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14. ABSTRACT
This study was designed to examine the relationship between load carriage, cognitive performance, and perceived workload. Participants carried equipment typically worn in combat, walked on a treadmill (simulating a dismounted patrol) for two hours, and concurrently performed a series of cognitive tasks similar to those required in combat (e.g., detection, recognition, working & spatial memory, and communication). All participants completed three two-hour sessions wearing a 0, 98 or 135 lb combat load. Physiology (kcals) highly correlated (r = 68, $p < .01$) with subjective rating of strenuousness. Results show that infantrymen can maintain a high level of physical performance over time; but at a cost to cognitive performance ($p < .05$). In addition, and potentially of great operational significance, is that after removing the 135 lb weight and resting for 5 minutes, cognitive performance did not return to baseline levels. Potential mitigations and implications of these results will be discussed.

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Cognitive Performance and Physiological Changes under Heavy Load Carriage

PSE Report: 10-12

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Executive Summary

The primary objective of this project was to empirically examine the relationship between heavy load carriage and cognitive performance. Participants carried standard USMC equipment typically used on patrol, walked on a treadmill for two hours at 2 mph (to simulate a movement on a patrol), and concurrently performed a series of cognitive tasks requiring skills (visual detection and recognition, working memory, and spatial memory) typically needed while on patrol. Seventeen Marines completed a series of three sessions carrying 0, 98, and 135 lb. loads.

For nine of the Marines, carrying 135 lbs. required them to carry a load equivalent to 90% or greater of their body weight. This extreme condition is not uncommon during current field deployments (Tyson, 2009). While the physiological demand notably increased with heavier loads, average heart rates only reached approximately 65% of the age predicted maximum for the majority of Marines. The relative intensity of physical work required during this task was Moderate / Hard based upon heart rate, Metabolic Equivalents (METS) and perceived exertion. The ability of Marines to sustain the relatively high physical demand of carrying 135 lbs. for two hours is testament to their successful physical training. However, carrying heavy loads negatively affects cognitive performance of combat-related tasks. These cognitive effects may be partially mitigated by the physical conditioning of Marines.

The findings reported here demonstrate that carrying a heavy load significantly increases physical strain (VO_2 and HR), perceived effort (RPE, Heaviness, TLX), decreases perceived comfort (CALM), and deteriorates cognitive performance (detection, working memory, and spatial memory).

This study yielded several important findings:

1. Cognitive performance degrades with increasing weight carried.
2. The decrement in performance between load conditions increases over time.
3. Physiological strain and cognitive performance are negatively correlated.
4. Cognitive performance is positively correlated with perceived comfort.
5. Cognitive performance is negatively correlated with perceived heaviness.

These results show that carrying heavy loads has an impact upon the ability of infantrymen to detect and identify potential threats (targets versus non-targets) in their environment while on patrols. Even under the favorable conditions of a laboratory setting, controlling for many of the other variables (heat, fatigue, etc.) that may be experienced on patrol, detection performance significantly decreased under the heaviest load condition. One of the major considerations of these results is that the decrements reported here occurred in *less than two hours*, and the typical patrol lasts considerably longer. Infantrymen are required to be vigilant and continually monitor their environment throughout long, and often non-kinetic, portions of a patrol.

Although the present results are clear, the performance decrements observed in this study likely underestimate the level of decrement that may be experienced in the field because the data was collected in a controlled laboratory environment. In the field, the performance decrement may be exacerbated by a wide variety of additional variables such as heat, altitude, stress, terrain, etc. Performance was also assessed for a subsample of participants after removing the load and resting for 5 minutes following the heaviest load condition. Performance recovery was not found and further research is needed to fully examine the recovery cycle of cognitive functioning. Such results would provide very critical information for small unit leaders to use in developing optimal work/rest cycles for patrol movements. A question that needs to be addressed in the future is what are the longer-term effects of carrying these heavy loads upon sustained cognitive performance, such as the duration of a typical patrol? Little is known regarding the sustained effects of this type of exertion on cognitive performance. Recommendations are provided regarding how such a study should be conducted.

Acknowledgements – We would like to express our gratitude to the Marines who volunteered to participate in this study. We would also like to thank Colonel Byrne, LtCol. Gideon, Captain Lee, and the staff at the School of Infantry at Camp Pendleton, for their help, participation, and coordination with this study. In addition, this study would not have been possible without the support, medical screening, and medical supervision provided by Drs Jourdain, Glass and Lin throughout the course of the study. A special thanks to Mr. Joe Artino, Manager, Area 52 Fitness Center, who provided equipment, space, and invaluable support during data collection.

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1. Introduction

Over the last twenty years, technological advancements in almost every aspect of combat performance have altered the way that the Warfighter prepares, approaches, and completes combat-related tasks. A plethora of new equipment has been developed and added to the ensemble of the modern-day infantryman. Often new equipment or changes in equipment design have occurred based upon only a single task end-state or goal rather than the requirements of the mission as a whole. This approach has led to what has been termed the "Christmas tree effect" by defense engineers, in which each piece of equipment that is designed to meet a single objective is added to the Warfighter (like ornaments on a holiday tree) without giving full consideration to their effect on overall mission objectives. This has resulted in individual troops carrying loads on patrols in excess of 150 pounds (Miles, 2003), almost equaling the weight of the average infantryman (160 lbs.). Such loads can lead to injury, significant impact on mobility, and reduced likelihood of meeting mission objectives.

Overloading infantrymen has been an issue for the military throughout the ages. During World Wars I, II, and Vietnam, instances were recorded of infantrymen carrying loads in excess of 85 lbs. during a variety of missions. In 1983, during the invasion of Grenada, when the enemy capability was considered minimal, the average weight carried by Army Rangers was reported as 167 lbs. (Ezell, 1992). Moreover today, in the villages of Iraq, or in the mountains of Afghanistan, the weight carried by infantrymen has been reported between 70 and 170 lbs. (Miles, 2003; Bachkosky, et al. 2007). Of the multitude of studies conducted investigating appropriate load carriage weight, virtually all have supported the general conclusion that the maximum load which infantrymen carry should never exceed one-third of their own body weight (FM 21-18, 1990; Ezell, 1992). These results are in concert with the landmark report of Marshall (1950) in which he concluded that the American soldier"s optimum load for combat should never be greater than 41 lbs. This result was based upon an optimal infantry *training* load weight of 51 lbs., whereupon Marshall (1950) suggested that the combat load should be less than the training weight to increase efficiency and mobility. More recent studies have suggested that weight carried could be significantly greater (Holewijin & Lotens, 1992) due to new designs in load bearing equipment. Holewijin & Meeuwsen (2000) suggested maximum loads of 70.5 lbs., but that this level should be reduced if marching speed increases.

Many studies concerning load carriage weight have investigated primarily the metabolic costs of carrying various loads. For example, in a study with soldiers completing an obstacle course under various load configurations, Polcyn, Bensel, Harman, and Obusek (2000) demonstrated that for every Newton of force expended due to increased load carriage, there was an increased metabolic cost of 2%, and a time loss (for completing the obstacle course) of 3%. In addition, studies have shown that exposure to stressful situations intensifies the problem by increasing fatigue and decreasing mobility (Ezell, 1992).

Not surprisingly, many studies have shown that carrying heavy loads has detrimental physiological effects on infantrymen. For example, excessively elevated heart rates were found for loads over 45 lbs. when marching rapidly (4 mph), for loads over 77 lbs. marching at a moderate speed (3.4 mph), and for even a slower marching speed (2.8 mph) when carrying 143 lbs. (Scott & Christie, 2000). Past research has also demonstrated that the metabolic and motivational effects of carrying 70% body weight loads caused significant increases in oxygen consumption, ventilation, heart rate, respiratory exchange ratio, and perceived exertion, when compared to loads of 30% or 50% body weight (Beekley, Alt, Buckley, Duffey, & Crowder, 2007). Significant decrements in military performance were also observed after soldiers had completed a maximal effort 20 km (12.5 miles) road walk carrying a total load of 101 lbs. (Knapik, Staab, Bahrke, Reynolds, Vogel, & O‟Connor, 1990). These impairments slowed soldiers‟ overall movements, leading to inhibited obstacle course performance, increased fatigue levels, and increases in the likelihood of injury. Marksmanship accuracy and grenade throw distance also decreased.

Heavy loads also have been shown to be detrimental to posture, movements, and gait (Attwells, Birrell, Hooper, & Mansfield, 2006; Knapik, Harman, & Reynolds, 1996). The higher muscular tensions needed to maintain adequate levels of biomechanical functioning have been associated with an increased likelihood of injury, muscle strain, and joint problems. In order to compensate for the altered posture caused by heavy loads, higher muscular tensions are necessary. Although the physical effects of carrying heavy loads have been fairly well documented and consequences apparent, infantrymen continue to carry these loads. In a recent study by Williams (2009) on lightening the load, he reported that a typical infantryman‟s combat load in Afghanistan averages 137 lbs.

There is little question that the loads carried by infantry in the field are beginning to take a toll on the individual infantryman. The physical strain from carrying heavy loads is evident in the number of muscle strain injuries and vascular problems reported of infantrymen returning from combat. In a survey conducted by the Marine Corps, 27% of Marines completing the form indicated that they suffer from some sort of back, joint, or muscle pain (Lamothe, 2009). Carrying these heavy loads and being unable to rest after minor injuries is thought to be the cause. In fact, lower back pain and other musculoskeletal-related injuries are the leading reasons infantrymen miss duty (Tyson, 2009a).

One question that has thus far gone unanswered is: What is the relationship between the physical exertion required to carry a heavy load and cognitive performance? This topic has proven difficult to characterize due to the wide range of research findings. Physical exertion appears to enhance performance on some cognitive tasks under some circumstances, but to inhibit performance on other tasks or on the same tasks under different conditions (Mastroianni, Chuba, & Zupan, 2003; Perry, Sheik-Nainar, Segall, Ma, & Kaber, 2008; Tomporoski & Ellis, 1986).

Load carriage is a form of strenuous exercise that infantrymen engage in on patrol while simultaneously performing cognitive tasks that require sustained attention, visual and auditory monitoring, situation awareness, and decision making. In a review of studies that investigated the effects of acute bouts of exercise on cognitive performance, Tomporoski (2003) concluded that sub-maximal aerobic exercise performed for one hour or less facilitates higher-level cognitive processes involved in problem-solving and goal-directed behavior, but does not affect processes involved in the earlier stages of information processing, such as sensory and perceptual processing. In contrast, longer or more intense periods of exercise impair both information processing activities and memory.

A study on the effects of movement and physical exertion on vigilance found that when walking with an 88 lb. load and climbing over obstacles, soldiers made more mistakes on a vigilance task than when walking unburdened or on an obstacle-free course (Mahoney, Hirsch, Hasselquist, Lesher, & Lieberman, 2007). Vigilance is important not only for situation assessment of the operational environment, but also for operating communications, information, and weapons systems. This study is notable because it assessed vigilance *during* physical exertion instead of after its completion. Another study reported similar results based on the assessment of physical workload on cognitive task performance and situation awareness (Perry, Sheik-Nainar, Segall, Ma, & Kaber, 2008). Increasing physical workload was accompanied by reduced perceptual knowledge, comprehension, and a reduction in situation awareness. However, performance on cognitive tasks involving planning and complex decision-making did not appear to be adversely affected by physical workload. The apparent inconsistencies among studies about the influence of physical workload on cognitive tasks underscore the need for additional research to clarify this relationship.

One specific concern regarding cognitive performance arises from infantrymen in combat providing anecdotal reports of getting “into the zone” or having “tunnel vision” while carrying heavy loads on long patrols. Easterbrook (1959) proposed that perceptual narrowing occurs when there is a reduction in the number of stimuli in the environment processed during a state of arousal, the end result being a narrowing of the attentional field. Research has shown that dividing attention between two cognitive tasks (visual and auditory) narrows the focus of visual attention, a phenomenon also referred to as “tunnel vision” (Rantanen & Goldberg, 1999). In fact, Wall, Woodward, and Brito (2004) demonstrated that when participants divide attention between two demanding tasks, performance on a simple perimetry test was negatively affected. One strategy infantrymen mention to use during long marches is to simply concentrate on the guy in front of you and keep putting one foot in front of the other to get through the march. Such anecdotal reports suggest cognitive involvement, or at least a potential shift in attention away from critical tasks.

However, studies specifically investigating the relationship between physical exertion and the focus of visual attention have yielded conflicting results (for a review, see Tomporowski, 2003). Several studies investigated the effects of short duration (15 min or less) physical exertion on visual performance (Aks, 1998; Allard, Brawley, Deakin, & Elliot, 1989; Paas & Adams, 1991), showing an enhancement in performance. For example, Aks (1998) found that after only 10 minutes of exercise, visual search time decreased for small array targets (2 items), but increased for larger target array (6 and 10 item) trials. Their interpretation of the results was that short-term exercise facilitates visual search over a smaller focused area. Yet, if one were required to search over larger areas post exercise, performance would decrease. Hancock and McNaughton (1986) investigated the effect of physical exertion on ability to process visual information. They found that participant responses to questions geared toward distance estimation and short-term memory improved during the exercise condition. However, accuracy of responses to questions requiring the recognition and interpretation of map features was significantly lower in the exercise condition than the resting condition. Furthermore, evidence of tunnel vision toward the center of the map was reported. It is important to note that both of these studies were short in duration (< 30 min) and participants were not carrying a heavy load.

