECG) that feed a set of "cognitive gauges" that make up the Cognitive

State Assessor (CSA). These include an engagement index, a stress gauge, an arousal meter, an executive load index, and a P300-driven novelty gauge.

2.2.1 Gauges

Engagement Index. The engagement index is a ratio of EEG power bands (beta/(alpha + theta)). The engagement index, as described by Freeman et al. (1999) is a measurement of how cognitively engaged a person is in a task, or their level of alertness. Adaptive systems have used this index to successfully control an automation system for tracking performance and a vigilance task (Freeman et al., 1999; Mikulka, Scerbo, & Freeman, 2002; Pope, Bogart, & Bartolome, 1995). Consistent with Freeman et al.'s work, EEG data is recorded from sites Cz, Pz, P3, and P4 with a ground site midway between Fpz and Fz. The Engagement Index is calculated from a running average of powers for different EEG frequency bands (Prinzel, et al., 1999). Prinzel, et al., (1999) reported that adaptive task allocation may be best reserved for the endpoints of the task engagement continuum. Therefore, two levels of engagement (low, high) were measured in this study. The engagement index reflects the selection and focus on some aspect at the expense of the other competing demands, thus it is a measure of focused attention. High levels of engagement reflect selection and attentional focus whereas lower levels of engagement indicate that the subject is not actively engaged with some aspect of the environment.

Arousal Meter. Clemson University's Arousal Meter (Hoover & Muth, 2003) derives autonomic arousal from the cardiac inter-beat interval (IBI), derived from the Electrocardiogram (ECG) at one ms accuracy. A three lead ECG is used to detect R-spikes and derive ms resolution IBIs that are then re-sampled at 4 Hz. A Fast Fourier transform (FFT) is computed for 16 s, 32 s, or 64 s worth of IBIs. A sliding window is established such that a new FFT is computed every .25 s. When the FFT is computed, the high frequency peak (max power between 9 and 30 cycles per minute) is identified and the power at that peak, termed respiratory sinus arrhythmia (RSA), is stored. Once one minute's worth of FFT results are stored, the arousal meter begins to generate a standardized arousal which is computed every 0.25 s using a z- log-normal score standardization and the running mean and standard deviation of the RSA values. The gauge has 3 levels (low, medium and high). Increases in this score are associated with increased autonomic arousal.

Stress Gauge. The Institute of Human and Machine Cognition developed a composite Stress Gauge (Raj et al., 2003; Kass et al., 2003). The gauge uses a weighted average of the four inputs (Video Pupilometry (VOG), High Frequency Electrocardiogram (HFQRS ECG), Electrodermal Response (EDR), and Electromyogram (EMG) from the left trapezius muscle to detect the subject's response to changes in cognitive load. The gauge was used to detect cognitive stress related to managing multiple competing tasks on a moment-to-moment basis.

P300 Novelty Detector. The EEG Auditory P300 reflects a central nervous system response to behaviorally relevant infrequent sounds. Previous literature (Wickens, Heffley, Kramer, & Donchin, 1980) suggests that P300 amplitude in response to a task relevant infrequent auditory stimulus is modulated by attentional resources: if the subject is very focused on a primary task the auditory stimulus will be missed and the corresponding P300 diminished. Columbia University and the City College of New York have created a gauge called the P300-novelty detector gauge (Sjada, Gerson, & Parra, 2003), that spatially integrates signals from sensors distributed across the scalp, learning a high dimensional hyperplane for discriminating between task-relevant (incoming message auditory alert) and task irrelevant responses. In the current task environment a tone is played before an auditory message to evoke a P300 activity. Mitigation strategies are based on the assumption that the presence of a strong evoked response indicates that subjects have sufficient attentional resources to process the incoming message. The gauge includes frontal and parietal electrodes.

