EFFECTS OF COGNITIVE WORKLOAD ON DECISION ACCURACY, SHOOTING PERFORMANCE, AND CORTICAL ACTIVITY OF SOLDIERS

S. E. Kerick* and L. E. Allender

U.S. Army Research Laboratory
Human Research and Engineering Directorate
Aberdeen Proving Ground, MD 21005-5425

ABSTRACT

The purpose of this research was to investigate dynamic cortical processes of soldiers during simulated shooting scenarios as a function of task demand. Task demand was varied among three two-level factors: task load (single, dual), decision load (no-decision, decision), and target exposure time (short, long). Dependent variables were measured at subjective, behavioral, and physiological levels. Subjective measures were self-reports of workload and stress, behavioral measures were primary and secondary task performance, and physiological measures were event-related spectral perturbation (ERSP, where event-related refers to target onset times) in theta (4-7 Hz) and alpha (11-13 Hz) frequency bands. Results from analyses of the subjective report data revealed that time stress and decision load main effects significantly influenced workload perceptions. Analyses of the shooting performance data revealed that the time stress main effect was significant for decision accuracy, shooting accuracy, and response time, and analyses of secondary task performance data revealed a time stress main effect for arithmetic accuracy. The interaction between time stress and decision load was also significant for shooting accuracy and arithmetic accuracy. Results from analyses of the ERSP data revealed that peak theta power differed as a function of time stress and peak alpha power differed as a function of task load and decision load. Overall, the results suggest that time stress had the most profound and widespread effects on workload perceptions and performance. Cortical responses exhibited different oscillatory patterns of communication at different frequencies and topographic regions in response to the different task demand factors.

1. INTRODUCTION

A major objective of the U.S. Army's Future Force Warrior program is to enhance situational awareness of the soldier by promoting technology to communicate real-time battlefield information. Given a limited capacity for human information processing and the increasing demands imposed on soldiers to consolidate information from multiple sources, there exists a need to better understand how increased cognitive workload affects soldier shooting performance. Cognitive effort and attentional processes have been inferred from real-time electroencephalographic (EEG) recordings of expert and novice marksmen during self-paced target shooting. One consistent observation from this research is greater left temporal alpha (8-13 Hz) synchronization in higher-skilled marksmen during the final second preceding the trigger pull (Haufler, Spalding, and Hatfield, 2000; Kerick, Douglass, and Hatfield, 2004). The response-related synchronization of left temporal alpha has been interpreted as inhibition of task-irrelevant cognitive processes and evidence of more highly organized sensorimotor integration as skill levels advance from controlled (explicit) to automatic (implicit). That is, skilled shooters are able to perform with less cognitive effort and rely less on working memory processes to execute shots.

However, no published research to date has examined cortical responses of skilled shooters in a reactive shooting task in which the shooter must search the environment for targets, detect and correctly identify them as enemy or friendly, and make a decision whether to execute or inhibit firing the weapon as soldiers must. Further, soldiers perform in even more dynamic, complex, and stressful environments and they are faced with other simultaneous task demands such as those expected to be imposed on the U.S. Army Future Force Warrior for maintaining situational awareness and monitoring communications. Scribner (2002) investigated the effects imposing a secondary task load (mental arithmetic) on soldiers during a shooting task that required enemy-friendly target discrimination. The results revealed that soldiers committed a significantly higher rate of friendly-fire errors during dual- versus single-task shooting conditions. This finding provides evidence of the high attentional demands of shooting and implies a limited information-processing capacity for secondary tasks with potentially lethal consequences.

Research is needed to better understand how cognitive workload influences central mechanisms underlying shooting performance. Accordingly, this study

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was designed to investigate cortical processes of soldiers during reactive shooting in simulated scenarios that varied in task demand. Task demand was manipulated among three two-level factors: levels of task load were single (shooting) and dual (shooting and mental arithmetic), levels of decision load were no-decision (all enemy targets) and decision (either enemy or friendly targets), and levels of target exposure time were short (2-4 s) and long (4-6 s). Arithmetic problem solving was implemented as the secondary task for dual-task load scenarios. Dependent variables were primary task performance (decision accuracy, shooting accuracy, and shooting response time), secondary task performance (arithmetic accuracy and arithmetic response time), subjective ratings of workload and stress, and ERSP in theta and alpha frequency bands.