To date, little research has been conducted investigating the effect carrying a heavy load for long durations has upon cognitive performance. Knapik, et al. (1990) found that load size (75, 106, and 134.5 lbs.) had no effect on memory recall, visual monitoring and mathematical reasoning, or on several typical soldier tasks after marching for 20 km (12.43 miles). However, the post-march performance data were collected after the load had been removed. In addition, testing occurred in the same order for all participants and took 60 minutes to complete. This raises the possibility that any potential decrement related to load weight may have been eliminated or reduced due to the time lag between the end of the march and the actual testing, thus allowing recovery. Knapik, et al., suggested that future research needs to be conducted to assess cognitive performance closer to the end of a march.

One way the effect of heavy load on performance may be measured is through change in perceived physical comfort. The Comfort Affective Labeled Magnitude (CALM) scale was developed to provide a method for assessing clothing comfort (Cardello, Winterhalter, & Schutz, 2003). Studies have shown that clothing comfort affects cognitive performance (e.g., Bell, Cardello, & Schutz, 2005). A load that is not being carried in the optimal manner or is too heavy, causing discomfort may divert attention and impair cognitive performance. Preliminary studies have indicated that equipment may reduce task performance unless it is comfortable and easy to wear (Dunne & Smyth, 2007).

Tyson (2009b) reported that not only are infantrymen in Afghanistan carrying loads in excess of 130 lbs., but typical missions are lasting three days. The effect of carrying heavy loads for such extended periods far exceeds the levels of the variables used in previous research. There is little question that effective combat and patrol missions require infantrymen to use their cognitive abilities to observe, detect, and collect vital information. Infantrymen must maintain their attention to make time-critical life-or-death decisions in unfamiliar, ambiguous, and often complex environments. Given this cognitive demand, it is important to understand the influence that carrying heavy loads may have on cognitive performance and how to effectively mitigate any impairment.

Very few studies have applied measures of cognitive performance to conditions relevant to today‟s patrolling requirements: that is, carrying a load of more than 100 lbs. for over 60 minutes. The effect of heavy loads on cognition, attention, and decision making needs to be investigated under a variety of conditions (duration, terrain, elevation, etc.) experienced by field-deployed infantrymen. The current study sought to systematically examine the relationship between weight carried, cognitive performance, and the individual‟s perception of workload, effort, and comfort during a simulated two hour patrol.

2. Method

2.1 Participants

Twenty-nine Marine infantrymen were recruited from the USMC School of Infantry (SOI) – West at Camp Pendleton, California. Females were excluded from the study because at the time of data collection there were no females in the USMC infantry. All participants were screened by a military physician and identified as fit for duty as defined by MANMED standards. Eighteen participants completed all study sessions. Eleven participants did not complete all of the sessions and missed one or more due to: illness (n = 1), previous injury (n = 1), discomfort (n = 3), exceeded physiological stop criterion heart rate (HR) exceeding 90% adjusted max HR for 5 minutes (n = 2), did not show up for a session (n = 2), or on-call physicians were unavailable thus we needed to cancel the data collection session (n = 2).

Out of the eleven Marines that did not complete all sessions, only two were stopped for exceeding the HR stop criterion set by the Institutional Review Board. Both men exceeded HR during the heaviest load condition after completing the 0 load condition on the previous day. One Marine exceeded HR only 8 minutes (186 bpm) into the session; whereas the second Marine exceeded criterion 45 minutes (181 bpm) into the session. The load to body weight ratio was 85% and 104% respectively.

Participants ranged in age from 18 to 24 yrs (M = 19, SD = 1.44). Their weight ranged between 130 to 221 lbs. (M = 165.8, SD = 22.55) and their height range was 63 to 76 inches (M = 70.05, SD = 2.81). These averages are in concert with the characteristics of the average Marine (169 lb., 71 inches). Participant ranks included 14 Privates, 13 Private First Class, and 2 Lance Corporals. Military Occupational Specialties (MOS) of participants varied including: Rifleman (n = 17), Reconnaissance (n = 2), Basic Infantry (n = 1), Machine Gunner (n = 1), Field Wireman (n = 1), Field Radio Operator (n = 1), Fire Support Man (n = 1), Basic Electronics Maintenance (n = 1), Data Network Specialist (n = 1), Mechanic (n = 1), Supply Administration and Operations Specialist (n = 1), and Food Service Specialist (n = 1). All Marines were junior enlisted, graduates of the SOI, and had no combat experience.

2.2 Experimental Design

Load carriage weight and time (on treadmill) were established as the independent variables. Cognitive performance, subjective ratings, and physiological strain were investigated as the dependent (criterion) variables. Cognitive performance was assessed from three tasks: (1) Visual Detection and Identification, (2) Abbreviated Five Paragraph Order, and (3) Memory Recall. The design of each task focused on cognitive skills and abilities normally required by Marines while on dismounted patrol, such as visual-spatial processing, working memory, and detection and response to stimuli in the environment. Each task was reviewed and revised with the assistance of experienced Marine Instructors from SOI West to ensure face validity. Therefore, these tasks enabled valid ecological assessments to be made of the influence of heavy loads (> 80 lbs.) on cognitive performance related to combat performance. Physiological workload was measured by calculating oxygen consumption and continuously monitoring heart rate. Eye tracking and head pitch data were collected during each of the Detection and Recognition tasks.

The carriage weights were (1) 0 (no load), (2) 98 lbs., and (3) 135 lbs. The heavier weights levels were selected to approximate operational Assault / Approach load weights identified in the theater by "Task Force Devil," 2003. The three load carriage conditions were operationally defined as:

- Baseline (no load): Battle Dress Uniform (BDU) with desert boots and hydration pack;
- 98 lbs.: BDU with desert boots, hydration pack, Kevlar helmet, simulated M16, recommended equipment (see Appendix A), and bags of sand if necessary;
- 135 lbs.: BDU with desert boots, hydration pack, Kevlar helmet, simulated M16, recommended equipment (see Appendix A) and bags of sand if necessary.

The assignment of load conditions and cognitive tasks were counterbalanced across all participants via a Balanced Latin Square Design (Meyers & Hansen, 2002) to reduce potential carryover effects. To reach the targeted weight for each condition, participants were provided a list of suggested equipment to bring to each session, as detailed in Appendix A. The weight of some equipment (radios, combat optics, ammunition), which is only issued in operational areas was simulated by adding sandbags of various weights and sizes (1 to 10 lbs.). Sandbags were placed in locations similar to where specific gear would normally be carried and in the appropriate pack (either rucksack or Improved Load Bearing Equipment (ILBE) main pack).

To control for individual differences and minimize the number of participants needed, a multifactor within-group experimental design was used. The following formula, provided by Naval Health Research Center (NHRC) San Diego, was used to determine the sample size: $\boldsymbol{n} \geq \frac{2(Z_\alpha+Z_\beta)^2\,S^2}{d^2}$. The values for estimated variance and difference between the means were based upon a previous study that employed similar variables (reaction time and physical work) to examine the effects of fatigue induced by combat stress and sleep deprivation (Tharion et al., 1997). This resulted in a sample size of *n* = 29 allowing for some attrition.

2.3 Materials

2.3.1 Environment

All sessions took place at the SOI 52 Area Fitness Center, Camp Pendleton. An indoor racquetball court served as an isolated data collection area. The fitness center was climate controlled with interior temperatures ranging between 59.70° and 76.1°F (*M* = 66.8). Temperature readings were recorded at the beginning, midpoint, and end of each session. Two re-circulating fans (Honeywell 16" Oscillating Stand Fan) were used throughout all sessions. Stand-alone incandescent lighting (60 W, floor lamp) was used instead of the over-head fluorescent lights to reduce glare and provide a clearer projected image of the tasks on the wall in front of the participant.

2.3.2 Equipment

Appendix B provides a brief description of all the equipment used during this study.

2.3.3 Behavioral Data Collection Instruments

Infantry relevant tasks were developed to assess aspects of cognitive performance (e.g., visual-spatial processing, working memory, attention, detection and identification) in a context analogous to those encountered by USMC Infantry in the field.

2.3.3.1 Detection and Identification Task

The Detection and Identification task required participants to continually view a static scene of an Iraqi village, as shown in Figure 1. The scene provided a linear perspective view which simulated looking down a street through a village. The participants" task was to respond by depressing one of two buttons on their weapon whenever they detected a stimulus displayed on the screen.

Figure 1. Projected scene of rural village providing linear perspective.

Stimuli were presented in random locations on the screen, using a random inter-stimulus interval (ISI) between 2-6 s. All stimuli were circular in shape (15 pixel by 15 pixels; visual angle = .72 degrees) with black and white bars. Targets were represented by a series of vertical bars and non-targets by horizontal bars. Both types of stimuli were the same spatial frequency and thus equally detectable. Figure 2 displays an example of the target and non-target stimuli. Fifty-four stimuli were presented in total (9 targets and 45 non-targets) within a total task time of approximately 5 min. The duration of the task varied due to individual response time differences and ISI randomness. Participants were instructed to respond to all stimuli as quickly and accurately as possible by depressing the appropriate button for each stimulus (a two-choice decision making task). The buttons were located on a remote attached to the side of the simulated weapon‟s trigger guide. The controller was attached to the left side of the weapon for left-handed participants (*n* = 2).

Figure 2. Detection and identification task stimuli

To ensure that stimuli were displayed uniformly, the scene was divided into nine equally-sized sectors of three rows by three columns. Stimuli appeared an equal number of times (one target to nine non-targets) within each sector. This division of the scene allowed for a determination of detection and identification changes across the visual field. Dependent variables included hit rate of targets and non-targets, accuracy of response, number of false alarms, and response time to both targets and non-targets. All data were captured on a laptop via wireless remote. Participants completed the task three times at equally-spaced intervals (40 minutes apart) during each load condition. For the 135 lb. condition participants completed the task one additional time following a 5-minute rest period.

2.3.3.2 Abbreviated Five Paragraph Order

This task was developed based upon the five paragraph order used by Marines. It was designed to evaluate spatial memory and recall ability - both necessary skills for all infantrymen while on patrol. Participants were required to retain information such as landmarks from a topographical map and patrol instructions. At the beginning of every session, the observer read the Abbreviated Five Paragraph Order to the participant. During this time, the corresponding topographical map, as shown in Figure 3, was displayed for the participant to view. The participants were given an opportunity to ask questions before the map was removed, after which they were required to retain all information in memory for later recall. Participants were asked five questions three times during the session, or every 40 min, and had 1 min to answer each item. After completing the 135 lb. condition, with a final 10 minute rest period, the participant was asked five additional questions. Questions were either (a) spatial in nature regarding locations on the map (e.g., which checkpoint was located furthest west?), or (b) required declarative knowledge regarding patrol instructions (e.g., what day will munitions be dropped off at checkpoint 23?). Sixty percent of the questions were based on spatial information and 40% were based on patrol instructions. The dependent variable was the number of correct responses (items with no response were recorded as incorrect).

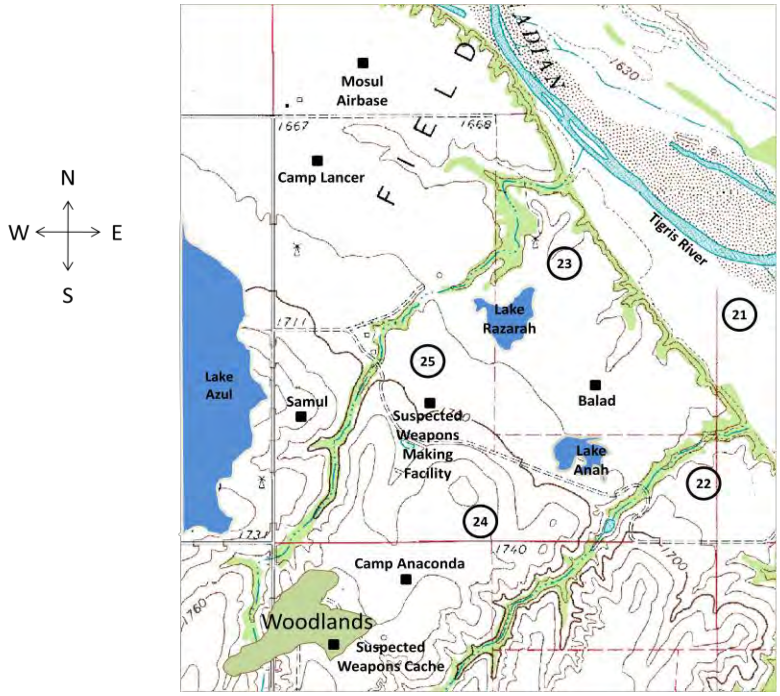

Figure 3. Example of abbreviated five paragraph order.

