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Mission-Based Scenario Research: Experimental Design and Analysis

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ABSTRACT

In this paper, we discuss a neuroimaging experiment that employed a mission-based scenario (MBS) design, a new approach for designing experiments in simulated environments for human subjects [1]. This approach aims to enhance the realism of the Soldier-task-environment interaction by eliminating many of the tightly-scripted elements of a typical laboratory experiment; however, the absence of these elements introduces several challenges for both the experimental design and statistical analysis of the experimental data. Here, we describe an MBS experiment using a simulated, closed-hatch crewstation environment. For each experimental session, two Soldiers participated as a Commander-Driver team to perform six simulated low-threat security patrol missions. We discuss challenges faced while designing and implementing the experiment before addressing analysis approaches appropriate for this type of experimentation. We conclude by highlighting three example transition pathways from MBS experiments to enhanced Army capabilities using a class of neurotechnologies called Brain-Computer Interaction Technologies.

INTRODUCTION

Imagine a system that can identify operator fatigue during a long-term vigilance task and automatically execute a fatigue mitigation strategy. This system would be an example of a Brain-Computer Interaction Technology (BCIT), a class of neurotechnologies, that aim to improve task performance by incorporating measures of brain activity to optimize the interactions between Soldiers and systems [2]. This example BCIT would use real-time processing of the system operator's neural data to identify a brain state that indicates suboptimal performance in the absence of any behavioral inaccuracies, as vigilance does not require overt responses. If research has identified fatigue mitigation strategies, the BCIT could automatically execute the mitigation strategy when a fatigue state is detected. This "automatic" interaction between the operator and the system

would minimize vigilance decrements based on operator fatigue. This is just one example to illustrate the potential performance enhancement of a fatigue-based BCIT where neural data indicates task-relevant brain states in the absence of overt operator behavior.

The goal of developing BCITs is to improve the performance of healthy individuals working in complex, real-world environments, such as a vehicle-based crewstation. A crewstation environment can provide a stepping stone between the simplified task and laboratory environment in traditional neuroscience experiments and the complexities of dismounted Soldiers navigating through a rich sensory world. The advantage of a transition from the laboratory to the real-world through a crewstation environment is especially clear when studying task performance under closed-hatch operations, where the only

view of the external world from inside the vehicle is through an indirect vision system. With no open windows on the vehicle, the crewstation environment can be precisely described and monitored based on the settings and logs of the vehicle systems. Thus, the crewstation is more constrained than a dismounted environment where it is much harder to monitor the events in the external world or know what sensory information about that world is available to the Soldier.

Of course, a crewstation environment has many substantial differences from a typical, neuroscience laboratory. A traditional neuroscience experiment is conducted in a quiet, barren room where stimuli are presented in isolation on a single computer monitor, and participants are asked to minimize both body movements and eye blinks in order to minimize artifacts in the physiological measurements. While this environment is designed for studying specific cognitive processes, without confounds of concurrent tasks or excessive noise overriding the physiological signal of interest, the laboratory may limit our understanding about how tasks are performed in the real-world, where our bodies and eyes move freely and we are often faced with multiple, concurrent tasks. The crewstation environment is one way to transition from the constrained, simplified laboratory to more complex environments where the sensory information is richer and more realistic than the lab, yet still definable based on the vehicle systems that enable closed-hatch operations.

A simulated crewstation environment provides the ability to extract multiple measures of a participant's interactions with the environment [3]. The sensory experience of the closed hatch environment can be captured based on system logs (crewstation state changes, screen configurations, sensor settings), and interactions with these systems provide behavioral measures (e.g., reaction times, accuracy of button presses). Eye-tracking measures capture where the participant is looking, while physiological measures (e.g., heart rate, galvanic skin response) can capture information about a participant's internal states (e.g., stress). This crewstation environment is also amenable for portable neuroimaging techniques (e.g., Electroencephalography (EEG), Functional Near-Infrared Spectroscopy (fNIRS)) to collect brain data during the execution of tasks to understand how the brain functions in this complex setting. These multiple measurements provide an avenue to record, analyze, and understand human behavior in more realistic settings.