Executive Load Index. Human Bionics developed the eXecutive Load Index (XLI) (DuRousseau, 2004) to measure cognitive state. It operates by measuring power in the EEG at frontal (FCZ) and central midline (CPZ) sites. The algorithm uses a weighted ratio of delta + theta/alpha bands calculated during a moving 2-second window. The current reading is compared to the previous 20-second running average to determine if the executive load is increasing, decreasing or staying the same. The index was designed to measure real-time changes in cognitive load related to the processing of messages. This gauge was previously validated to discern trial difficulty in a continuous performance high-order cognitive task battery.

2.2.2 Cognitive State Profile

The CSA outputs a Cognitive State Profile comprised of two decision state variables: *workload* and *comprehension*. The CSP drives the mitigations of the Augmentation Manager. Currently a simple set of rules is used to derive the assessment of Workload and Comprehension, although work is underway to define this step with neural networks, in order to better account for individual subject differences (see companion paper in these proceedings: Mathan, Mazaeva, & Whitlow, 2005). For this CVE, *workload* was considered high is any of the three gauges, Engagement, Arousal, or Stress, registered high. This was done to allow for the fact that on any given subject, only a subset of the gauges may be able to discriminate differing levels of workload, based on individual differences in subject's cognitive response to the scenario workload manipulation. Likewise, in order to bias *comprehension* towards false positives, both the P300 Novelty Detector Gauge and the XLI gauge had to be high (i.e. reporting a yes that the subject comprehended the message) for the *comprehension* variable to be set to "True".

2.3 Augmentation Manager

The Augmentation Manager (AM) is the primary reasoning component of Application, tasked with determining what and how information will be displayed to the human, the allocation of tasks between the human and automation, and the management of the automation and the interaction with the human. The goal of the Automation Manager is to adapt the human's work environment to the current state of the user, the current state of the world, and the current state of the tasks the joint human-automation system is performing. As such, when the CSA determines that the human is overloaded, stressed, or no longer able to handle the task load, the system employs a mitigation strategy to adapt the system to maintain or enhance performance. There are four broad categories of possible mitigations in an Augmented Cognition system:

- Task/Information Management
- Modality Management
- Task Offloading
- Task Sharing

The AM's major functions are described in Table 1 below:

Table 1. The major functions of the Augmentation Manager.

AM Function	**Component**	**Requirements**
Information Management	Interface Manager	• Decide information content • Decide information abstraction needed to support the human tasks. • Decide information presentation modality.
Task offloading.	Automation Manager	• Decide which functions allocated to human, which to automation. • Function allocation that is dynamic, responsive to changing context.
Task Sharing.	Automation Manager	• Decide which tasks can be shared • Determine effects of function allocation on task-subtask interactions, workload, mission management, and performance 7under stress.
Task Scheduling and Management.	Automation Manager	• Prioritize tasks to minimize multi-tasking costs. • Model the current and projected tasks, • Schedule tasks, and manage human's "automation awareness."
Task Tracking	Context Manager	• model dynamic multitasking • model task objectives
Performance tracking	Context Manager	• Model current performance, • predict performance

Honeywell has developed the Communications Scheduler to mitigate situations where the user is forced to divide their attention between multiple tasks and performance breaks down due to information overload. Of particular importance is the soldier's ability to handle continuous inflow of netted communications and directing his or her attention to the highest priority task to complete his/her mission in this highly dynamic environment. This is crucial to not only the soldier's own survival but that of his or her fellow soldiers (Dorneich et al, 2004). The

Communications Scheduler mitigates divided attention demands via task-based management and modality-appropriate information presentation strategies. The Communications Scheduler is described in detail in Section 3.

2.4 Human-Machine Interface

The Human-Machine Interface (HMI) realizes the interaction design of the Interface Manager outputs by configuring a multi-modal user interface to optimally support cognitive throughput of the next generation warfighter. In the system configuration described in this paper, the HMI consists of four components:

- Head-Up Display (HUD). The subject will see various icons in his or her field of view. There is also a limited ability to display a text message. In addition, in the upper left corner a ego-centric compass displays the current heading.
- TabletPC Display Device. This device contains a messaging application that allows the soldier to interact with deferred messages.
- Tactile Display. This system was used to provide tactile navigation cues via 24 tactors (2 rows of 12 columns) worn in a belt about the upper abdomen (for a description of its use, see companion paper: Dorneich et al 2005).
- Aural Alerting System. Prior to presenting an incoming radio messages, the HMI had the ability to insert a tone to alert the user of the priority of the message.