2.3.3.4 Memory Recall

The Memory Recall task was based upon the Keep in Memory (KIM) exercise currently used during USMC training (Valdes, 2009). Participants were instructed to view a scene of objects and to be prepared to recall them when the image was extinguished. Each scene contained 20 non-related objects, as shown in Figure 4, and displayed for 1 minute. When the scene was removed, participants were immediately asked to verbally recall as many objects as they could remember within the next 2 min. Responses were recorded by the experimenter and with a handheld audio recorder. The task was repeated with a different images three times during each session at 40 min intervals. Accuracy and intrusions within each session set and for each load condition were recorded.

Figure 4. Example of Memory Recall task items displayed.

2.3.4 Subjective Data Collection Instruments

Subjective ratings were collected from the participants every 40 minutes (three times during each load condition) to record perceived comfort, exertion, heaviness, and workload. Participants were asked to base their responses on how they were feeling while performing the corresponding set of tasks. The items presented were based on the following questionnaires: (a) Comfort Affective Labeled Magnitude, (b) Borg Rating of Perceived Exertion, (c) Rating of Perceived Heaviness, and (d) NASA Task Load Index. A post-session interview, in the form of a short questionnaire, was also administered at the end of the session.

2.3.4.1 Comfort Affective Labeled Magnitude

The Comfort Affective Labeled Magnitude (CALM) measures participant perceived discomfort. Participants provided a number from -100 (greatest imaginable discomfort) to 100 (greatest imaginable comfort) based on their comfort level during the tasks (Cardello & Winterhalter, 2003).

2.3.4.2 Borg Rating of Perceived Exertion

The Borg Rating of Perceived Exertion (RPE) measures participant perceived exertion during exercise - how hard he felt his body was working. Participants provided a rating from 6 (no exertion at all) to 20 (maximal exertion) to represent the amount of physical work required during the tasks (Borg, 1998).

2.3.4.2 Rating of Perceived Heaviness

The Rating of Perceived Heaviness (RPH) is a measure of participant perception of the load carriage weight. Participants provided a rating from 1 (not heavy at all) to 5 (extremely heavy) based on how heavy the load felt to them during the tasks.

2.3.4.3 NASA Task Load Index

The NASA Task Load Index (NASA-TLX) measures workload experienced by participants while performing tasks. Participants provided a rating from 0 (very low) to 100 (very high) on six questions assessing mental, physical, temporal (time pressure), performance, effort (both physical and mental), and frustration (Hart, 2006; Hart & Staveland, 1988). Participants were also shown 12 pairs comprised of the six categories. For each pair the participant was asked to select the category that contributed most to the workload. These responses were used to weigh the six questions in accordance with the NASA-TLX scoring procedure.

2.3.4.4 Post-session Interview

The Post-session Interview was designed with the intention of capturing each participant‟s experience with the load carriage at the end of each session. Items addressed load balance, difficulty on the treadmill, whether tasking was outside of their daily activity, any specific difficulties with the task (cognitive or physical), load influence on performance, comfort of the HR monitor, and past experience with carrying loads.

2.3.5 Physiological Measuring Devices

2.3.5.1 Eye Tracking

All eye movement data were collected using the Smart Eye Pro 4.5.4 system by Smart Eye. The system uses unobtrusive, remote sensors that do not require any interaction from participants. The Smart Eye hardware consists of a standard computer and monitor system, two cameras, two infrared (IR) lights, and corresponding connectors and cables. The cameras and IR lights are European standard EN 60 825-1:1994 compliant (based on IEC 60 825-1). The eye tracking system records real-time measurement at a sample rate of 60 Hz with a system lag typically < 50 ms. Head tracking was also monitored using this system and provided six Degrees Of Freedom (DOF) with an accuracy of 0.5 deg in rotation and <1 mm in translation. Gaze tracking software was used providing two DOF with one degree gaze-vector accuracy. The Smart Eye hardware was placed on a cart approximately three feet in front of the participant for remote data capture.

The Smart Eye tracking software used a customized “participant profile” created specifically for each participant in accordance to his facial features. A “world model” simulating the projected image, was created in accordance with the lab setup and measurements. As a participant actively scanned the image during a task, the eye tracking software computed and logged the participant‟s head pitch as well as the intersecting location of their gaze on the image. Gaze data collected were used to determine visual scanning patterns across sets within a session and across load conditions. Head pitch data was captured to measure changes in the participant‟s posture between each of the load conditions.

2.3.5.2 Heart Rate

A Garmin Forerunner 50 HR monitor was used to monitor participant HR during each session. The HR monitor includes a transmitter strap, worn around the participant‟s chest, directly on their skin and just below their breastplate, and a digital display watch that was secured to the treadmill railing. The exercise physiologist assisted the participant with proper placement of the transmitter strap. The watch displayed and saved real-time HR data, which was obtained wirelessly from the transmitter, and later transferred to Garmin Training Center® 3.4.3 software on the laptop for further analyses. The watch was attached to the treadmill rail so that it could be easily read by researchers. The HR was also monitored and manually recorded on a data collection sheet every five minutes by the corpsman during each session.

2.3.5.3 Indirect Calorimetry

Indirect calorimetry is a process that measures oxygen consumption (VO_2), carbon dioxide production (VCO_2), and the Metabolic Equivalents (METS) to estimate energy expenditure. These measurements were taken using a ParvoMedics TrueOne® 2400 indirect calorimetry system and Hans Rudolph Two-Way Non-Rebreathing Valves (T-Shape™ Configuration Series 2700 Large). Prior to the arrival of each participant, gas and flow meter calibrations were conducted using a 16% O_2 / 4% CO_2 E-cylinder calibration gas, and a Rudolph Volume Calibration 3 L syringe respectively. The cart and its supplies were provided by Naval Health Research Center (NHRC).

2.4 Procedure

2.4.1 Recruitment

Participants were recruited through SOI West, Camp Pendleton. Volunteers were either Marines waiting to start classes or currently assigned to the Student Administration Company (SAC). The experimenter introduced the study to potential participants, the Privacy Act was reviewed, and all participants completed an informed consent form. A military licensed physician performed medical screening of all participants to ensure fitness for duty as defined by MANMED standards. SOI Instructors were not present during the recruitment process.

All participants were instructed to abstain from strenuous physical activity, medication, dietary and health supplements, and alcohol consumption 8 hours prior to each of the sessions, and caffeine and nicotine products 3 hours prior to the sessions. To insure proper hydration, participants were advised to drink 16 oz. of water the night before each session and another 8 oz. before reporting to the test facility.

2.4.2 Sessions

The experiment consisted of three 3-hour sessions either in the mornings (0745) or afternoons (starting at 1245) on consecutive days. The first session required an additional 30 minutes for equipment familiarization (treadmill safety, metabolic cart, and eye tracking), as well as task instructions and practice. During practice the participant stood on the treadmill without any load. Practice consisted of a two-minute version of the Detection and Identification task (participants practiced until they reached a 90% accuracy criterion level; only two participants required additional training). Instruction and practice also included; one trial of the Five Paragraph Order task, one trial of the Memory Recall task, and the participants were provided with a definition for each of the subjective rating questions. Demographic data was also collected during the first session.

2.4.2.1 Pre-test

Participants completed a 24 Hour Medical / Activity Questionnaire upon arrival to each session. The questionnaire, developed by NHRC, was designed to ensure participants had not developed an acute illness or injury in the previous 24 hours that would disqualify them from participation. A “positive” response on the questionnaire required the on-call physician‟s approval before continuing with data collection. Urine specific gravity (USG) was measured to determine the participant was adequately hydrated for intense exercise. A USG of < 1.028 was required for participation. A USG reading > 1.028 required the participant to consume 8 oz. of water within 15 minutes followed by re-testing until a reading of < 1.028 was reached.

Pre-test weights were measured and recorded at the beginning of each session: dry gym shorts and t-shirt, for the baseline condition, and total weight with load carriage for both of the heavier load conditions. The hydration pack pre-test weight was also taken prior to each session. Participants fastened the HR monitor chest strap around their chest and the experimenter verified the monitor was working properly. Lastly, the participant stood on the treadmill to develop the eye tracking "participant profile" and world model verification. All data were recorded on a data collection sheet and a session checklist was used by the experimenter to ensure all study procedures were completed in sequence.

2.4.2.2 Test

For each weight condition the participant walked on the treadmill for 120 minutes with one 5 minute break to "take a knee," or sit, at time 60. This procedure simulated how Marines typically operate while on patrol - resting 5 minutes after walking for 60 minutes. The pace of walking was 2.0 miles per hour, which was validated by an SOI instructor as a good patrol speed, on a level treadmill (0% grade).

Participants completed three sets of cognitive tasks and subjective ratings while walking on the treadmill during each session. Eye movement data was collected remotely during the Detection and Identification and Memory Recall tasks. HR was continuously monitored and recorded every 5 minutes. Metabolic values were collected four times during the session, which required the participant to put on a nose clip and breathe into a mouthpiece for 5 minutes. The timing for the administration of each cognitive task is outlined in Table 1. A non-task walking period, which included the transition (T), break (B), and metabolic measurement, occurred prior to and following each cognitive task or subjective rating. The frequent occurrence of tasks simulated the constant vigilance demand required of infantrymen while on patrol. A fifth metabolic reading was taken after the participant finished walking on the treadmill and was resting seated in a chair. To investigate the ability of cognitive performance to recover after the 135 lb. load condition was concluded, two additional tasks were performed, 1) the Detection and

Identification Task (after a 5 minute rest) and 2) the Abbreviated Five Paragraph Order task (after a 10 minute rest). During these tasks the participant stood on the treadmill without the load carriage.

Table 1. Timeline of scheduled tasking during road march.

	Time (minutes)	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125
Walking		T																								
	Detection/Recognition																									
	Metabolic																									
	Spatial Memory & Communication																									
						T																				
	Working Memory																									
								T																		
	Subjective Ratings																									
	Metabolic																									
	Detection/Recognition																									
												T														
	Spatial Memory & Communication																									
	BREAK													B												
Walking	Working Memory																									
	Metabolic																									
	Subjective Ratings																									
																		T								
	Detection/Recognition																									
																				T						
	Spatial Memory & Communication																									
	Metabolic																									
	Working Memory																									
																								T		
	Subjective Ratings																									
	Metabolic																									

Subjective Ratings
Detection/Recognition
Metabolic
Spatial Memory & Communication
Working Memory

Break B
Transition T

During the session, participants were reminded to drink water, which was available through their hydration pack ad libitum. If needed, participants were allowed to stop momentarily to adjust and re-tighten the pack straps.

2.4.2.3 Termination criteria

Participants were free to withdraw for any reason without consequence. Additionally, three stop criteria were established to ensure no physical harm would come to the Marines during testing. If the participant‟s HR exceeded 90% of his age-adjusted max HR (MHR) for 5 min while walking on the treadmill, or 80% of his age-adjusted MHR for 5 min during the break, the session would be stopped immediately. Age-adjusted MHR was calculated using the formula: 206.9 - (0.67 x age). A second measure was Ear temperature that was measured with a thermometer at the beginning of the 5 min break. To establish accurate temperature readings, participants were asked to cease drinking water 10 min before the temperature reading. The session was terminated if the participants‟ temperature was above 38.8^{o}C. If the participant‟s temperature was between 38.6^{o}C and 38.8^{o}C an additional measurement would be administered 30 min later to ensure the participant‟s temperature did not exceed 38.8^{o}C. None of the participants‟ temperature readings exceeded the 38.8^{o}C criteria during the study. The final termination criterion was related to individual self-report of any of the following: discomfort such as leg cramp, back ache, muscle soreness, headache, etc., or if they had an onset of chills, nausea, dizziness, light-headedness, chest pain, disorientation, or cessation of sweating. A corpsman was present at all times during the testing session and was instructed to evaluate the participants every 5 to 10 minutes to ensure their safety.

2.4.3 Post-test

Upon completion of the patrol, participants removed their load and sat comfortably in a chair in the testing area. Participants remained seated until the corpsman approved their release from the test facility based upon the following criteria: HR ≤ 100 bpm, and blood pressure (BP) within a normal range (systolic: 90-140; diastolic: 60-90). Post-test weight was then measured following the same protocol identified during the pre-test. The post-test hydration pack weight was also taken. The session was concluded with a post-session interview questionnaire.

3. Results

Eighteen Marines completed the detection and identification task for each of the three load conditions; however data for one participant were lost due to a computer malfunction. Therefore, all analyses were conducted using only the 17 participants with complete data. Bonferroni comparisons were utilized to examine all pairwise comparisons and simple effects throughout this section. Greenhouse-Geisser adjustment to degrees of freedom was used to comply with sphericity assumption for repeated measures when indicated by Mauchly‟s test. Error bars in all figures represent $\pm$ one standard error.