The underlying argument here is that to develop BCIT for a real-world crewstation, the neuroscience experiment needs to match the real-world environment as accurately as possible. The need for this fidelity occurs on many levels. The brain measures needed to augment a BCIT must be robust to the increased signal artifacts based on body and

eye movements in complex environments compared to constrained movements in laboratory environments. The physiological signatures of the task may change when a person performs multiple tasks in the crewstation, compared to single, isolated tasks in the laboratory. The physiological signatures may change based on the sensory complexity of a crewstation compared to the white, barren walls of a laboratory. With finite resources, the BCIT development approach that is most likely to succeed seems to require experimentation in a targeted environment in order to minimize differences between development and implementation. This shift from a laboratory to a crewstation necessitates changes in both the experimental designs used to simulate a more realistic complexity of the tasks and the data analyses employed to account for the decrease in task constraints and signal to noise ratio. Consequently, scientists at the Army Research Laboratory (ARL) are developing the Mission-Based Scenario (MBS) experimental design concept to balance the needs for constraining experimental environments (i.e., minimize confounds, make data analysis tractable) and the need for sensory and task complexity (i.e., better emulate real-world environments).

Mission-Based Scenario (MBS) Design & Analysis

To invoke more realistic responses in a simulated environment, an MBS experiment must ensure that the simulated environment does not actively disrupt the participant's behavior, either through surprise, unusual occurrences or forced, unnatural behavior. These types of surprises result in a breakage in the Soldier's sense of presence or suspension of disbelief in the environment [4]. Presence can be viewed as the extent to which a user feels physically present within a virtual environment [5], while suspension of disbelief describes the extent to which an individual becomes mentally engrossed in the environment [4]. If the participant's presence and suspension of disbelief are regularly disrupted by the experimental environment, it is difficult to argue that the resulting studied behavior will be in any way natural [6]. The MBS concept aims to address this issue in three ways: 1) to situate experiments within a more realistic mission context; 2) to incorporate tasks, task loadings, and environmental interactions that are consistent with the mission's operational context; and 3) to permit multiple sequences of actions/tasks to complete mission objectives [1]. In short, an experiment employing a mission-based scenario design aims to simulate a more realistic mission experience in order to capture the relevant contextual effects on the participant's tasks, actions, and environmental interactions.

MBS experimental designs demand different data analysis approaches. Traditional neuroimaging experiments in a laboratory isolate task processing by time-locking to the period of time (experimental trial) when a single task occurs;

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however, in simulated missions, the timing of events and tasks differ with more variability. Consequently, the analysis approach for a mission-based scenario design must provide a way to capture task-relevant features in the EEG signal despite the complexity of a less constrained scenario design. Although traditional, event-related analyses could still be used for an MBS experiment, this paper will emphasize analyses that employ a pattern classification analysis approach. These classification examples aim to identify features of EEG dynamics that reflect global patterns that can predict particular mission tasks or relevant brain states that impact task performance. These task-relevant features could then be used in the design of BCIT neurotechnologies that allow systems to adapt to the dynamic changes in a user's brain state to enhance performance [2].
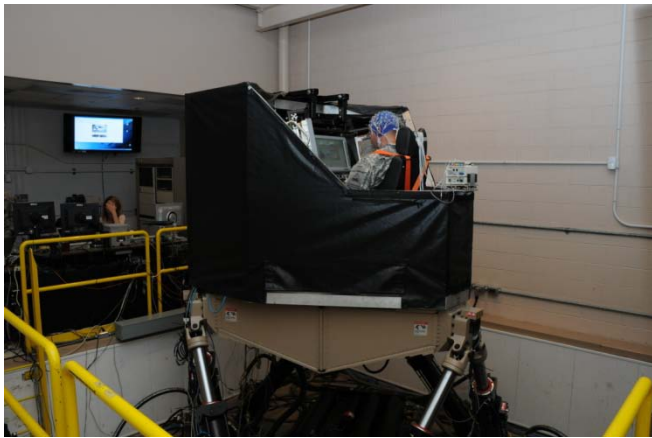
Figure 1: Soldier sitting on a six degree-of-freedom Ride Motion Simulator to simulate realistic movements of a vehicle. Photo provided by Detroit Arsenal Media Services.

Paper Overview

In this paper, we discuss a mission-based simulation experiment looking at a Commander-Driver team that aimed to link behavioral task performance during low-threat security patrol missions with neural data captured by scalp EEG sensors. The study emphasizes the role of a Vehicle Commander. In security patrol missions, the Commander is responsible for many tasks, including route planning and navigation, responding to various auditory communications about mission status and coordination, and maintaining local situational awareness (LSA) to detect and report targets. The frequency and difficulty level of these numerous tasks will vary throughout the mission, and it is likely that the Commander will often have to manage many of these tasks concurrently.