2.5 Virtual Environment

The Honeywell Augmented Cognition program required a Virtual Environments (VE) with a with appropriate fidelity to support sensor-suite validation, and concept validation. The VE provides a realistic, tactically correct MOUT battlefield environment, with opposing forces (OPFOR) and friendly forces (BLUFOR) that can be controlled either by “botAI” (automated behavior scripts) or additional human operators. The VE is of a sufficient fidelity to represent the visual complexity of a MOUT environment in order to appropriately tax a subject’s workload when interacting with the VE, with the following properties to add to the realism and immersiveness of the environment:

- Visually complex MOUT world
- Building interactivity to allow subject to enter buildings
- Three-dimensional world for mobility in the lateral and vertical directions
- Several subject behavior characteristics including: crouching, running, walking, jumping, firing weapon, climbing stairs, depreciated health upon sustaining enemy attack.
- Team members (BLUFOR) with the following characteristics: ability to fire at enemy, defend a position (or objective), move realistically, ability to follow the subject, ability to navigate to objective, ability to be tasked by subject, depreciate in health upon sustaining enemy hit.
- Audio to provide environmental sounds, weapons, and ability to insert audio messages from external Communications Scheduler

Evaluations of the Communications Scheduler (described in Section 4) utilized a desktop-PC Virtual Environment based on a modified Quake3 TeamArena game engine. The VE, illustrated in Figure 2, depicts a small area of a city, with realistic textures, and detailed models, but little interactivity (doors do not open, crates do not move, etc.). The city was comprised of narrow streets, surrounded by two and three story buildings. The environment had an industrial appearance. The subject is entered into the environment in one of many predetermined locations in the map. In addition to the subject there are some number of simulated players (bots), some opposing forces and some blue forces. These forces were presented both at street level and above as snipers. The specific numbers of OPFOR and BLUFOR were adjusted at runtime. Each bot was assigned a skill level between 1 (easy) and 5 (hard), therefore workload was adjusted easily. Each player (subject or bot) had a realistic visual representation, with subtle details (primarily color and pattern of uniform) distinguishing blue forces from opposing forces. The subject performed tasks in the environment using a combination of keyboard and mouse controls. The controls allowed the subject to look around the world. They also enabled the subject to move (walking forward or backward, sidestepping left or right, jumping, and crouching).

Figure 2. The Honeywell FFW Virtual Envuironment.

3 Communications Scheduler

3.1 Overview

The Communications Scheduler mitigates the attention bottleneck via task scheduling and modality management of incoming communications. The system is tasked with determining when and how information is displayed to the soldier. The Communications Scheduler schedules and presents messages to the soldier based on the cognitive state profile, the message characteristics, and the current context (tasks). Based on these inputs, the Communications Scheduler can pass through messages immediately, defer and schedule non-relevant or lower priority messages, escalate higher priority messages that were not attended to, divert attention to incoming higher-priority messages, change the modality of message presentation, or delete expired or obsolete messages.

3.2 Message Characteristics

All messages have a priority associated with them, depending on how critical they are. High priority are ,ission-critical and time-critical, medium priority messages are mission-critical only, and low priority messages are not critical (although they may still be important).

When the augmentation is in effect, messages will be scheduled according to certain rules. High priority messages are mission critical and time critical, which means they must be heard and understood as soon as they arrive. Medium priority messages are mission critical, but have a larger time window to work with. A medium priority message could potentially be deferred if the system finds that you are highly engaged in another task. All medium priority messages will be played before the end of the mission. Low priority messages are not mission critical or time critical. They will be presented if the subject is not engaged in another task. If the system finds that the subject is engaged in another task, the low priority message will be presented in text format in the message window.