3.1 Assessment of Physical Strain

Physiological measures were collected for two reasons, 1) to monitor the participant for safety, and 2) to assess the level of physiological strain or workload under each load condition. Two physiological measures were collected during each session; heart rate and Oxygen uptake (VO_2). All physiological analyses were conducted on the same Marines (n = 17) included in the behavioral data analysis. The average weight of Marine participants was 168.6 lbs. (range 142 - 221 lbs.); therefore in the two loaded conditions (98, 135 lbs.) subjects were on average carrying 58% and 80% of their total body weight. However, this percentage ranged from 44% and 61% for the heaviest (221 lbs.), to 69% and 95% for the lightest (142 lbs.) participant. Separate One-way repeated measure ANOVA"s were calculated for each of the physiological variables across each of the load conditions.

3.1.1 Heart Rate (HR)

Results indicate that HR values were significantly different across the three load conditions ($F(2, 32) = 121.7$, $p < .001$. Figure 5 displays the mean heart rate (in beats per minute) for participants for each of the load conditions. Pairwise comparisons show that HR values increased as load carriage increased across the three load conditions. All comparisons were significantly different from one another ($p < .001$).

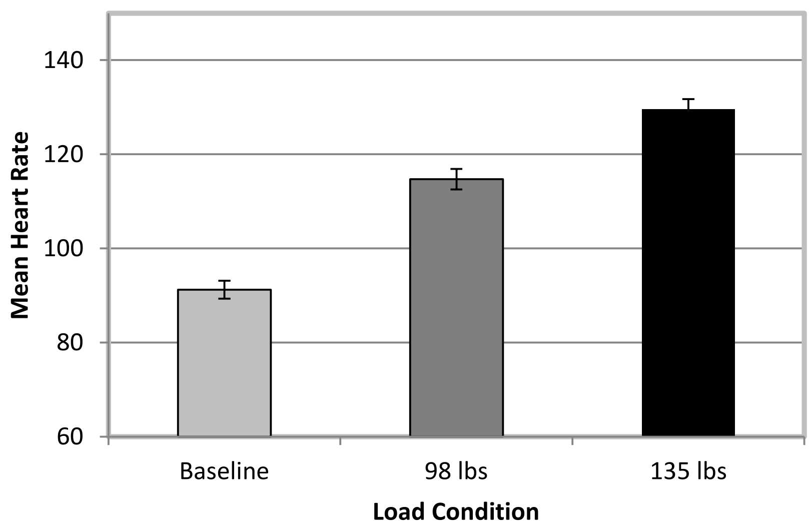

Figure 5. Average heart rate (BPM) for each load condition.

3.1.2 Oxygen uptake (VO_2)

A One-way repeated measures ANOVA was also calculated for average VO_2 measures for each of the load conditions. Statistically significant differences in VO_2 were found across the load conditions ($F(2, 32) = 181.6$, $p <$ 001). Figure 6 displays the average VO_2 for each load condition. Pairwise comparisons show that VO_2 values were significantly different among all load conditions ($p < .001$).

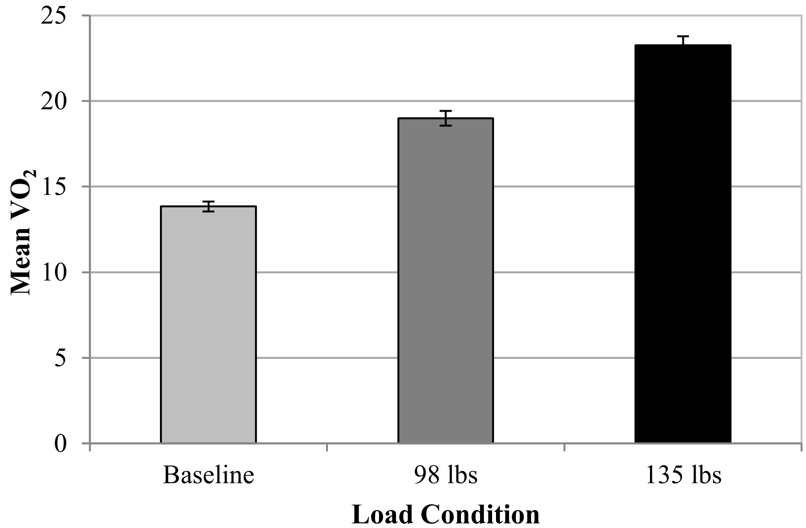

Figure 6. Average VO_2 for each load condition.

The physiological measures indicate that the physiological strain placed upon the participants ranged from very light (Baseline) to moderate/hard for the 135 lb. load condition. METS values were determined based upon VO_2 values (METS = (VO_2/ 3.5). Table 2 displays the physical strain levels experienced in accordance with the Physical Activity and Health Report from the Surgeon General (1996).

Table 2. Physical strain levels based on Surgeon General‟s report for each load condition.

Load Condition	Avg. HR	Avg. METS	Physical Strain Level*
Baseline	91.2	3.95	Very Light - Light
98 lbs.	114.7	5.43	Light - Moderate
135 lbs.	129.6	6.64	Moderate - Hard

* Based upon Surgeon General‟s report (1996)

3.2 Detection and Identification

The ability of participants to detect and identify (target, non-target) stimuli on the visual display was investigated. To examine the effect of load carriage on performance several dependent variables were collected: response time, detection (hit) rate, number of false alarms and identification (accuracy) were examined.

3.2.1 Detection (Hit) Rate

Detection rate was defined as the proportion of stimuli responded to versus the number of stimuli presented. A Two-way repeated measures ANOVA, 3(load) X 3(task time) was conducted and a main of effect of load ($F(2, 32) = 5.2$, $p < .05$) was found. Pairwise comparisons revealed that participants detected fewer stimuli when carrying the 135 lb. load ($M = 87.6$, $SE = 1.62$) than when carrying no load ($M = 92.0$, $SE = .72$), $p < .05$. No other comparisons were statistically significant. Figure 7 shows the mean hit rate for each load condition.

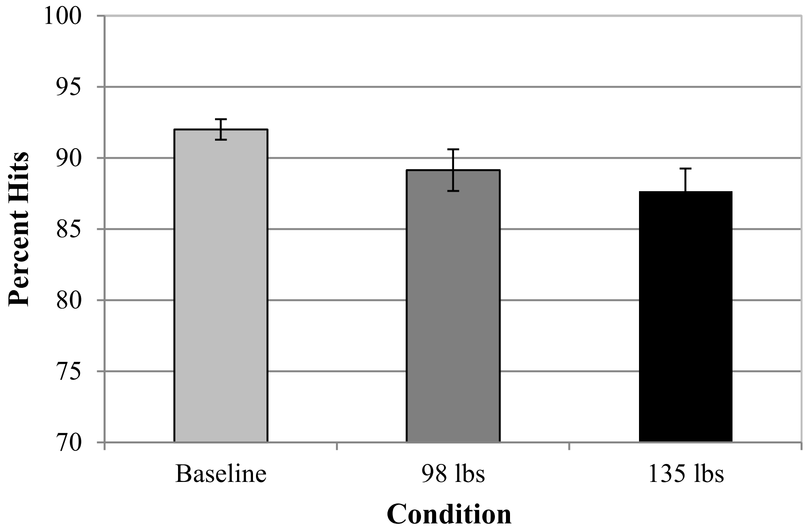

Figure 7. Percent detection (hit rate) across load conditions.

In addition, results indicate a statistically significant interaction, $F(4, 64) = 3.43$, $p < .05$, as shown in Figure 8. Further analyses of the simple main effects of the interaction show that the results are primarily driven at the 85 min point in the session. Until this point in time, performance on the task reveals no statistically significant differences in hit rate across the three load conditions. However at the 85 min point, participants detected significantly ($p < .05$) fewer stimuli when carrying 135 lbs. ($M = 85.84$, $SE = 2.19$) than when carrying no load ($M = 94.12$, $SE = .89$), or when carrying the 98 lb. load ($M = 89.87$, $SE = 1.21$). None of the other comparisons were significantly different.

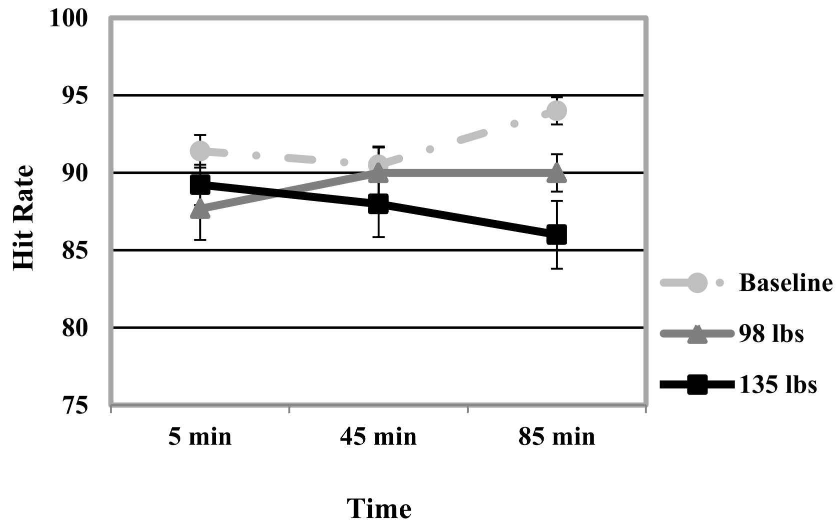

Figure 8. Percent detection (hit rate) for each test across load conditions.

The results suggest (Time x Load interaction) that the effects of load increase over time. This is in concert with previous research that does not show a cognitive decrement for studies lasting less than one hour. To further investigate the performance differences found at time 85, hit rate changes across the visual image were analyzed. To investigate whether scanning patterns changed with increasing load weight, the image was divided into three equal rows and simply labeled top, middle and bottom. Hit rate across each row was then determined for each load condition.

A Two-way repeated measures subjects ANOVA, 3(load) X 3(row) was then computed and a statistically significant effect was found for both Load ($F(2, 32) = 10.8$, $p < .01$) and for Row ($F(2, 32) = 34.0$, $p < .01$). In addition, a significant Load and Row, $F(4, 64) = 6.7$, $p < .01$, interaction was found. Simple main effects of the interaction reveal that hit rate in top row was significantly ($p < .01$) lower when carrying the 135 lb. load ($M = 72.6$, $SE = 4.2$) than when carrying no load ($M = 90.9$, $SE = 1.7$), or when carrying the 98 lb. load ($M = 85.0$, $SE = 3.0$). Hit rate was always greatest ($p < .01$) for stimuli occurring in the middle row for all conditions. These results may be related to the tendency of participants to lean forward under the heaviest load condition, directing their gaze lower on their field of view. These results are shown in Figure 9.

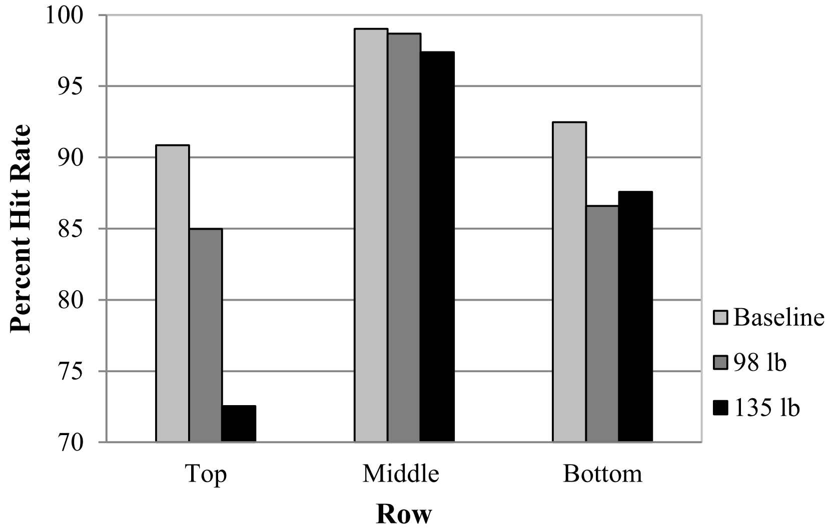

Figure 9. Detection hit rate across the three load conditions by display row.

3.2.2 Identification Accuracy

Accuracy was examined by determining the number of identification errors (i.e., a target was detected but incorrectly identified) that occurred during each session. A One-way repeated measure ANOVA was conducted and indicated a statistically significant difference in number of errors across the three conditions ($F(2, 32) = 3.58$, $p < .05$). Pairwise comparison indicated that the number of errors committed under the 135 lb. load condition was significantly greater than when carrying no load. All other comparisons were not statistically significant, $p > .05$.