With our initial research emphasis on MBS for crewstation environments, this experiment was conducted on a Ride Motion Simulator (RMS, Figure 1) that simulates as realistically as possible the movements of vehicles at the Tank Automotive Research, Development and Engineering Center's (TARDEC) Ground Vehicle Simulation Laboratory (GVSL) at the Detroit Arsenal in Warren, MI. Thus, this experiment emphasizes another layer of transition from the laboratory to the real-world – before moving the MBS to a field experiment with vehicles navigating around unconstrained terrain, the transition begins with a simulated, mobile crewstation environment to gradually move from a fully constrained, stationary laboratory environment to the dynamics of a field test.

After providing an overview of the simulated mission environment, we discuss the design challenges and decisions stemming from the three aims of the MBS concept. Analyses of this dataset are underway [7], but instead of describing a specific result, this paper discusses three example pathways to characterize how MBS experiments foster the development of BCITs, and how these neurotechnologies show the potential for neuroscience experiments to enhance Army capabilities.

MISSION-BASED SCENARIO EXPERIMENT

This experiment was performed using a simulated crewstation environment for a Vehicle Commander and Driver during a series of low-threat security patrol missions. With space for only one crew member on the RMS (Figure 1), we focused on the Commander and his tasks. The experimental objective was to study brain dynamics of the Commander during as realistic as possible task performance.

Experiment Overview

Each week for seven weeks, two Army Sergeants were flown in from U.S. Army Maneuver Center of Excellence at Fort Knox, KY and Fort Benning, GA. All of the male participants had a Military Occupational Specialty (MOS) 11B (Infantryman), MOS 19D (Cavalry Scout), or MOS 19K (Armor Crewman). The Soldiers were all combat veterans of Iraq or Afghanistan. Except for the final week, the Soldiers did not know each other before arriving for the experiment, and in all cases, the Soldiers had not been deployed together. After completing a day of training, the participants completed two days of experimentation. On day one, one Soldier served as Commander and the other as Driver, and on day two, the Soldiers swapped roles. Consequently, a total of 14 Commander-Driver datasets were collected across the seven weeks of data collection between September and November 2010.

Each team pair completed six, low-threat security patrol missions through a simulated urban desert terrain. The Commander sat on a six degree-of-freedom, ride motion

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simulator using two touchscreen interfaces to interact with the environment through a 360 degree LSA system (Figure 2). The Commander also had a digital map with real-time information about vehicle location, a printed map to his right with the mission checkpoints and his hand-drawn mission route, and a touchscreen button interface for radio-related tasks. The Driver sat on a static platform using a single monitor with only a 60 degree horizontal, straight ahead view of the environment (Figure 3) and no map. The Driver's steering wheel controlled the movements of the RMS, allowing him to follow the Commander's directions to maneuver the vehicle through the simulated mission. The Driver was not instrumented for any physiological monitoring, while both eye-tracking and EEG data, which reflects brain activity through measurement of the pattern of electrical activity at the scalp, were collected on the Commander. Even though the two Soldiers were not on the same platform, the two communicated with one another through a two-way radio headset, and they also heard additional, pre-recorded audio communication from other simulated agents in the environment through a separate set of loudspeakers. One of the pre-recorded voices was a simulated tactical operating commander (TOC) who provided the mission directives a Commander would expect on a patrol mission. One of the experimenters also operated a soundboard with controls to activate pre-recorded TOC responses, facilitating simulated interactions between the TOC and Commander; for example, one button allowed the TOC to respond "Roger" when the Commander called in mission reports.

Figure 2: Vehicle Commander interacting with the simulated mission environment, wearing a 64 channel EEG cap. Photo provided by Detroit Arsenal Media Services.

For each mission, the pair drove from a Forward Operating Base (FOB) to their patrol sector in the city, Desert Metro. The Commander then navigated through a simulated city to reach three security checkpoints at specified times for mission-specific simulated rendezvous operations with local forces (e.g., deliver medical supplies to local clinic) while aiming to maintain a presence patrol in the sector. At each checkpoint, no squad dismounts were simulated in the environment; instead, the Commander just communicated with headquarters as if the dismount activity had occurred. There was no mandatory wait time at the checkpoints, so the Commanders continued on to the next checkpoint as quickly as they desired. After completing the city mission, the pair drove back to the FOB to complete the mission.