3.3 Message Alert Modes

High priority messages have a tone played before they are presented. If the system finds that the subject is highly engaged in a task it will play the same tone ,but louder and more saliently. If the system finds that the subject missed a high priority message after it has been presented, it will repeat the message once using the same tone, but louder again. In summary, there are three versions of the same tones associated with high priority messages. Medium priority messages will also have a tone played before they are presented. It is recognizably different than the high priority tone. Medium priority messages will also be repeated once if the system finds that the subject missed a message, however, the tone will remain the same. It will not change in loudness like the high priority tone does. Low priority messages do not have a tone associated with them. Low priority messages will not be repeated.

3.4 System Logic

The Cognitive State Assessor (CSA) determines two cognitive state profile decision variables: *workload* and *comprehension* (see section 2.2.2). The Communications Scheduler determined the initial message presentation based on a user's current *workload*. The Communications Scheduler performed one of three actions when deciding how to first present the message:

- Present the message immediately in the audio modality with the appropriate "normal" tone proceeding it.
- Present the message immediately in the audio modality preceded by the appropriate "higher saliency" tone.
- Present the message immediately in the text modality on the subject's TabletPC.

After the first presentation of a message to the user (in audio modality), the Communications Scheduler determined whether to take further action on a message depending on the CSA's assessment of *comprehension*. Comprehension is an assessment of whether the subject had the attentional resources at the moment of message presentation to properly attend to and understand the message. Based on Comprehension, it performed one of four actions:

- Replay the message immediately in the audio modality preceded by the same tone used previously.
- Replay the message immediately in the audio modality preceded by a higher, more salient tone than used previously. Note if first presentation was the "higher" tone, this replay would use the "highest" tone.
- Do nothing as the gauges have sensed that the subject comprehended the message.
- Not Applicable – the "before" decision precludes any need to make an "after" decision.

The decision logic of the Communications Scheduler is summarized in Table 2. Each Workload cell has a rule P(modality, saliency) where P = Play, modality = audio or text, and saliency = normal, higher, highest. Each Comprehension cell has a either rule Replay(saliency) where saliency = up (i.e. the previous salience was higher, escalate to highest) or same, or Done or NA = not applicable.

Table 2. Communications Scheduler decision rule set, where each rule is of the form Play(modality, saliency).

	Before first message presentation			After first message presentation		
CSP Variable -Priority	High	Med	Low	High	Med	Low
Workload High	P(audio,higher)	P(text,normal)	P(text,normal)			
Workload Low	P(audio,normal)	P(audio,normal)	P(default,normal)			
Workload Low after High	P(audio,higher)	P(text,normal)	P(text,normal)			
Workload Unknown	P(audio,normal)	P(audio,normal)	P(audio,normal)			
Comprehension High				Done	Done	N/A
Comprehension Low				Replay(up)	Replay(same)	N/A
Comprehension Unknown				Done	Done	N/A

3.5 System Behavior

High priority messages are mission critical and time critical, which means they must be heard and understood as soon as they arrive. Thus the Communications Scheduler took the following actions on high priority messages:

- High priority messages were preceded by a tone (normal or escalated)
- A visual icon reminded the subject to pay attention (see left side of Figure 3)
- High priority messages that required an overt response were accompanied by a visual summary
- Message may have been repeated

Medium priority messages are mission critical, but have a larger time window to work with. A medium priority message may have been deferred if the system found that the subject was highly engaged in another task. All medium priority messages were played before the end of the mission. Low priority messages are not mission critical or time critical. They were presented if the subject is not engaged in another task. If the system found that the subject was engaged in another task, the low priority message were presented in text format in the message window. Specifically, low and medium priority messages were deferred to the Tablet PC application, and a visual icon appear on the HUD to alert to the action the scheduler has taken (see right half of Figure 3).

