Improved Team Performance Using EEG- and Context-Based Cognitive-State Classifications for a Vehicle Crew

Kevin R. Dixon[1,*], Konrad Hagemann[2], Justin Basilico[1], Chris Forsythe[1] , Siegfried Rothe[2], Michael Schrauf[2], and Wilhelm E. Kincses[2]

[1] Sandia National Laboratories, P.O. Box 5800, Mailstop 1188, Albuquerque, NM 87185, U.S.A.
jcforsy@sandia.gov
[2] Daimler AG, Group Research, 059/G024-BB, 71059 Sindelfingen, Germany

Abstract. We present an augmented cognition (AugCog) system that utilizes two sources to assess cognitive state as a basis for actions to improve operator performance. First, continuous EEG is measured and signal processing algorithms utilized to identify patterns of activity indicative of high cognitive demand. Second, data from the automobile is used to infer the ongoing driving context. Subjects participated as eleven 2-person crews consisting of a driver/ navigator and a commander/gunner. While driving a closed-loop test route, the driver received through headphones a series of communications and had to perform two secondary tasks. Certain segments of the route were designated as threat zones. The commander was alerted when entering a threat zone and their task was to detect targets mounted on the roadside and engage those targets To determine targeting success, a photo was taken with each activation of the trigger and these photos were assessed with respect to the position of the reticle relative to the target. In a secondary task, the commander was presented a series of communications through headphones. Our results show that it is possible to reliably discriminate different cognitive states on the basis of neuronal signals. Results also confirmed our hypothesis: improved performance at the crew level in the AugCog condition for a secondary communications tasks, as compared to a control condition, with no change in performance for the primary tasks.

1 Introduction

Currently, crews for military light vehicles face a significant challenge due to information overload. Within a context where one individual serves as driver and navigator and a second as commander and gunner, each crew member must continuously manage their primary and one or more secondary tasks. For instance, the driver may be required to simultaneously operate the vehicle, navigate to an objective through unfamiliar roadways and terrain, and monitor radio traffic. In addition, these tasks may

* Corresponding author.

D.D. Schmorrow et al. (Eds.): Augmented Cognition, HCII 2009, LNAI 5638, pp. 365–372, 2009.

need to be performed under the stress of hostile attack or improvised explosive device. For the operational effectiveness and safety of these military personnel, technology solutions are needed that allow crews to operate more effectively in multi-tasking, information-intensive, high-stress environments.

This paper describes research conducted by Daimler AG, Research Group and Sandia National Laboratories to prototype and test an augmented cognition system for enhancing team performance for crews of military light vehicles. In this system, continuous EEG is measured and signal processing algorithms utilized to identify patterns of activity indicative of high cognitive demand. Second, data from the automobile is used to infer the ongoing driving context, and corresponding levels of cognitive demand. Based upon these measures, mitigation mechanisms were initiated to lessen the cognitive demand upon crew. During the fall of 2007, experimental tests were conducted at Marine Corps facilities at Camp Pendleton, CA with U.S. Marine Corps personnel serving as experimental test participants.

2 Augmented Cognition System

For this study, a Mercedes G-Wagon was modified to serve as military-relevant experimental test platform. With respect to the exterior, this primarily consisted of an M-45 M240G 7.62 Machine gun mount on the roof of the vehicle. For experimental testing, there was no gun in the Machine gun mount.

Fig. 1. Exterior of modified Mercedes G-Wagon used in experimental testing

The interior was modified in accordance with a two-person concept of operations in which one person serves as the driver and the second the commander/gunner. For the commander's station, arm rests on either side of the passenger seat were equipped with joysticks. These joysticks provided the interface for controlling the Machine gun mount (e.g. rotating the turret, adjusting magnification, and simulated firing). A dash-mounted display provided the image from a camera positioned on the Machine gun mount which was used in aiming by placing a reticle on the desired target. In addition to the camera controls, the left joystick had two push buttons which were utilized by

Fig. 2. Interior of modified Mercedes G-Wagon to be used for experimental testing

experimental participants in performing a secondary task. Headphones were utilized to present experimental stimuli and provide sounds consistent with test scenarios (i.e. simulated gunfire).