Figure 3: Vehicle Driver sitting at the static driver station, talking to the Commander over a headset and controlling the movements of the RMS with a yoked steering wheel. Photo provided by Detroit Arsenal Media Services.

The experimental emphasis was on the Commander and his numerous tasks, including route planning and navigation, responding to various auditory communications about mission status and coordination, and maintaining local situational awareness (LSA) to visually detect and identify specific individuals. In a patrol mission, these tasks often occur simultaneously, especially with a live driver who is dependent on the Commander for navigation directions and wayfinding information, since the Driver had only a 60 degree field of view and no map of the Commander's planned route. As experimenters, we faced the challenge of how to implement each of these tasks in a realistic fashion given the technical constraints of the available simulation environment. The task implementation also had to preserve enough experimental control to conduct an analysis of the EEG data.

Experimental Questions

The main experimental objective was to acquire neural data for these Commander tasks with as realistic task loading and environment interactions as possible within the simulation. We will highlight three of our experimental questions, and each will be discussed in more detail in the Three Example Pathways discussion in the MBS Data Analysis section.

First, although the mission tasks have dynamic and variable overlap with one another, can the neural data reveal timeframes when the Commander is busy with many tasks

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compared to times when he is more idle with less frequent task demands? The design facilitated this analysis by varying the task difficulty during two fixed sections of each mission. The drive between the FOB and the city at the beginning and end of the mission (4 minutes each way) was intentionally quiet with only 2-3 mission queries from the TOC and minimal navigation oversight for the Driver since the outskirts route was learned easily by all participants. Meanwhile, the mission in the city was busy with consistent queries from the TOC, constant chatter on the radio network among other platoons, navigation oversight required for the Driver, dynamic traffic and obstacle challenges along the mission route, and time pressure to arrive at the rendezvous checkpoints at a specified time. Here, the question is not what task the Commander is performing, but whether he is completing many tasks or just a few. If this neural information can be identified despite the movement artifacts and differences in the task-specific brain processing, a BCIT may be designed to optimize Soldier performance during times of potential task overload (see Pathway Example 1).

Second, can the neural data capture when the Commander listens to a mission-relevant compared to a mission-irrelevant auditory communication? The design used both pre-recorded TOC communication to the Commander as well as pre-recorded communication among members of a complementary, but not mission-relevant, platoon. All communications to the Commander required a verbal and/or motor response. Accuracy in these responses indicates whether the communication was successfully comprehended. If neural measures of auditory comprehension can be identified in complex mission environments, a BCIT may be developed to adapt the interface for efficient behavioral responses (see Pathway Example 2).

Third, can the neural data indicate detection of a visual target? The Commander was responsible for detecting and reporting the locations of the local coalition forces within the city. Similar to the second question about detecting auditory communications, neural markers for visual target detection would enable a BCIT to facilitate the supporting detection tasks and adapt the interface for efficient behavioral responses (see Pathway Example 3).

In the next section, we will describe how we overcame some of the challenges for task implementation to achieve the three MBS aims during mission scenario development.

MBS EXPERIMENTAL DESIGN CHALLENGES

As discussed earlier, an MBS design has three main aims: 1) to situate experiments within a more realistic mission context; 2) to incorporate tasks, task loadings, and environmental interactions that are consistent with the mission's operational context; and 3) to permit multiple sequences of actions/tasks to complete mission objectives

[1]. Each of these aims had practical implications for the experimental design.

MBS Aim 1: Situate in mission context

The first MBS design aim is to establish a mission framework to obtain neural data that is obtained in a context relevant for an intended BCIT design. For this experiment, the chosen mission context was low-threat security patrols. Therefore, a specific joint operation with the local forces was specified for each of the six missions, and the TOC communications for each checkpoint were in line with this overall mission objective. For example, one mission was a Knock and Treat operation aimed to provide medical treatment to local civilians, and a simulated operation within this mission for the dismount squad at a checkpoint was to deliver an injured child to a local hospital. Another mission was a Snap Vehicle Checkpoint operation, where one of the simulated checkpoint operations delivered the necessary supplies for the snap VCP. By situating each mission with a low-threat operation, the experimental design facilitates an immersive environment for the Soldier participant to conduct Commander tasks in an environment that matches his expectation from his experience in theatre. The match between the simulated tasks and his experience-based expectations fosters behavioral actions and neural responses that are as realistic as possible given the necessary constraints for a neuroscience-based analysis of task performance.