Figure 3. High priority messages are alerted by an icon and (possibly) a text summary on the HUD (right). Deferred messages appear on the Tablet PC with an icon on the HUD (left).

3.6 Automation Etiquette

Poorly designed automation can be dangerous. Research shows that unless users are able to predict clearly how an automated system is likely perform, automation may introduce more problems than it solves (Sarter, Woods, & Billings, 1997). The mitigations strategies described here have very clear rules to eliminate uncertainty and unpredictability. The Communications Scheduler benefits uses by allowing the user to defer responses to messages under conditions when attention has to be split between competing tasks, thus allowing users to focus on higher priority tasks first. However, this kind of automated system behavior has negative side effects: Loss of momentary situational awareness, and lags in responses could break coordination among teams and introduce inefficiencies in the mission. Thus it is important that the Communications Scheduler be invoked only when the benefits of its use outweigh its costs. For that reason the Communications Scheduler would not be used continuously, but rather only in times of high cognitive stress of the user, when faced with competing tasks that overload his or her ability to comprehend and process all incoming information.

Since the Communications Scheduler will not be used continuously, the issue of automation etiquette becomes important. The Communications Scheduler should be invoked (and should cease) in such a manner that does not exacerbate confusion. The Communications Scheduler mitigation was invoked when Workload was high – for instance low priority messages were deferred to the TabletPC. However, when workload lowered below the threshold used to trigger the message deferral, the Communications Scheduler continued to defer messages. This is due to the fact that deferring communications on the basis of moment to moment fluctuations in gauge values can be confusing. Messages could be misinterpreted without surrounding context if they were to be played in audio modality after its predecessor messages have been deferred to the TabletPC (and remain unread for a period of time). If expected messages were not heard, it may have been hard to disambiguate whether this is because of the communications scheduler or some mission related cause. To avoid confusion, once communications scheduling was activated, all low and medium priority messages were deferred to tablet PC until user has caught up on all messages and clicked a ‘messages read’ button. The subject of automation etiquette is discussed in more depth in a companion paper in these proceedings (Mathan, Dorneich, & Whitlow 2005).

4 Evaluation

Results from an evaluation on the first iteration of the Communications Scheduler (Dorneich et al 2004) indicated that augmentations benefited subjects under high workload conditions. Under high workload conditions, the communications scheduler produced better situation awareness and improved the ability of participants to correctly identify and engage the foes. These results are consistent with many program findings (e.g., Prinzel et al., 2003) that show the benefit of augmentation at the extreme ends of the workload space. In addition, the analysis of the behavior of the system with regards to subject acknowledgement and comprehension of messages was compelling. Based on cognitive state, the system was able to infer a subject’s message comprehension and repeat unattended messages in the majority (71.6%) of cases, with a false alarm rate (23.7%) that can be partially attributed to the subjects’ automatic acknowledgment of a truly unattended message. It is important to remember that these mitigations were driven solely by the cognitive state of the subject, as measured in real time by five cognitive gauges. These findings were used to guide the development of the second iteration of the Communications Scheduler, described in this paper.

The evaluation of the second iteration is detailed in a companion paper in these proceedings (Dorneich et al 2005), and briefly described below. Concurrent with this evaluation, another version of the Communications Scheduler was evaluated in a more mobile setting, as described in a companion paper in these proceedings (Whitlow and Ververs 2005).

The Concept Evaluation Experiment (CVE) involved 14 participants (M_{age} = 25.4 years) with an average education level of 15 years. To reduce the effect of learning (of the VE) for this experiment, participants were chosen who rated their skill level at first person shooter games as average to above average. The average skill rating was 3.4/5 (Range = 2-4), with only 1 person rating himself as a 2/5. Overall, participants' average time playing was 5.7 hours per week. There were two independent variables in this study: 1) Mitigation (on/off), and 2) Scenario (three, which vary by attention type). The study consisted of three two-factor experiments. Each experiment compared performance under gauge driven mitigation with performance without mitigation. Scenario 1 utilized the Communications Scheduler as the mitigation, and will be described here.