The driver's station consisted of the standard steering wheel and steering column controls, and dash-mounted vehicle displays (i.e. speedometer). A dash mounted panel contained push buttons utilized in performing secondary tasks for the experiment. Also, as with the commander, headphones were utilized to present experimental stimuli.

3 Experimental Tasks

Subjects consisted of 22 U.S. Marine Corps active-duty personnel who participated as eleven 2-person crews. Each crew was composed of a driver/navigator and a commander/gunner, with each assigned primary and secondary tasks.

3.1 Driver Experimental Tasks

The primary task of the driver was to drive the vehicle. During the experiment, the driver operated the vehicle on a prescribed test course along existing roadways. The driver was instructed to drive no faster than 30 KPH and a governor was set to prevent the driver from exceeding this speed limit.

In addition to the primary task of driving, the driver had two secondary tasks. In one, the driver listened to reports that were presented through the headphones and categorized the reports by pressing one of five buttons mounted on the dashboard next to the steering wheel. In the other secondary task, the driver occasionally heard a call sign through the headphones and responded by pressing one of two buttons depending on whether the call sign included a designated identifier.

3.2 Commander/Gunner Experimental Tasks

To simulate the detection and engagement of adversaries, targets were placed on the roadside within so called "threat zones". The primary task of the commander/gunner was to aim and fire at targets in accordance with prescribed target sequences. The commander/gunner was also given the same call sign task as described above for the driver.

4 Augmented Cognition Mitigation Conditions

There were three experimental conditions. In the reference condition (REF), participants performed tests without the aid of mitigation. In one mitigation condition (i.e. Augmented Cognition condition, MIT), the system used the measured workload of the participants as a basis for switching tasks between crew. In a second mitigation condition (i.e. Design-based Mitigation, S_MIT) the system automatically delayed all communications that occurred when the participants were engaged in a competing task. These conditions provided two bases for comparison on the proposed system. One comparison considers mitigation versus no mitigation, whereas the second compares mitigation to a "perfect" state in which there is a priori knowledge of impending workload conditions. Each experimental condition involved one trip around the test course and took approximately 35 minutes.

To assess periods of high workload, two EEG classifiers were used:

(a) Based on 32 channel EEG input, one classifier was trained to assess the driver's workload induced by the categorization task.
(b) Based on 32 channel EEG input, the second classifier was trained to assess the commander's workload induced by the gunning task.

Difficult driving situations were determined by the context (vehicle data) classifier provided by Sandia National Laboratories.

Mitigation was applied for the call sign task. As described above, the call sign task was continuously presented to the driver and to the commander. In the unmitigated condition, a call sign was alternately presented every 30 seconds to the driver and to the commander. In the mitigated "AugCog" condition, whenever the EEG classifiers detected high workload or the context classifier detected a difficult driving situation, the call sign stream was shifted to the crew member experiencing low workload. In this case, the respective crew member received the call signs with double the usual frequency (i.e. a call sign every 15 seconds).

In the case where both crew members were in high workload, the call signs were stored in a first-in-first-out (FIFO) buffer and as soon as one of the crew members went into low workload, the FIFO buffer was emptied with the call signs stored in the buffer presented every 5 seconds.

5 Results

In assessing the performance of the EEG classifier, we considered the percentage of time in which the classifier output coincided with the experimental condition (high or low workload). Classifiers were trained for each subject. At the beginning of the experiment, the EEG data of the two crew members was recorded while they performed the same tasks as during the actual experiment. The EEG data was labeled according to the workload attributed to the tasks and fed into the classifier training algorithm. The algorithm which determines the classifier parameters with the best classification result relative to the labels was chosen. Once the classifier was determined, it was fixed and left unchanged for the remainder of the experiment.

In a second step, the classifier performance was evaluated during a reference session in which no mitigation was provided, which also served as a baseline for comparison with the mitigation session.