MBS Aim 2: Appropriate tasks & interactions

The second MBS design aim strives to link the implementation of the tasks based on the situated mission context. For this experiment, this critical link was implementing the expected Commander tasks while minimizing tasks that would require engagement, since the simulation environment used for this experiment did not support combat-related behaviors (e.g., vehicle firing capability, appropriate attacking or fleeing behaviors for human entities, etc). In order to minimize immersion-breaking events [4], the simulated tasks must match the capabilities of the simulation environment with the expected participant responses. One salient challenge for implementing this aim was identifying a low-threat, visual target detection task.

A large part of a Commander's job on a security patrol is to maintain local situational awareness (LSA), and our mission-based scenario needed to include a target detection task to incorporate this component. To avoid engagement requirements, the task could not place human threats in the environment to detect since the Commander would not be able to respond and engage the threat in appropriate and expected ways. Likewise, we could not place IEDs in the environment for the Commander to find since the vehicle

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team would not just report the IED and then drive by it as an appropriate, realistic response. We settled on a task to report the location of local coalition forces, explaining the operational relevance of ensuring that the local forces were out on patrol as part of shared security measures for both local and US forces. The reporting requirement for this task also provided a mechanism to quantify the Commander performance for analysis purposes (see Pathway Example 3).

In addition to reporting local Soldiers on patrol, a Commander also had a dynamic visual target detection task where the TOC identified a new target to find after the mission began. The motivation here was to increase the LSA responsibilities of the Commander, allowing him to feel the more realistic sensation of several tasks building up as he executed his planned route through the city to reach his checkpoints at the assigned mission time. This task also increased the intensity and frequency of the tasks within the city, which was essential for the experimental question about identifying neural patterns indicative of variable task loads on the Commander throughout the mission (see Pathway Example 1).

The selection of these visual target detection tasks highlight the influence that the MBS aim to enable appropriate tasks and environment interactions had on this experiment design. The targets had to fit the low-threat mission profile to eliminate the need for engagement, but the target task needed to be demanding with a challenging number of targets. The reporting task for all targets provided the necessary metrics for analysis.

MBS Aim 3: Enable participant-specific actions

The third MBS aim addresses the desire for an interactive experience between the participant and the simulation environment. For this experiment, the challenge arose when balancing a Commander's route planning task with the two visual target detection tasks and the timing of mission-relevant auditory communications from the TOC.

Before each of the six missions, the Commander planned a route through the city to the three checkpoint locations that ensured he arrived at the checkpoints at the assigned mission times, while still patrolling enough of the city to maintain a presence patrol. This meant that, as experimenters, we did not know which roads in the city would be traversed during any particular mission; however, during scenario development for the experiment, every visual target had to be assigned a specific location in the environment. Likewise, each audio communication from the TOC had to be timed to play in conjunction with particular events in the mission scenario. In short, the route planning task implemented an expected task for the Commander, but it also created a challenge for target placement and communication timing.

For the visual targets, our solution emphasized the most likely routes through the city. In particular, more targets

were placed along the major streets in the city since most routes would have to incorporate sections of these streets. In addition, some targets were placed in the vicinity of the checkpoints since all Commanders would traverse these streets as part of the mission requirements.

We used two alternative approaches for ensuring mission-appropriate timing for the TOC's audio communications – vehicle trip lines in the environment and a live experimenter who was able to play particular auditory files with a soundboard. Each of these decisions still resulted in some minor, unsolved design challenges. The trip lines for the radio change were triggered anytime the vehicle headed down that road, even when the traversal was for presence patrol and not checkpoint arrival. The soundboard ensured that the checkpoint arrival and departure messages did not face this same challenge, but it required human intervention which is not preferred. Nonetheless, although not perfect, the vehicle trip lines and soundboard did ensure that all Commanders heard the required communications and supported the realism of the TOC interactions expected during a security patrol.

The third MBS aim to enable participant-specific actions within the simulated mission environment provides a host of challenges for the experimental design, highlighted here with a discussion of target placement and communication timing. The intended development of an interactive narrative algorithm will certainly address some of these implementation challenges [1], but managing the competing interests of enabling participant control while maintaining sufficient experimental precision will be an on-going challenge for MBS experimentation.