This scenario focused on divided attention bottleneck in multi-tasking, and consisted of the subject performing three tasks: 1) Navigate to Objective, 2) Engage Foes, and 3) Manage Communications. The subject was a platoon leader, whose goals were to lead the platoon along a known route through a hostile urban environment to the objective, while being careful to engage enemy soldiers. Participants also received incoming communications throughout the scenarios, with some messages requiring an overt, behavioral response. Participants received status updates, mission updates, requests for information, and reports; these incoming communications are a primary source of their situation awareness. Radio communications volume was extremely high. The scenario only included two or three high priority messages, which told the soldier to hold at certain locations for a specified amount of time, or that the objective location had changed. Failure to heed these high priority messages caused the subject to encounter an ambush.

Scenario 1 was designed to put subjects into distinct periods or extreme high and extreme low workload periods. The high workload times included a high volume of communications traffic to the subject, just at the time when their workload was high due to being targeted by foes. The principal metrics were

- *Message Comprehension* inferred from correct change in overt behavior due to message instruction, and correct responses to message queries.
- *Situation Awareness* inferred from the number of correct post-trial questions to ascertain if they could recall mission-critical information relayed through the communications.

The goal was to improved performance on these tasks while not degrading performance on the Navigate to Objective and Engage Foes tasks, and no increase in workload:

- *Message Comprehension*. Subjects in the unmitigated condition correctly responded to 57 of 143 possible messages (39.9%). Subjects in the mitigated condition correctly responded to 114 of 143 messages (79.7%). The mitigated condition shows a significant ($p<0.0001$) performance increase of 100%.
- *Situation Awareness*. Subjects in the unmitigated condition correctly responded to 22 of 84 situation awareness questions (26.2%). Subjects in the mitigated condition correctly responded to 49 of 84 situation awareness questions (58.9%). The mitigated condition shows a significant ($p=0.009$) performance increase of 125%.
- No negative affect on ability to engage foes.
- No negative affect on workload.
- 85% of subjects felt communication easier with augmentation

5 Discussion

The Communications Scheduler has been developed to help the Future Force Warrior manage the high volume of incoming information in a netted communications and collaborative situation awareness environment. With the aid of our proposed adaptive system we aim to decrease the soldier's risk by improving their ability to comprehend and act on available information. The Communications Scheduler was designed to improve message comprehension and situation awareness while not decrementing performance on concurrent tasks under high workload. Evaluations of the Communications Scheduler have shown over 100% improvement in message comprehension and situation Awareness. Situation Awareness is key to the ability to effectively manage mission priorities and coordinate with team members. Performance in this area is particularly difficult in high workload periods, as evidenced by the low overall scores in the evaluation. Even with the dramatic improvement as a result of the mitigation strategy, there is an opportunity here for further improvement.

6 [x] Acknowledgements

This paper was supported by a contract with DARPA and the U.S. Army Natick Soldier Center, DAAD-16-03-C-0054, for which LCDR Dylan Schmorrow serves as the Program Manager of the DARPA Augmented Cognition program and Mr. Henry Girolamo is the DARPA Agent. The opinions expressed herein are those of the authors and do not necessarily reflect the views of DARPA or the U.S. Army Natick Soldier Center.

The Honeywell team would like to acknowledge the efforts of Mr. Trent Reusser, Ms. Janet Creaser, Mr. Jeff Rye, and Ms. Danni Bayn for work on the pilot studies, scenario definition, and data analyses.

References

Dorneich, M.C., Mathan, S., Creaser, J., Whitlow, S.D., and Ververs, P.M. (2005). “Enabling Improved Performance though a Closed-Loop Adaptive System Driven by Real-Time Assessment of Cognitive State.” *Proceedings of the11th International Conference on Human-Computer Interaction (Augmented Cognition International)*, Las Vegas, Jul 22-27, 2005

Dorneich, M., Whitlow, S., Ververs, P.M., Carciofini, J., and Creaser, J. (2004) “Closing the Loop of an Adaptive System with Cognitive State,” *Proceedings of the Human Factors and Ergonomics Society Conference 2004*, New Orleans, September.