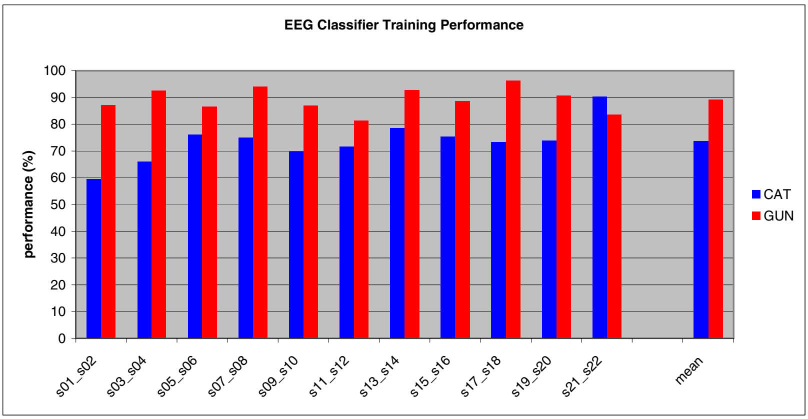

Fig. 3. EEG classifier performance (%) for all eleven teams: for the driver's categorization task (CAT, blue) and for the commander's gunning task (GUN, red) in the reference session (REF)

Detailed analysis revealed that if the EEG data from the "no mitigation" session was fed into the classifier training algorithm, usually a new classifier was obtained, leading to better classifier performances. This instability may be caused by either endogenous factors (e.g. unstable neurophysiological processes) or exogenous causes such as different experimental conditions (i.e. different rounds, different setting, variable electrode impedance, etc.).

When considering episodes in which the classifier output does not coincide with imposed experimental conditions, what may appear to be an imperfection with regard to the experimental design is always a correct decision from the classifiers point of view. It may be that the subject's workload was sometimes low during high-workload blocks or high during low-workload periods. In the current experimental setup, it was not possible to identify periods of high or low workload by means of an additional brain-based gauge that operated independent of the EEG cognitive-state classifiers.

Given the "real" cognitive state is always unknown, it is not possible to exactly determine the performance of mitigation measures. Due to an inbuilt hysteresis, as well as system intrinsic runtimes, the augmentation manager usually responded with a delay to cognitive-state changes. However, speeding up the reaction time of the system would have decreased its reliability. The configuration used in the present study was a reasonable compromise between response speed and classification reliability. Delay times after task onsets show that the system was capable of reacting within a few seconds. In cases where delays were longer, it has to be assumed that the driver actually did not experience an instantaneous cognitive state change.

5.1 Categorization Task (CAT)

Being a primary task, no changes in performance were expected between experimental conditions for the categorization task and results confirmed this hypothesis.

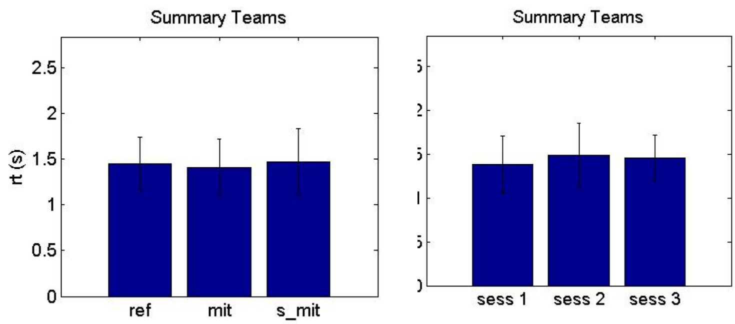

Fig. 4. Mean (n = 11) reaction times (seconds) for the categorization task (CAT) stimuli for all three experimental conditions

5.2 Gunning Task (GUN)

The gunning task (GUN) was the commander's primary task and as expected, no changes in performance were found between experimental conditions.