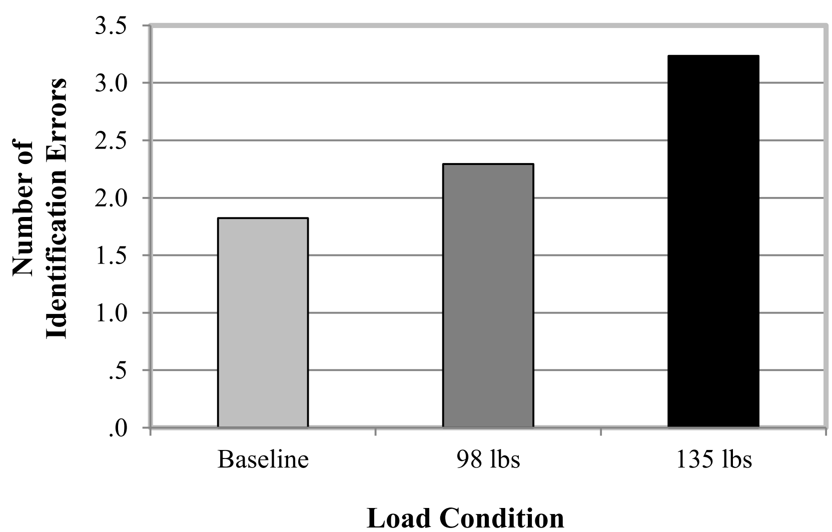

Figure 10. Number of errors for each load condition.

Figure 8 shows the identification accuracy (number of errors) for each of the load conditions. Although the number of errors significantly differed across the three load conditions the number of overall errors was low and therefore analysis across time was not calculated.

3.2.3 Response Time

A one-way repeated measures ANOVA was conducted to evaluate changes in response time across the three load conditions. No statistically significant differences in response time were found.

3.2.4 False Alarms

A One-way repeated measure ANOVA was conducted to determine if the number of false alarms produced was significantly related to load carried. Results indicate that although the number of false alarms increased across the load conditions (3.1, 3.9, and 4.5 respectively) the results were not statistically significant.

3.2.5 Gaze during Detection & Identification Task

Gaze data was also collected during the detection and identification task and is indicative of the amount of time a participant spent viewing each area of the scene. Analysis was performed for participants for whom at least 80% of the data was captured for all three sessions. Under the heavier load conditions eye/head data was sometimes lost due to the change in pitch of their head. This resulted in only eight participants for this analysis. An estimate was produced for the amount of time looking at one of the three rows (across the top, middle and bottom of the display). Time points which could not be tracked by the eye tracking system were included in the location analysis as „unclassified".

A Two-way repeated measures ANOVA 3(load carriage) X 4(row) was computed and resulted in a statistically significant main effect for Row, $F(3, 21) = 28.1$, $p < .01$, indicating that participants spent most of their time observing a specific row location. Specifically, participants had a higher ($p < .05$) concentration of gaze points in the middle row ($M = 56.1$) than the top ($M = 13.4$; $SE = 3.38$), bottom ($M = 16.0$, $SE = 3.29$), or unclassified ($M = 14.5$; $SE = 2.75$). The Load by Row interaction was not statistically significant. Figure 11 shows the mean percent of time spent in each row. No differences were found between load conditions and gaze time indicating that the location the eyes were directed was not affected by load condition. These results are not in concert with the behavioral detection results reported earlier but may be explained by the sample size differences between the two groups. Reliable eye gaze data was only available for a smaller sample ($n = 8$).

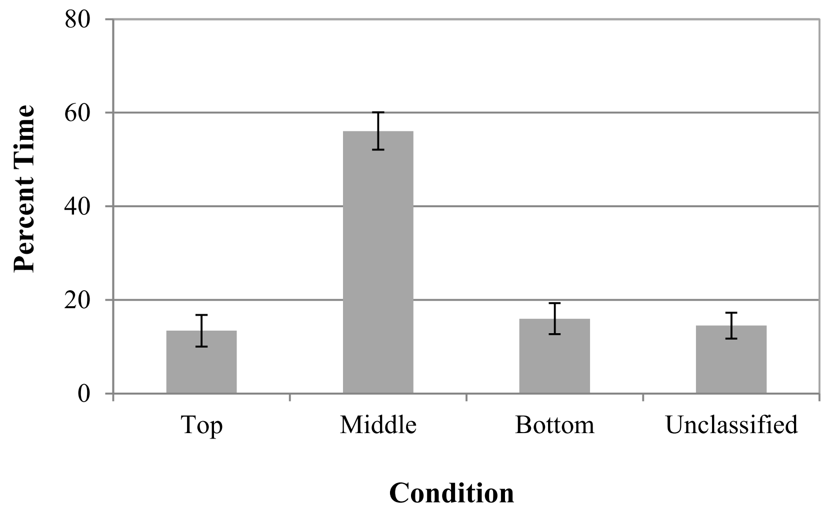

Figure 11. Mean gaze point percent time spent within each row of the display.

3.3 Abbreviated Five Paragraph Order

A Two-way repeated measure ANOVA was conducted to investigate whether time on task affected the participant"s accuracy in responding to questions about information presented in the Five Paragraph Order task. Results show a main effect of load was statistically significant, $F(2, 32) = 4.3$, $p < .05$. Pairwise comparisons indicate that Marines were significantly ($p < .05$) less accurate when carrying the 135 lb. load ($M = 57.5$, $SE = 2.3$) than when carrying no load ($M = 71.53$, $SE = 3.49$). Although performance on this task is somewhat confounded by time (normal memory decay), it should be pointed out that the differences found between weight conditions are based upon results that follow the same time course. In other words, the differences found are related to weight carried and not the normal progression of memory decay. No statistically significant difference was found between 98 and 135 lb. nor the 98 and no load condition. All other results were not statistically significant. Figure 12 shows the mean percentage of correct responses across the three load conditions.

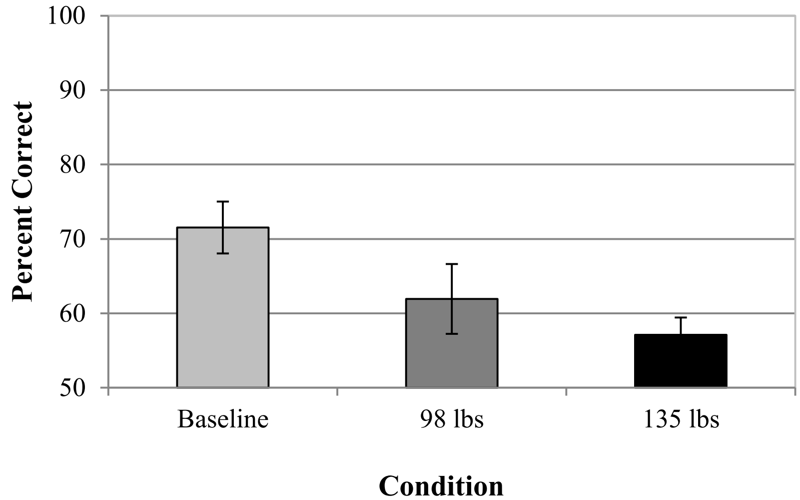

Figure 12. Mean Abbreviated Five Paragraph Order results for each load condition.

3.4 Memory Recall

A two-way repeated measures ANOVA (Load (3) x Time (3)) was conducted on the percentage of items correctly recalled in the KIM-like task. A main effect of load was found to be statistically significant $F(2, 32) = 4.2$, $p < .05$, indicating that ability to recall items was affected by the amount of weight carried. Pairwise comparisons revealed that the number of items recalled was significantly ($p < .05$) lower when carrying the 135 lb. load ($M = 63.35$, $SE = 2.16$) than when carrying no load ($M = 69.58$, $SE = 1.93$). All other comparisons failed to show statistically significant differences. Neither the main effect of Time, nor the interaction was found to be statistically significant. Figure 13 shows the average percentage of objects recalled (three tests, 20 items each) during each of the three load conditions.

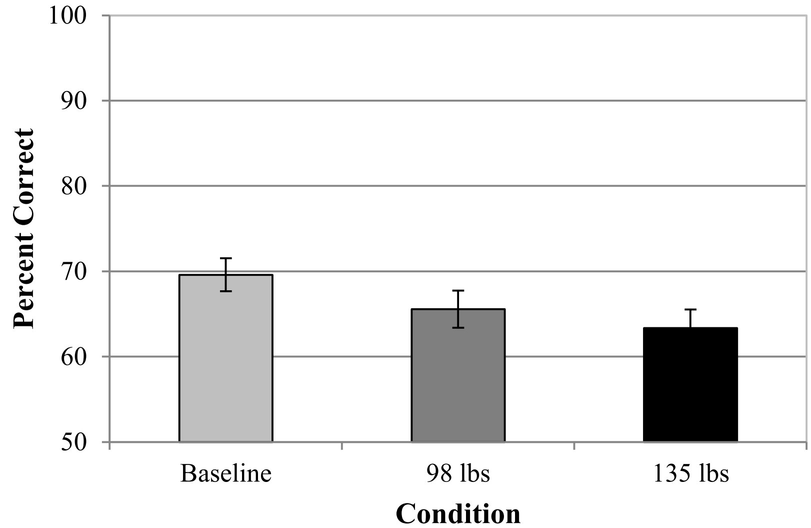

Figure 13. Memory Recall main effect of load carriage.

3.5 Head Pitch

Posture (head pitch) data was collected via the eye tracking equipment during the detection and identification task. If head pitch was too great the system was unable to track head position and data was lost. Therefore, analysis was conducted only for those participants in whom 90% of the data was captured. This reduced the sample size to sixteen (n = 16).

A one-way repeated measures ANOVA was conducted and found a statistically significant effect of Load, $F(2, 30) = 16.6$, $p < .01$, indicating the amount of weight carried affected the participants‟‟ head pitch. In particular, participants titled their heads significantly ($p < .05$) lower (leaning forward) when carrying either 98 lbs. (M = 0.123, SE = .03) or 135 lbs. (M = 0.129, SE = .03), than when carrying no load (M = 0.240, SE = .02). No statistically significant difference was found between the 98 and 135 lb. load conditions. Figure 14 displays the mean head pitch graphically across the three load conditions. Figure 15 illustrates the change in head pitch of one participant during each load carriage condition, relative to a central axis that is perpendicular to the treadmill surface.

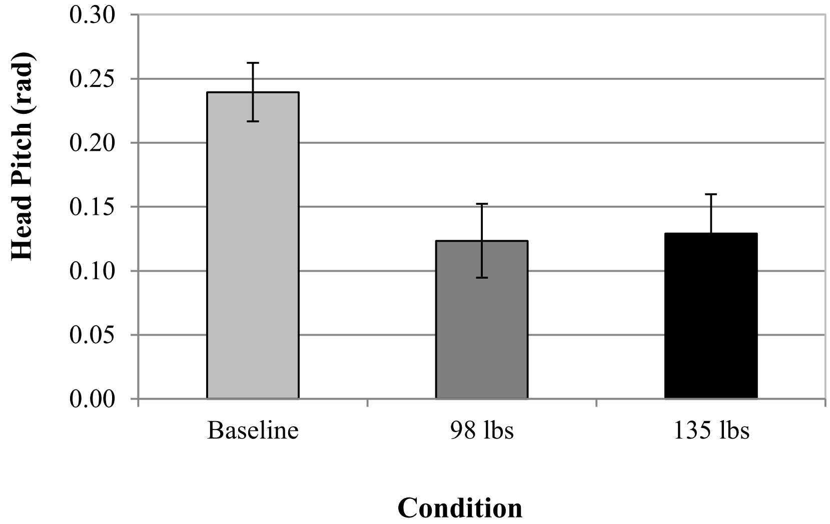

Figure 14. Mean head pitch by load condition.

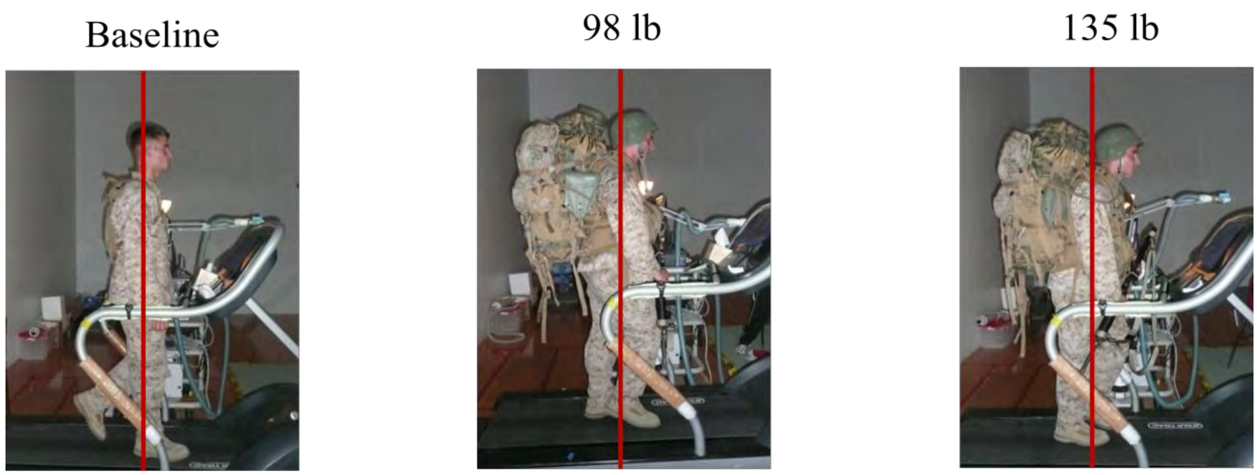

Figure 15. Participant head pitch during each load carriage condition.