MBS DATA ANALYSIS

The increased complexity of the experimental environment utilized in this MBS experimental design requires different data analysis methods and data interpretation than a standard laboratory experiment.

An event-related potential (ERP) analysis is a common approach for laboratory experiments. An ERP is calculated by segmenting the EEG signal into epochs of time surrounding the event of interest, such as the appearance of a specific sensory stimulus, and then averaging time epochs of this repeated stimulus type to reveal a common EEG waveform. Based on the precise timing of a single event, the ERP is likely to indicate brain processing related to that event of interest. With the increased complexity of this experiment, where different event types often occurred simultaneously, it is difficult to use this experimental methodology to study the brain signatures underlying specific event types. Critically, our experimental objective is not to describe the neural processing for a particular Commander task; instead, we aim to investigate whether any neural signature of task-relevant behavior could be identified

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despite the complexity of a mission with concurrent tasks and noise artifacts introduced by less constrained movements of a Commander's head, torso, and hands [8].

Consider an analysis of brain data from this experiment that seeks neural patterns indicative of successful visual target detection. Essential to this analysis is the ability to know whether a given target, i.e., a coalition Soldier, is detected and when this detection occurred. While the Commander reports when they see a target, this response does not indicate the time of detection. First, the Commander was performing multiple tasks at once, so the response time of the verbal report was often more correlated with the number of simultaneous tasks being performed than it was with the precise time of the target appearing. Second, the targets did not suddenly appear on the Commander's screen, but due to visual perspective, appeared off in the distance and grew as the Commander approached them. This change in perspective makes it difficult to code an algorithm for when the target was detectable to the human eye. Third, the Commander manipulated camera sensors of the environment, so how much of the environment was processed (or what entities were detected) during frequent sensor changes is hard to quantify. In short, establishing a precise time that a target was detected is non-trivial.

We are currently exploring several methods for addressing this event timing issue. First, we are using pattern classification methods to determine whether it is possible to identify brain states related to the visual target processing in time windows occurring around the onset of the visual target, rather than a precise detection time within a few milliseconds for an ERP analysis. This approach to data analysis is useful as a pragmatic approach to developing BCITs, but provides limited useful information about underlying brain processing for specific tasks in real-world environments since targets in our MBS experiment co-occur with other events. This hinders our ability to determine what neural patterns relate to the target detection event and what relates to the co-occurring event(s). It does not preclude, however, identifying features of a brain state that are predictive for a specific task. These features are one critical element for developing a BCIT.

In addition to pattern classification techniques, we are also exploring combining eye-tracking information to augment the timing accuracy of a visual target detection event [9] by using the time an eye gaze locks the target entity as a proxy for the time the target was detectable by the participant. Finally, we are examining bottom-up, data-driven methods to detect similarities in brain signals detected throughout the experiment, and check their correlations with experimental stimuli in order to identify relevant brain signals for further processing.

Through the use of these and other techniques [10], we aim to reveal predictive features in the EEG signal for a brain state of interest. These features can then feed the development of a BCIT to detect brain states that indicate time frames when a predetermined change to the system interface could optimize performance.

THREE EXAMPLE PATHWAYS: MBS TO BCIT

Thus far, this paper has only discussed the challenges when implementing an MBS study. This section describes the expected Army relevant capabilities afforded by MBS experimentation by discussing three example pathways of how an MBS analysis could lead to the development of a BCIT. These three pathways link back to the three experimental questions highlighted in the section describing the Mission-Based Scenario experiment.

Pathway Example 1: Commander Taskload

During each mission, the number and frequency of the Commander's tasks varied during different segments of the mission. The drive between the FOB and the city at the beginning and end of the mission had infrequent tasks, while the mission to the three checkpoints in the city had many tasks occurring simultaneously, all competing for the Commander's time and attention. This design enables an analysis to identify neural signatures of taskload intensity.

This analysis could lead to a BCIT that can mitigate task overload during times of peak intensity. The appropriate mitigation strategy would need to be identified experimentally, but some potential mitigation strategies may include supporting a simplified version of the interface. This simplified interface would minimize the visual complexity of the screen (decreasing sensory overload) while preserving the essential elements for the critical mission tasks. If the system is set up for alerts on both critical and non-critical mission elements, the system could revert to critical information only. A crewstation contains many systems with many levels of alerts and system information, so identifying times when the crewstation may be too overwhelming based on the Commander's taskload could serve to improve mission performance.