2. METHOD

The Dismounted Infantryman Survivability and Lethality Testbed (DISALT; NAVAIR, Orlando, FL) simulated an outdoor shooting range at Aberdeen Proving Ground (i.e., M-Range), controlled the presentation of pop-up targets (target type, location, time of onset, and exposure time), and recorded weapon aim point data and shot results from an M16A2 rifle equipped with an infrared emitting diode and collimator lens (see Figure 1). Weapon recoil was simulated using an electromechanical recoil subsystem and weapon sounds were simulated via digital audio surround-sound. Each subject (17 Marines, 1 Army Ranger) completed eight different shooting scenarios (each consisting of 36 pop-up targets) and an arithmetic-only task (i.e., non-shooting scenario consisting of 30 arithmetic problems). For the shooting scenarios, targets were presented individually at variable intervals (10 s ± 2 s) and remained exposed for variable durations depending on the time stress factor (2-4 s or 4-6 s). Target presentations were distributed randomly across each of 18 range locations on two occurrences ([left, center, right] x [50, 100, 150, 200, 250, 300 m]). For decision load shooting scenarios, either an enemy (brown) or friendly (olive) target was presented on any given trial with equal probability and instructions were to identify the current target and shoot only at enemy targets. For dual-task shooting scenarios, arithmetic problems were presented verbally via digital audio player at variable intervals (2 s ± 1 s) before the onset of the targets and instructions were to verbally answer the problems as quickly as possible while maintaining optimal shooting performance. For the arithmetic-only task, subjects were required only to verbally answer arithmetic problems as quickly as possible. Continuous EEG recordings were acquired from 36 standard scalp locations during all scenarios. Single-trial epochs, time-locked to target onset times, were extracted and ERSP was derived. ERSP was analyzed at theta (4-7 Hz) and alpha II (11-13 Hz) frequency bands. The subjects completed subjective reports of workload (Subjective Workload Assessment Technique, SWAT) and stress (Subjective Ratings of Events, SRE) immediately following the completion of each scenario. The nine different sequences of the nine scenarios were counterbalanced for order and data were analyzed using a nine period by nine treatment crossover design with sequence and period included in the model.

Figure 1. Task environment illustrating a soldier wearing EEG cap while scanning for targets to appear on the simulated target range. Targets were either enemy (brown) or friendly (green).

3. RESULTS

3.1 Shooting Performance

A significant main effect of time stress was observed for decision accuracy (F [1,52] = 6.08, $p < 0.05$), shooting accuracy (F [1,111] = 196.15, $p < 0.01$), and response times (F [1,111] = 239.16, $p < 0.01$). Specifically, a higher percentage of friendly-fire errors was observed for short (M = 2.93, SE = 0.66) vs. long (M = 0.62, SE = 0.66) exposure times; a higher percentage of target hits was observed for long (M = 58.89, SE = 2.17) vs. short (M = 36.39, SE = 2.17) exposure times; and shooting response time (ms) was lower for short (M = 2732, SE = 76) vs. long (M = 3296, SE = 76) exposure times. The interaction between time stress and decision load was also significant for shooting accuracy (F [1,111] = 10.85, $p < 0.01$). A higher percentage of target hits was observed for enemy-only targets with long exposure times (M = 61.26, SE = 2.45 vs. M = 56.52, SE = 2.45) but a higher percentage was observed for enemy-friendly targets with short exposure times (M = 39.31, SE = 2.45 vs. M = 33.46, SE = 2.45).

3.2 Arithmetic Performance

A significant main effect of time stress was observed for arithmetic accuracy (F [1,43] = 8.57, $p < 0.01$). A higher percentage correct was observed for long (M = 65.36, SE = 1.93) vs. short (M = 58.69, SE = 1.93) exposure times. The interaction between time stress and decision load was also significant for arithmetic accuracy (F [1,43] = 13.28, $p < 0.01$). A higher percentage correct was observed for enemy-friendly targets with short exposure times (*M* = 63.82, *SE* = 2.51 vs. *M* = 53.55, *SE* = 2.51) but a higher percentage was observed for enemy-only targets with long exposure times (*M* = 68.54, *SE* = 2.51 vs. *M* = 62.19, *SE* = 2.51).

3.3 Subjective Report

Significant main effects were observed for task load (F [1,111] = 68.10, $p < 0.01$) and exposure time (F [1,111] = 13.35, $p < 0.01$. Workload ratings were higher for dual- (*M* = 46.91, *SE* = 3.67) vs. single- (*M* = 19.81, *SE* = 3.67) task scenarios and they were higher for shorter (*M* = 39.32, *SE* = 3.67) vs. longer (*M* = 27.40, *SE* = 3.67) exposure time scenarios. Significant main effects were observed for task load (F [1,111] = 40.05, $p < 0.01$) and exposure time (F [1,111] = 12.64, $p < 0.01$). Stress ratings were higher for dual- (*M* = 23.76, *SE* = 4.14) vs. single- (*M* = 13.69, *SE* = 4.14) task scenarios and higher for shorter (*M* = 21.56, *SE* = 4.14) vs. longer (*M* = 15.90, *SE* = 4.14) exposure time scenarios.

3.4 Event-Related Spectral Perturbation

Analyses of ERSP data revealed a significant time stress main effect for peak theta (F [1,83] = 5.57, p = 0.02). Peak power (dB) was higher for short (*M* = 3.22, *SE* = 0.27) vs. long (*M* = 2.93, *SE* = 0.27) target exposure times with maximum peak observed in the central parietal region (Figure 2). Peak alpha differed as a function of task load (F [1,83] = 6.59, p = 0.01) and decision load (F [1,83] = 5.39, p = 0.02). Peak power (dB) was higher for single- (*M* = 3.19, *SE* = 0.55) vs. dual- (*M* = 2.66, *SE* = 0.55) task scenarios and higher for enemy-only (*M* = 3.17, *SE* = 0.55) vs. enemy-friendly (*M* = 2.68, *SE* = 0.55) target scenarios with maximum peak observed in the left temporal region. Figures 2-4, illustrate topographic maps (top) of the ERSP data (bottom) at the time of peak power (indicated by the red reference lines) time-locked to the onset of targets (indicated by the Y axis). The X axis ranges from 3976 ms before to 4976 ms after the onset of targets (0 ms). Latencies are indicated by the horizontal red reference lines and printed in text below each map.