3.6 Subjective Measures

All subjective measure analyses were calculated based upon the responses from the same sample of Marines ($N = 17$) that provided the behavioral and physiological data.

3.6.1 Rating of Perceived Heaviness (RPH)

A one-way ANOVA was conducted to examine the effect of carrying three different loads on subjective Ratings of Perceived Heaviness (RPH). A statistically significant main effect was found among the weight conditions, F (2, 32) = 251.33, $p < .001$, indicating participant ratings of perceived heaviness were dependent on the amount of load carried. Pairwise comparisons revealed that when carrying 135 lbs., participants rated the load as significantly heavier (M = 4.06, SE = .13), than when carrying the 98 lb. load (M = 2.68, SE = .13) or when carrying no load (M = 1.0, SE = .00). All other comparisons between mean ratings were also statistically significant ($p < .001$). Figure 16 shows the mean score of subjective RPH across the three load conditions.

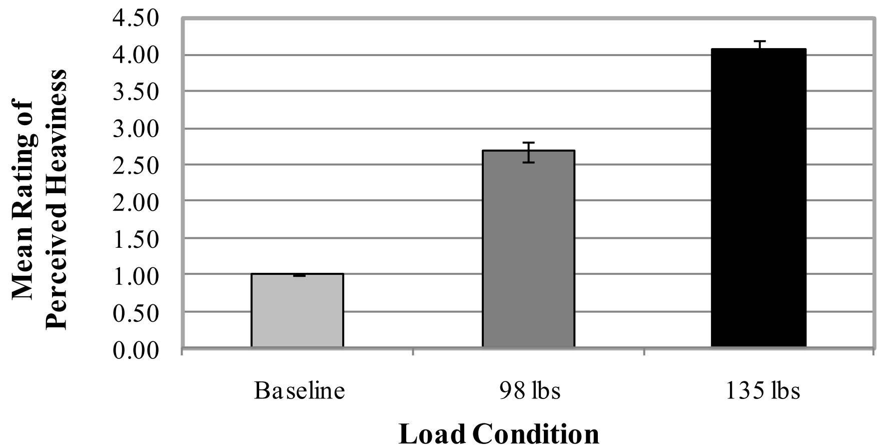

Figure 16. Average subjective rating of perceived heaviness for each load condition.

3.6.2 Rating of Perceived Exertion (RPE)

A One-way repeated measures ANOVA was conducted to examine the effect of load carriage weight on the perceived exertion (RPE), resulting in a statistically significant main effect of Load $F(2, 32) = 145.33$, $p < .001$. Pairwise comparisons indicated participants perceived they were exerting a greater amount ($p < .001$) of effort for each increasing load carriage condition. The average RPE rating was higher during the 135 lb. load condition (M = 15.39, SE = .57), than during the 98 lb. (M = 11.51, SE = .59) or no load (M = 6.63, SE = .17) condition. The average RPE for each condition was statistically different from the RPE rating of the other two conditions. Figure 17 shows the mean RPE across the three load conditions.

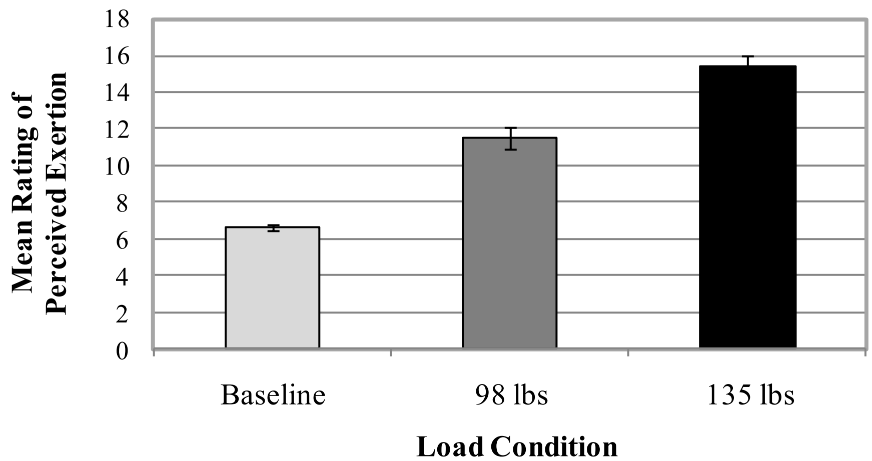

Figure 17. Average rating of perceived exertion for each load condition.

3.6.3 CALM Rating

A one-way ANOVA was conducted to examine the effect of carrying three different loads on CALM (comfort/discomfort) ratings. A statistically significant main effect was found among the weight conditions, $F(2, 32) = 136.02$, $p < .001$, suggesting that comfort ratings were significantly affected by the amount of load carried. Pairwise comparisons revealed that participants perceived their comfort level at each load condition to be significantly different from all other load conditions ($p < .001$) with the most comfortable condition being the no load condition and the most uncomfortable condition being the 135 lb. load condition. Figure 18 shows the mean CALM scores across the three load conditions. Note that positive ratings indicate comfort, while negative ratings indicate discomfort.

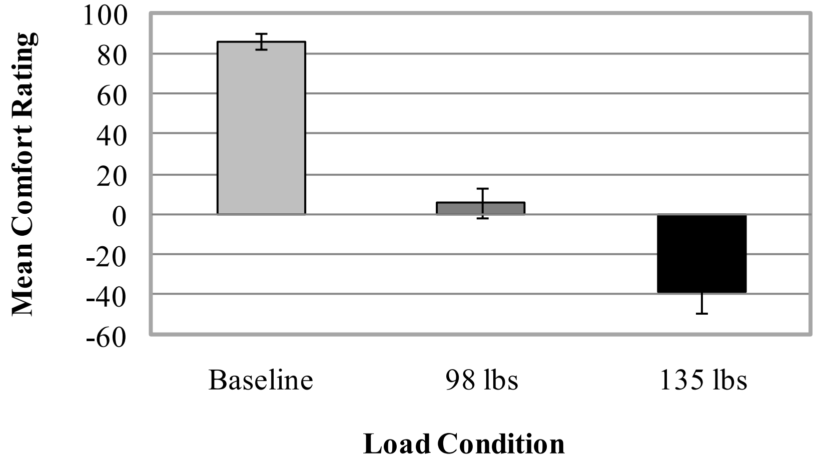

Figure 18. Average rating of perceived comfort for each load condition.

3.6.4 Task Load Index score (TLX)

A One-way repeated measure ANOVA was conducted to examine the effect carrying various loads would have upon TLX (workload) scores related to the cognitive tasks. A statistically significant main effect was found between load conditions, $F(2, 32) = 30.67$, $p < .001$. Interestingly, although the cognitive tasks were the same across all conditions, participants rated the workload as significantly ($p < .01$) greater for each increase in load carriage. More precisely, when participants were carrying 135 lbs., their perceived workload on the cognitive tasks was perceived as higher ($M = 49.01$, $SE = 4.96$) than when they were carrying either 98 lbs. ($M = 30.58$, $SE = 4.10$) or carrying no load ($M = 17.62$, $SE = 3.66$). All pairwise comparisons between conditions were statistically significant ($p < .001$) from one another. Figure 19 shows the mean TLX scores across the three load conditions.

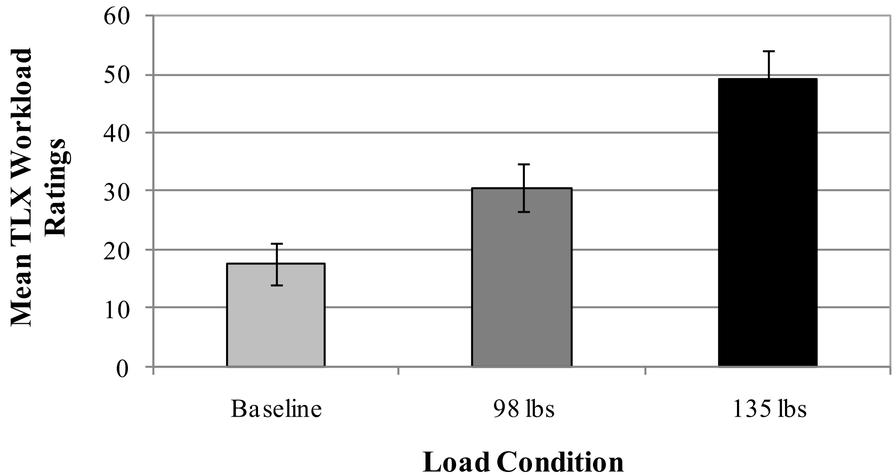

Figure 19. Mean TLX rating scores for each Load condition.

3.7 Post Session Interview

Percent agreement with each statement is shown in Table 2 for each of the seven post session interview items for each load condition. Individual questions are listed in Table 2. In general, the number of participants that indicated they had problems or distractions, increased with increasing load weight. These results are in concert with the findings of RPE and CALM which showed significant increases in exertion and decreases in comfort with increase in load carried.

Table 3. Post session interview response frequencies.

Question	Baseline	98 lbs.	135 lbs.
Problems with balance of load?	0%	24%	47%
Any difficulty while walking on TM?	6%	77%	82%
Outside normal daily activity?	0%	35%	71%
Any specific difficulty with any tasks?	12%	41%	59%
Did the load influence performance?	18%	82%	100%
Was the HR monitor uncomfortable or distracting?	6%	6%	6%
Was the load greater than weights carried in the past?	0%	12%	93%

3.8 Correlations

Multiple correlations were conducted to determine the relationship between physiological and cognitive measures and subjective ratings. Data was collapsed across the three load conditions for each of the correlations. Table 3 shows the relationship between physiological measures related to effort and cognitive performance and subjective ratings. Two physiological measures demonstrated a weak but statistically significant negative correlation with cognitive performance. Hit rate performance was negatively correlated with HR (r (49) = -.3, p < .05) but not with VO_2. In other words as these physiological variables increased with greater load, Hit Rate performance decreased. The same relationship existed between Five Paragraph Order performance and HR (r (49) = -.31, p <.05), and VO_2 (r (49) = -.32, p < .05) demonstrating that as these physiological measure would increase across load conditions, performance on the Five Paragraph Order would significantly decrease. No statistically significant correlation was found between the memory task (KIMs) and any of the physiological measures. The TLX also failed to correlate with performance on any of the cognitive performance measures.

The correlations between each of the physiological variables and the subjective ratings of CALM, RPE, RPH and TLX were also highly significant (p < .001). Two of the subjective ratings of physical effort (RPE and RPH scale) were expected to mirror physiological data to reflect that participants are in touch with demand put upon them physically. The TLX was an assessment of cognitive workload, yet was highly correlated to measures of physical effort (p < .001). Lastly, the comfort scale was also very highly correlated to physiological measures of effort (p < .001). None of the physiological measures correlated significantly with memory performance.

Table 4. Correlation between physiological variables and cognitive/subjective rating scales.

	Hit Rate	**Accuracy**	**5-Para**	**Memory**	**Calm**	**RPE**	**Heaviness**	**TLX**
HR	-.3*	.19	-.31*	-.18	-.73***	.76***	.80***	.44***
VO_2	-.21	.07	-.32*	-.18	-.78***	.86***	.88***	.63***

A second set of correlations was conducted between cognitive performance results and subjective rating scales. Ratings on the CALM significantly correlated with performance on the detection task (r (49) = .33, p < .05) and the Five Paragraph Order Task (r (49) = .32, p < .05). RPE ratings were significantly correlated (r (49) = -.33, p < .05) with performance on the Five Paragraph Order task, indicating that as perceived exertion increased performance on the Five Paragraph order task decreased. The RPH ratings were significantly correlated to Hit Rate (r (49)

= -.3, $p < .05$) and to Five Paragraph Order performance (r (49) = -.36, $p < .01$), and were the only measure correlated to performance on the KIM task (r (49) = -27, $p < .05$). Although statistically significant, these correlations are relatively weak. The TLX was not significantly correlated to any of the cognitive performance measures. Table 4 displays all of the correlation levels calculated between cognitive and subjective variables.

Table 5. Correlation between cognitive performance and subjective rating scales.

	Hit Rate	Accuracy	5-Para	Memory
CALM	.33*	-.26	.32*	.21
RPE	-.24	.20	-.30*	-.26
Heaviness	-.3*	.21	-.36**	-.27*
TLX	-.08	.06	-.26	-.26

4. Results Performance Recovery (Exploratory)

To examine whether Marines quickly regain performance levels after a brief rest immediately following a load carriage march, a subset of participants were asked to complete one additional session of the detection identification task and the abbreviated Five Paragraph Order task following a five minute rest period. Recovery was only assessed following the 135 lb. load condition. Eleven Marines participated in the recovery trial condition. Data analysis for the detection and identification task is comprised of data from ten Marines due to a computer error, whereas analysis for the abbreviated five paragraph order is comprised of all eleven Marines that completed the tasks. The sample size was too small to draw valid conclusions regarding recovery, however these preliminary results are suggestive.