Pathway Example 2: Communication Actions

During each of the six missions, the TOC communications about the mission required just a verbal response or a verbal response plus a touchscreen button response. This design facilitates a pattern classification analysis to investigate if EEG signal features can indicate when the communication requires a verbal-only response versus communications that require both verbal and button response.

If these two response states can be differentiated, the system could dynamically alter the size of the interface buttons to make it easier for the Commander to touch the correct button despite the jostling of the body due to the motion of the vehicle over terrain. This dynamic interface adaptation may improve the response time and/or the

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accuracy for that task by increasing the ease of interaction between the Commander and the interface.

Pathway Example 3: Visual Target Reporting

In this experiment, the Commander was responsible for reporting the location of visual targets in the local environment. Using an ERP approach, neuroscience research in the laboratory has identified a stereotypic response in the EEG signal, known as the P300, which reflects the detection of a target with a *positive* deflection of the wave approximately *300* milliseconds after the target stimulus is detected [11]. Pattern classification approaches may identify a neural signature that captures this marker of the target detection process without requiring a time-locked signal average (i.e., ERP). Thus, a classification analysis of the general timeframe of the visual target detection events in this dataset would reveal whether a neural signature for the detection event is discernable despite the increase in task complexity and movement artifacts and decrease in the precision of the event timing.

A common mission task is to mark a digital map of the sector with the location of identified targets, although that was not a task we incorporated based on our decision to simulate low-threat security patrols. For missions where a map of detected targets is critical, the efficiency of the markup may be improved by linking a neural response to a target to the fixation point of the Commander's eyes as an estimate of where to place the target on a digital map of the environment. The system would link the gaze point on an indirect vision camera system to a grid location that links the current zoom/focus on the vehicle camera to a point in the mission map of the patrol sector. The system could then prompt the Commander to accept, modify, or reject the target placement. This type of BCIT may optimize target reporting. Further discussion of this idea can be found in [12].

Future Pathways

These three examples highlight a sample of the possible BCIT-based capabilities, but they are not an exhaustive list. This experiment is part of an initial effort at implementing a neuroimaging experiment that employs an MBS design and analysis. Each will continue to improve over time, identifying pathways to transition MBS analyses to a BCIT within a definable timeframe for particular performance enhancements and enable Army-relevant capabilities.

SUMMARY

The overarching goal of an MBS design is to enable the development of a BCIT that can leverage measures of brain activity to enhance the interactions between Soldiers and the systems required to execute their missions. To optimize BCIT development, we argue that the experiment must match as closely as possible the targeted environment for implementation, and we propose two specific elements to accomplish this aim.

The first element is the simulated environment, using a closed-hatch crewstation environment as a critical venue to transition neuroscience research from constrained laboratory settings to unconstrained, real-world environments. The second element is the MBS design and analysis framework. The three aims of an MBS design capture the relevant contextual effects on the Soldier's mission tasks, actions, and environmental interactions in order to understand how the brain functions in complex, real-world environments. The MBS analysis approaches emphasize methods to identify predictive neural signatures for brain states relevant for task performance. By incorporating these two elements, neuroscience experiments hold promise for enhancing Army capabilities by using BCITs to improve Soldier-system performance.

MBS scenario development marks a shift in experimental design from earlier EEG studies conducted on the Ride Motion Simulator. Prior experiments have used fixed routes with only one participant, where a solo Commander is driven by the simulation through the patrol mission. This fixed route ensures that all targets placed are seen, and any communications that require precise timing within the mission scenario can be scripted easily. While this more controlled design facilitates traditional neuroscience-based analyses, it fails to capture the contextual effects on the participant's tasks, actions, and environmental interactions. It is not clear that our brains will perform tasks identically in a simplified environment (fixed route, single rather than concurrent tasks, etc) and in a dynamic, complex environment (route navigation and alterations, concurrent tasks, etc). Consequently, the design challenges tackled during our first mission-based scenario experiment on the RMS seem necessary to capture a Commander's dynamic mission behavior. While design enhancements are targeted for future MBS studies, this experiment provides our first neuroimaging dataset on the RMS that captures dynamic Commander-Driver teaming during a more realistic simulation of a low-threat security patrol mission. We argue that these types of datasets will enable a pathway between simulation experiments and BCIT development that reveal the promise of neuroscience research for the Army.

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