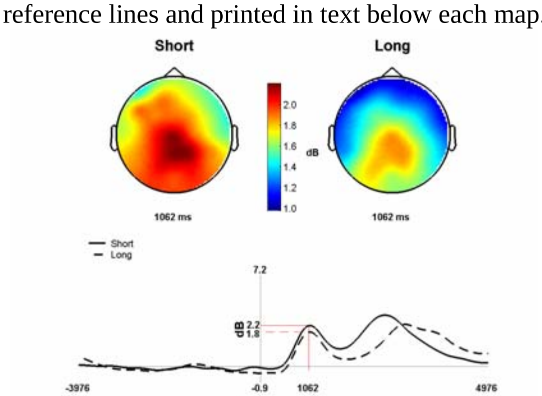

Figure 2. Main effect of target exposure time for peak theta power (dB): topographic maps for short (top left) and long (top right) target exposure time scenarios and ERSP plot of theta power in the central parietal region (Pz) for the short (solid line) and long (dashed line) exposure time scenarios (bottom).

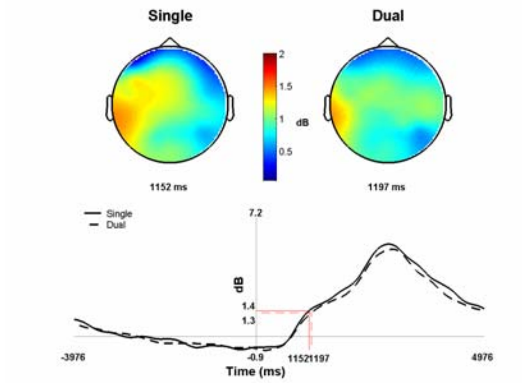

Figure 3. Main effect of task load for peak alpha power (dB): topographic maps for single- (top left) and dual- (top right) task load scenarios and ERSP plot of alpha power in the left temporal region (T7) for single- (solid line) and dual- (dashed line) task load scenarios (bottom).

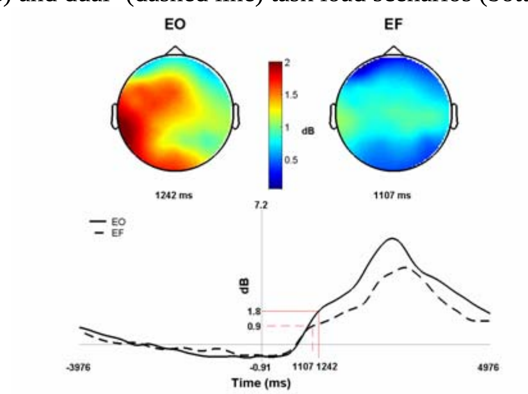

Figure 4. Main effect of decision load for peak alpha power (dB): topographic maps for enemy-only (EO, top left) and enemy-friendly (EF, top right) decision load scenarios and ERSP plot of alpha power in the left temporal region (T7) for enemy-only (solid line) and enemy-friendly (dashed line) decision load scenarios (bottom).

CONCLUSIONS

The results of this study suggest that time stress had the most profound and widespread effects on workload perceptions and performance. With respect to cortical dynamics, different oscillatory patterns of cortical communication were observed at different frequencies and topographic regions in response to the different task demand factors. The higher peak theta activity observed in the central parietal region in response to short versus long target exposure times suggests that synchronized oscillations associated with stimulus encoding were more coherently activated, perhaps constrained by the time pressure imposed by the task. The greater alpha suppression observed during dual-versus single-task scenarios despite the lack of a task load effect for either primary or secondary task performance suggests that the soldiers engaged in different strategies or worked harder in order to maintain performance in the more difficult dual-task scenarios. Consistent with data provided by subjective report, the soldiers exhibited greater alpha suppression during the more difficult dual-task load scenarios. This finding supports other research which has shown that alpha suppression is associated with modulation of sensorimotor information processing and is more strongly suppressed during the processing of complex tasks involving perceptual, judgement, memory, and motor demands (Klimesch, 1999). These findings provide new insights into the dynamic brain processes associated with stimulus encoding and response preparation of soldiers during real-time performance of a reactive shooting task under varied conditions of cognitive workload. and have important implications for advancing cognitive models and human systems engineering. Follow-up research will examine cortical responses of soldiers performing in more ecologically valid environments while performing more realistic secondary tasks relevant to the Future Force Warrior. Technological advances in wireless recording systems, sensor technologies, and signal processing algorithms for removing environmental and movement artifacts are essential to this effort.

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