4.1 Detection (Hit) Rate

To analyze performance recovery, the average hit rate for each load condition was compared to performance after a 5 minute recovery period. A one-way repeated measure ANOVA was conducted using data from the sub-sample of ten Marines. Results approached but did not reach statistical significance ($F(3, 27) = 2.61$, $p = .072$). For these ten Marines performance was lower for the heavier load conditions and did not show recovery after a 5 minute rest. Although these results did not reach statistical significance based upon the $p < .05$, the results need to be considered in the context of this overall study. The results are primarily driven by the performance during the three loaded conditions. A paired t-test does indicate that detection performance during recovery is significantly lower than baseline performance. Figure 20 shows the average hit rate for each of the load conditions.

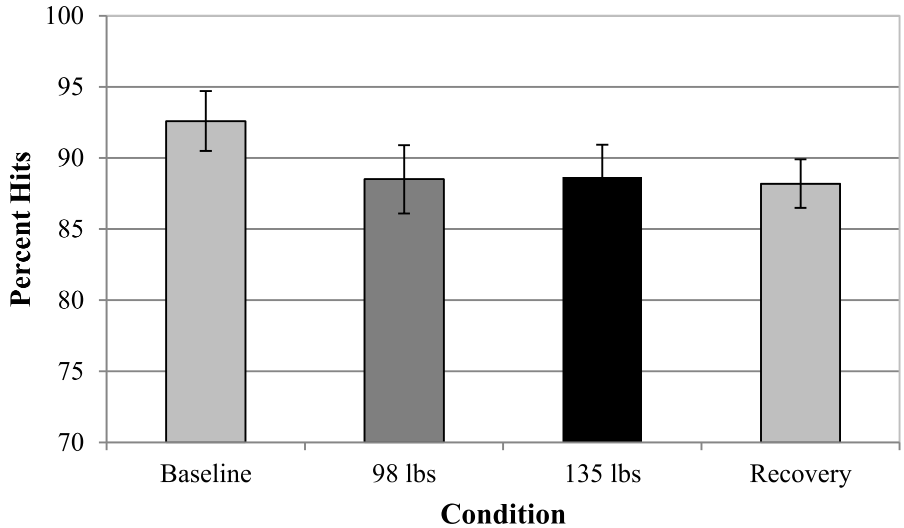

Figure 20. Hit rate across all load conditions for the recovery sample.

4.2 Eye Gaze

Figure 21 and 22 provide illustrations of a potential reason for a decrease in visual performance. During the Baseline (no Load) condition eye movements appear to cover the full screen (See Figure 21). However, under the heaviest load condition (135 lbs.; Figure 22) eye movements appear to be primarily directed toward the bottom of the image. These Figures represent momentary gaze points for one participant under both conditions.

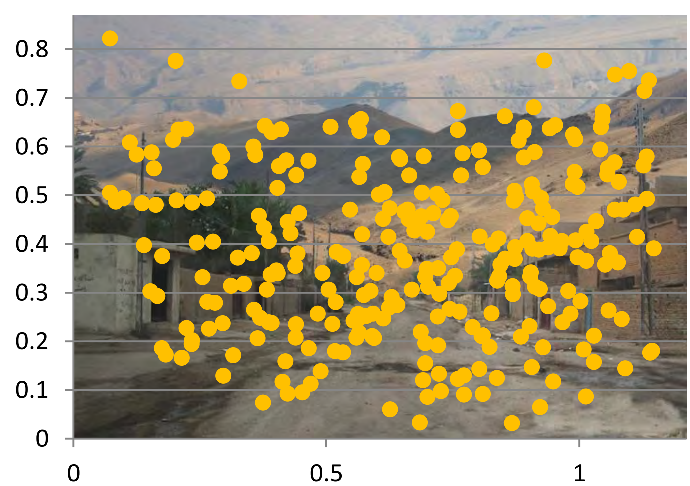

Figure 21. Eye scan locations noting fixation points during the no-load condition.

The results demonstrate a tendency to shift attention away from the upper visual field when carrying heavy loads. However, during the 135 lb. (see Figure 22) condition there is a tendency to narrow the focus as fixations are concentrated down the central street through town. These results although suggestive, were not statistically significant due to the small sample size (n = 8) and are presented here for consideration for more detailed measurement in future research. These results are in concert with the Hit Rate by Row data shown in Figure 9, but not with the Gaze data shown in Figure 11.

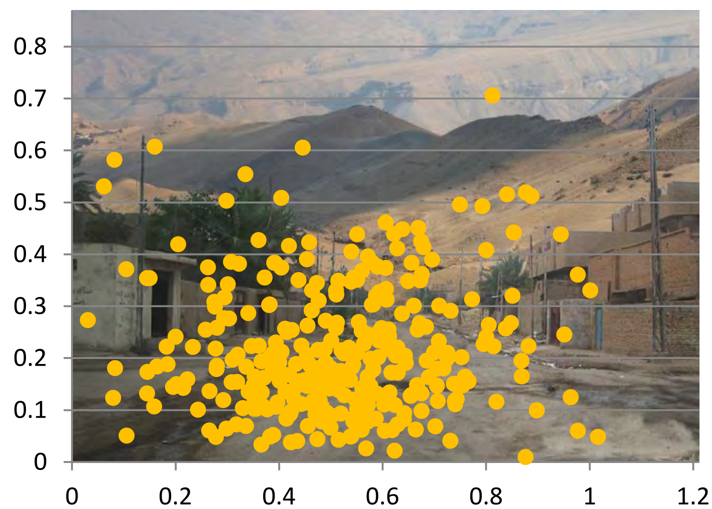

Figure 22. Eye scan patterns noting fixation points during the 135 lb. load condition.

Figure 23 shows the average amount of time (percent time during each test) participants spent looking in each sector of the visual display. This Figure shows that under the heavier load conditions, participants had a tendency to look lower in the visual field (bottom of display) than when carrying no load. Note that Sector 0, lost trial data, also increased as load increased.

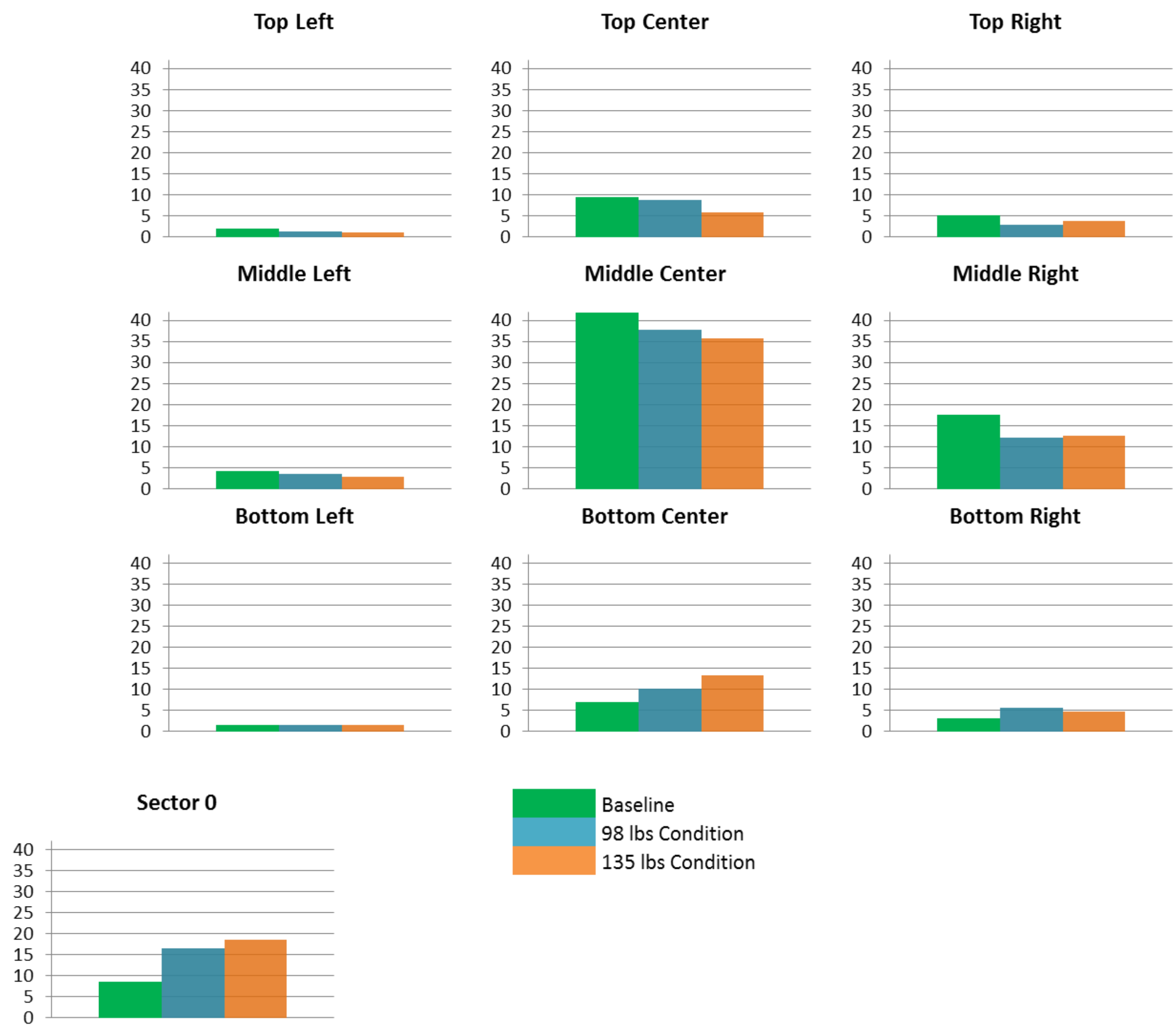

Figure 23. Percent time spent looking in each sector of the visual display for each load condition.

4.2 Abbreviated Five Paragraph Order

A one-way within-subjects ANOVA was conducted to evaluate participant ability to recover order information following a 10 minute rest period at the end of the patrol. No statistical differences were found, indicating that performance was no different from the baseline condition for this sample of participants. A potential confound with this recovery data may exist related to a general decay of memory over time. However, the time course across the three load conditions is the same and performance was significantly lower for the 135 lb. load condition as shown in Figure 24. A paired *t*-test using data from this limited sample does indicate that the differences between baseline and the recovery period were statistically significant ($t(9) = 2.3$, $p < .05$).

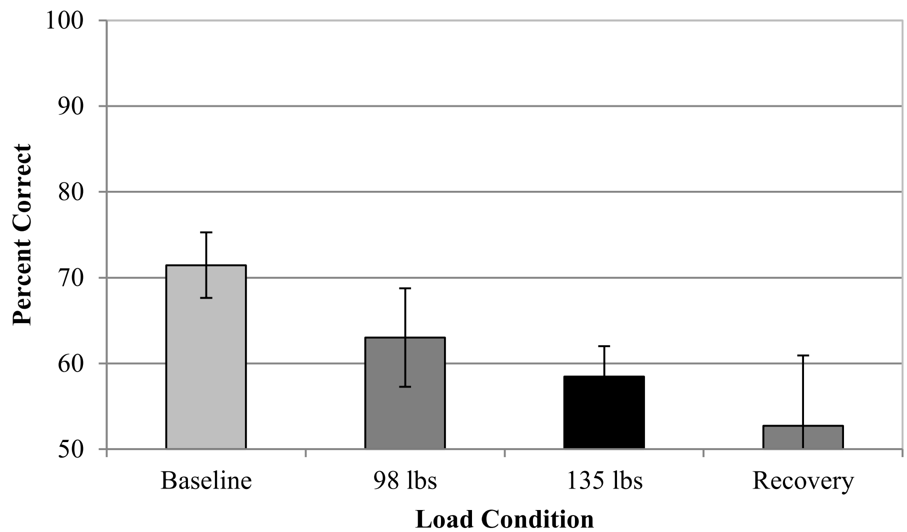

Figure 24. Accuracy for the Five Paragraph Order task across the load conditions and recovery.

4.3 Head Pitch

Data for ten Marines were used to analyze head pitch collected during the detection and identification task across the three load conditions and the recovery period. To determine if head pitch returned to a baseline state when load was removed following a five minute rest period at the end of the session. A one-way repeated measure ANOVA was conducted and a main effect of load was found to be statistically significant, $F(3, 27) = 5.051$, $p < .01$. However, pairwise comparisons indicated that Marines posture, following five minutes of rest ($M = 0.22$, $SE = .04$), was not statistically different from their posture when carrying no load ($M = .23$, $SE = .03$), suggesting posture recovered after removing the 135 lb. load and resting for five minutes. Further, head pitch during the 98 and 135 lb. load conditions was statistically significantly lower than for the recovery group. Figure 25 illustrates the average posture value across each of the four load conditions.