Dorneich, Michael C., Whitlow, Stephen D., Ververs, Patricia May, Rogers, William H. (2003). “Mitigating Cognitive Bottlenecks via an Augmented Cognition Adaptive System,” *Proceedings of the 2003 IEEE International Conference on Systems, Man, and Cybernetics*, Washington DC, October 5-8, 2003. (Invited)

DuRousseau, D.R., (2004) *Multimodal Cognitive Assessment System*. Final Technical Report, DARPA, DAAH01-03-C-R232.

Freeman, F.G., Mikulka, P.J., Prinzel, L.J., & Scerbo, M.W. (1999). Evaluation of an adaptive automation system using three EEG indices with a visual tracking system. *Biological Psychology, 50*, 61-76.

Hoover, A. & Muth, E.(in press). A Real-Time Index of Vagal Activity. *International Journal of Human-Computer Interaction*.

Kass, S J, Doyle, M Raj, AK, Andrasik, F, & Higgins, J (2003, April). Intelligent adaptive automation for safer work environments. In J.C. Wallace & G. Chen, *Occupational health and safety: Encompassing personality, emotion, teams, and automation*. Symposium conducted at the Society for Industrial and Organizational Psychology 18th Annual Conference, Orlando, FL.

Mathan, S., Mazaeva, N., & Whitlow, S. (2005). Sensor-based cognitive state assessment in a mobile environment. *Proceedings of the 11th International Conference on Human-Computer Interaction (Augmented Cognition International)*, Las Vegas, Jul 22-27, 2005.

Mathan, S., Dorneich, M., & Whitlow, S. (2005). Automation Etiquette in the Augmented Cognition Context. *Proceedings of the 11th International Conference on Human-Computer Interaction (Augmented Cognition International)*, Las Vegas, Jul 22-27, 2005.

Mikulka, P. J., Scerbo, M. W., & Freeman, F. G. (2002). Effects of a Biocybernetic System on Vigilance Performance. *Human Factors, 44*(4), 654-664.

Pope, A.T., Bogart, E.H., & Bartolome, D.S (1995). Biocybernetic system validates index of operator engagement in automated task. *Biological Psychology, 40*, 187-195.

Prinzel, III, L.J., Hadley, G., Freeman, F.G., & Mikulka, P.J. (1999). Behavioral, subjective, and psychophysiological correlates of various schedules of short-cycle automation. In M. Scerbo & K. Krahl (Eds.), *Automation technology and human performance: Current research and trends*. Mahwah, NJ: Lawrence Erlbaum Associates.

Raj A.K., Perry, J.F., Abraham, L.J., Rupert A.H. (2003) Tactile interfaces for decision making support under high workload conditions, *Aerospace Medical Association 74th Annual Scientific Meeting*, San Antonio, TX..

Sajda, P., Gerson, A., & Parra, L. (2003). Spatial Signatures of Visual Object Recognition Events Learned from Single-trial Analysis of EEG, *IEEE Engineering in Medicine and Biology Annual Meeting*, Cancun, Mexico.

Sarter, N. B., Woods, D. D., Billings, C. E., “Automation surprises,” Handbook of Human Factors and Ergonomics, 2nd Edition, Salvendy, Gavriel (Ed)., Wiley and Sons, 1997.

Whitlow S.D., and Ververs, P.M. (2005). “Scheduling Communications with an Adaptive System Driven by Real-Time Assessment of Cognitive State.” Accepted to the *11th International Conference on Human-Computer Interaction (Augmented Cognition International)*, Las Vegas, Jul 22-27, 2005

Wickens, C.D., Heffley, E., Kramer, A. & Donchin, E. (1980) The event-related brain potential as an index of attention allocation in complex displays. *Proceedings of the 24th Annual Meeting of the Human Factors Society*. Santa Monica, CA, 1980.