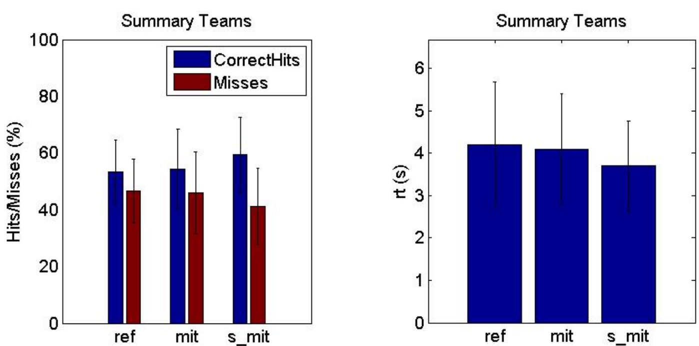

Fig. 5. Results of the GUN task plotted for three experimental conditions. (left) percent hits & misses, (right) reaction times (in seconds).

5.3 Call Sign Task (CALL)

The call sign task was the task that was mitigated and therefore represents a main outcome of the experiment. According to our hypothesis, the crew performance in this task should be better in the mitigated AugCog session (MIT) as compared to the unmitigated reference session (REF), as well as compared to the design-driven mitigation (S_MIT).

The crew performance in this task was analyzed with respect to two measures: reaction time (RT) and discriminability (d’). The results confirm the hypothesis showing that the driver’s best performance was obtained in the cognitive state and driving context mitigated condition (MIT) for both reaction times (RT) and discriminability (d’). The commander’s performance confirms the hypothesis in part, showing best reaction times in the MIT condition, whereas the highest d’ performance was obtained in the unmitigated condition (REF). Since the call sign task (CALL) was shared by driver and commander and was mitigated between them, it is meaningful to calculate the performance measures for the entire team. This analysis shows that both performance measures are in accordance with the hypothesis, namely the reaction time is shortest and the discriminability is highest in the cognitive state and driving context based condition (MIT).

6 Conclusion

This experiment served two purposes. First, it provided an initial assessment of the viability of augmented cognition technology for military platforms. Second, the study provided experimental data to assist developers in refining the technology to enhance its potential effectiveness and relevance to military applications. This development is important because military forces are being increasingly challenged by the need to manage large volumes of information imposing high levels of cognitive load, while successfully fulfilling their assigned missions. However, it should be noted that beyond the military application targeted in these experiments, vital insights are provided for adapting the same technology for incorporation into general automotive applications providing an opportunity to enhance overall automotive safety.

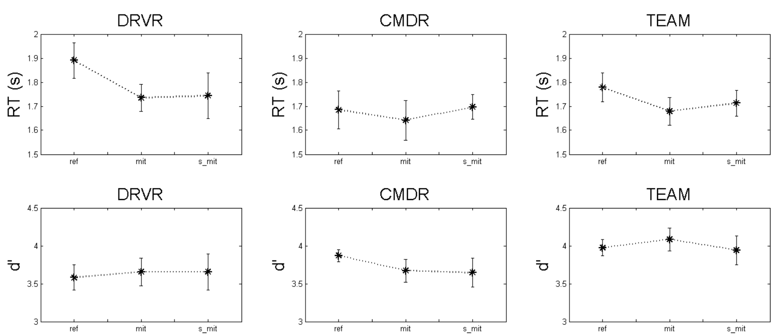

Fig. 6. Mean reaction time (RT – seconds) and mean discriminability (d’ – adimensional) for driver (DRVR, left), commander (CMDR, middle) and team (TEAM, right) for three experimental conditions (REF, MIT and S_MIT)

To date, Augmented Cognition research by this team has focused on cognitive overload situations. Looking toward a complete solution for Augmented Cognition, another situation which requires understanding is the concept of task underload. Together, the measure of overload and underload, allow us a complete measure of operator "vigilance." "Vigilance" is defined as a state of mind in which a person has their attention focused on a task at a level sufficient to perform that task. When fully recognized, a vigilant system will minimize the impact of underloaded personnel while maximizing the task loading that personnel can successfully execute.

Acknowledgements

This work was supported by ONR under contract N00014-06-2-0041. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.