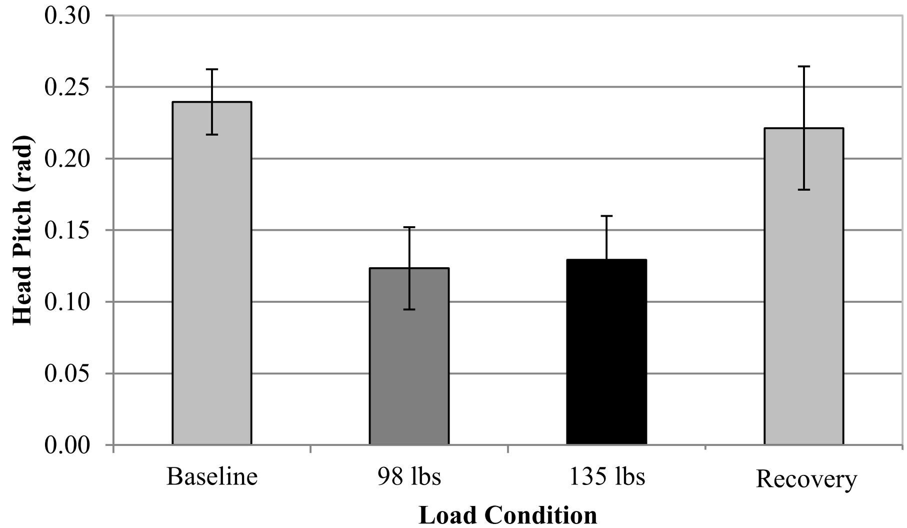

Figure 25. Average head pitch for each of the load conditions and after a 5 minute rest period.

5. Discussion

This is the first study to investigate the effects of very heavy loads (135 lbs.) on cognitive performance over an extended period of time (2 hours) while walking (2 mph). The findings reported here demonstrate that carrying a heavy load significantly increases physical strain (VO_2 and HR), perceived effort (RPE, Heaviness, TLX), decreases perceived comfort (CALM), and deteriorates cognitive performance (detection, working memory, and spatial memory).

This study yielded several important findings:

1. Cognitive performance degrades with increasing weight carried.
2. The decrement in performance between load conditions increases over time.
3. Physiological strain and cognitive performance are negatively correlated.
4. Cognitive performance is positively correlated with perceived comfort.
5. Cognitive performance is negatively correlated with perceived heaviness.

There is little question that many variables affect cognitive performance in combat, such as fatigue, heat, altitude, stress, etc. (Russo, Fiedler, Thomas, & McGhee, 2005). This study sought to isolate the effects that heavy load carriage may have on cognitive performance during a controlled study. The results demonstrate that carrying a heavy load is yet another contributor to decrements in cognitive performance, and that its impact increases over time. Performance on all three of the cognitive tasks demonstrated a significant decrement with increasing load, with the 135 lb. load condition showing the poorest performance on all measures. Although these changes are small, the data was collected under conditions that would minimize or eliminate other variables such as heat, altitude, stress, etc. which are likely to be faced in the operational environment. Therefore, decrements found in this study are probably less severe than would be expected in the operational environment and their operational significance should not be underestimated. Such a concern is in concert with the findings of Lieberman, et al. (2002), who caution that cognitive performance decrements found during operational simulations would always be lower than what could be observed in combat under higher levels of stress.

One of the most critical tasks for any infantryman is the ability to detect meaningful information in the environment. Marines continually emphasize throughout training that “every Marine a collector.” During the target detection task in this experiment, Marines were walking on a treadmill under various load conditions and were required to respond whenever they detected a stimulus displayed on the screen. Coincidentally, they were also to indicate whether the stimulus was a target or non-target. They were tested for five minutes on three separate occasions during each two-hour session. Under these conditions, the ability to detect stimuli was significantly reduced when carrying the 135 lb. load. Results also indicated that these decrements in performance increased over time. Due to the fact that infantry patrols are longer than two hours, with loads often heavier than 135 lbs., it will be critical to obtain a better understanding of the time course of these changes. In an attempt to capture data related to a potential cognitive rebound effect after removing the load, Marines were tested a fourth time after removing the load in the 135 lb. condition. Results failed to show recovery of performance back to that of the baseline condition, however the sample size used for this investigation was small (n = 10) and the time elapsed after removing the load (5 min) was short, thus further investigation is needed.

The detection results also suggested that visual focus is directed lower in the visual field with increased load carriage, demonstrating a significantly lower hit rate along the top of the visual field under the heaviest load condition. Exploring eye gaze data from a subsample of participants failed to corroborate these results, although there did appear to be a trend showing that participants spent more time looking lower in their visual field when carrying a very heavy load. Results such as these have critical implications for infantrymen when operating in the field. Having an understanding that performance declines with very heavy loads and that threat detection particularly in specific parts of the visual field may suffer as a consequence, may suggest that certain individuals within a squad (e.g., pointman) carry less weight to help mitigate such effects. However, additional data need to be collected to more completely characterize performance over the time course of a typical patrol.

The relationship between perceived comfort level and cognitive performance was also statistically significant. These results are in concert with the findings of Bell, Cardello, & Schutz (2005), demonstrating a reduction in performance with increasing discomfort. The current study shows that as load weight increased, comfort values decreased (increasing discomfort), and so did cognitive performance, although the correlation was low. This result may be indicative of discomfort demanding participant"s attention, causing them to divide their attention and acting as a distractor from their primary task. A low correlation may be explained by 1) the restricted range in values in the performance measures, 2) high level of physical fitness and training of the participants, or 3) a general reluctance of the participants to admit discomfort (this is a general problem with using subjective reporting in the military).

For nine of the Marines, carrying 135 lbs. required them to carry a load equivalent to 90% or greater of their body weight. This extreme condition is not uncommon during current field deployments (Tyson, 2009b). While the physiological demand notably increased with heavier loads, average heart rates only reached approximately 65% of the age predicted maximum for the majority of Marines. According to the Physical Activity and Health report published by the Surgeon General (1996), the relative intensity of physical work required during this study was moderate to hard. The ability of Marines to sustain the Moderate to Hard physical demand of carrying 135 lbs. for a duration of two hours is testament to their successful physical training. However, carrying heavy loads negatively affects cognitive performance of combat-related tasks. These cognitive effects may be partially mitigated by the physical conditioning of Marines.

These results show that carrying heavy loads has an impact upon the ability of infantrymen to detect and identify potential threats (targets versus non-targets) in their environment while on patrols. One of the major take-home messages of this research is that the decrements reported here occurred in less than two hours, and the typical patrol lasts considerably longer (8-10 hours). Therefore, without coming in contact with the enemy, infantrymen carry these heavy loads for multiple hours (with short breaks periodically) and are required to continually monitor their environment. Although the present results are clear, a question that needs to be addressed in the future is what are the effects of carrying these heavy loads upon sustained cognitive performance over an extended period, such as that of a typical patrol? Little is known regarding the sustained effects of this type of exertion on cognitive performance.

In the current study, detection performance was evaluated every 40 minutes. Participants were prompted the task was about to begin and to monitor the screen. Such prompting, probably enhanced performance, by re-directing their focus of attention. Further, participants knew that they only had to maintain focus for a 5-minute task. Even under these favorable conditions, detection performance significantly decreased under the heaviest load condition. In retrospect, the task that needs to be conducted is to evaluate detection performance continuously throughout the session – without prompting. On patrol, detection performance is continuously required and is difficult to maintain without a vigilance decrement. We contend that the vigilance decrement is exacerbated when carrying heavy loads, and is probably greater in the field than demonstrated in this study. Detection performance needs to be evaluated over long patrol durations (6-8 hours), carrying very heavy loads to truly assess the changes in cognitive performance that may be experienced under operational conditions.

The intent of this study was to determine whether increasing load carriage weight affected cognitive performance. However, after starting the study it became apparent that a key question would be how quickly performance would recover after removing the load? To begin to address this question, a change in protocol was immediately submitted to the IRB and approved. Data were collected on two of the subtasks (Detection and Five Paragraph Order) after only the heaviest load condition. These results failed to show any significant improvement in performance after the load was removed compared to performance during the heaviest load condition. However, the sample size was too small to make statistical inferences. Identifying the recovery period needed for cognitive performance may provide critical insight for operational mission planning (optimal work-rest cycles).

Overall, there are several considerations that need to be addressed by future research. First, the time course of the session needs to better approximate that of a patrol. Previous studies that have failed to show a decrement in cognitive performance have studied various levels of physical performance for less than one hour (Krausmen, Crowell, & Wilson, 2002; Perry, Shiek-Nainar, Segall, & Kaber, 2008; Sibley & Beilock, 2007). Most of the participants in these studies were physically fit and able to sustain performance through an acute bout of physical activity. In the current study, a session lasted two hours, yet this still is significantly less than what infantrymen train for, or are expected to do in the field, possibly allowing them to sustain higher levels of performance during the study. Secondly, many studies have been conducted using periodic, short duration cognitive tasks (Crowell, et. al., 1999; Mastroianni et al., 2003; Williams, Englund, Susec, & Overson, 1998) with few effects on performance observed. The current study falls into this same category. Participants were asked to perform tasks infrequently and were prompted prior to each task, plus they only needed to focus their concentration for brief moments at a time. These conditions are likely to facilitate performance. Therefore, the performance decrements observed in this study likely underestimate the level of decrement that may be experienced in the field. Thirdly, diet and nutrition were not controlled during the current study. All participants ate regular meals at the base chow hall, but specific menus were not documented. Dietary information should be collected in the future to determine whether any effects may be related to a neurophysiological change (reduced carbohydrates). Lastly, there is a need to fully examine the recovery cycle of cognitive functioning. Such results would provide very critical information for small unit leaders to use in developing optimal work/rest cycles for patrol movements.

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7. Appendix A. List of Suggested Equipment

Date Scheduled: ____________________	**Time: ____________________**	
Session Days: ______________________		
Load Condition Order:		
Day: ____________	**Day: ____________**	**Day: ____________**
Required Equipment – **0 load**	**Required Equipment –** **98 lb. load**	**Required Equipment –** **135 lb. load**
Bring every session:	**Same as 0 load** **Plus the following:**	
• Battle Dress Uniform • Hydration Pack (**filled**) • Gym Shorts • T-Shirt • Towel • Shower shoes	MTV (A1 First Aid Kit, stock stop, Double/Double Mag Pouch, M16-M4 Speed Reload Pouch, M67 Grenade Pouch x 2, M16-M4 Double-Single Pouch, Dump pouch)	**Same as 98lb load**
	MCCUU (Marine Corps Combat Utility Uniform)	
	Helmet(covered) with Nape pad and goggles	
	100 oz Hydration system (filled)	
	Assault Pack (Entrenching Tool with cover), (2 plastic canteens with cap and pouch(filled)), (Gortex tops/bottoms), (coyote fleece cap - neck gaiter - drawers(2) - undershirt(2) - Pullover Fleece), (ILBE-MACS Sack(2) - ILBE-W/P Main Pack Liner - ILBE W/P Assault Pack Liner), (Fighting Load Carrier Molle II and SAPI plates)	
		Plus the following:
		ILBE Main Pack with ILBE Hip Belt and Lid Pack
		Black and Green Sleeping Bags w/ Compression sack and Bivy Cover
		Field MARPAT Reversible Tarpaulin
		Foam Sleep Mat
		MARPAT Poncho Liner

8. Appendix B. List of Equipment used in the Lab

Equipment	Model	Properties and settings	Reason for use
Treadmill	Star Trac E-TR	0% grade, 2.0 mph	Equipment used in the SOI gym.
Laptop	IBM Lenovo ThinkPad T60		Administer cognitive and subjective tasks.
Smart Eye Pro system	Smart Eye 4.5.4	60 HZ sample rate Head tracking: 6 DOF Gaze tracking: 2 DOF	Data collection of gaze and head pitch during the Detection and Identification task.
Projector	Proxima UltraLight X350	Connected to the laptop via a VGA cable.	Project task images.
Remote	Kensington Wireless Presenter 33374	Wireless laser connection through a USB key to laptop. Placed by trigger of simulated weapon.	Response for Detection and Identification task.
Voice recorder	RCA Digital Voice Recorder RP5022		Record participant recall during KIM"s task.
Clock and room thermometer	RadioShack Wireless Weather Forecaster BAR668HGA	Clock set at Pacific Standard Time (PST). Thermometer set to Fahrenheit.	Clock used to aid delivery of tasks in accordance to the timeline. Thermometer used to monitor room temperature.
Ear thermometer	Braun ThermoScan Compact IRT3020 CO	Digital readout thermometer.	Measure participants" ear temperature at the start of break.
Blood pressure monitor	Omron Digital Blood Pressure Monitor HEM-712C	Collects blood pressure and HR (bpm)	Measure participant systolic and diastolic blood pressure, and pulse at the end of each session.
Heart Rate Monitor	Garman Forerunner 50	Digital wrist watch readout and chest strap.	Real time HR data observed and recorded during session.
Urinometer	Grafco Junior Flint Glass 90-3530	Sample collected tube and marked measuring stick	Measure participant pre-test hydration status.
Simulated weapon	M16 rifle	Three point sling used to carry riffle during load carriage condition	Simulate patrol weapon - provided to participants during load conditions.
Sandbags	Weights included: 1, 2, 5, 10 lb. bags	Strategically placed in rucksack and/or attached to Flak.	Used to add to individual weight to reach specified load conditions.