Effects of Increases in Mental Workload on Avoidance of Ground Hazards

Monica M. Glumm

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Thurmon E. Lockhart, Chair
Maury A. Nussbaum
Tonya L. Smith-Jackson

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(ABSTRACT)

New sensor and display technologies are expected to enhance the performance of soldiers by providing them more information about the battlefield. However, there is concern that greater quantities of information and increases in mental workload might cause distraction, reduce attention to dangers in the immediate environment, and threaten soldier survival. The purpose of this laboratory investigation was to quantify the effects of increases in mental workload on one of the soldier's most basic tasks --- avoiding ground hazards while walking. The participants were 12 U.S. Army infantry soldiers. The study was conducted on a treadmill that was modified to provide the participants a view of impending ground hazards up to 5 meters forward of their walking position. The study was a 2X3 fixed factor design with two levels of terrain difficulty (No Hazards and Hazards) and three levels of mental workload (No Load, Moderate load, and High load), all as within-subject effects. Mental workload was increased from the "No Load" to a "Moderate" level by requiring the participants to perform a mental arithmetic task while walking. Mental workload was increased from the "Moderate" to the "High" level of load by increasing the difficulty of arithmetic problems. The dependent variables included time and error in the performance of the mental arithmetic task, the mean and standard deviation in step length and step rate, the number of ground hazards contacted, and subjective ratings of workload. The participants' scores on the Armed Forces Qualification Test (AFQT) and subtests of the Armed Services Vocational Aptitude Battery (ASVAB) related to arithmetic skills were also obtained. The results of the investigation indicated that when the participants were required to avoid hazards, step length decreased and step rate increased, as was expected. Both measures of gait increased in variability. Subjective ratings of physical demand and effort obtained across the three levels of mental workload increased significantly, along with perceptions of workload associated with a perceived decline in performance. Subjective ratings obtained across the two levels of terrain difficulty indicated that ratings of mental demand and effort increased with each increase in level of mental workload. When the participants were confronted with the more difficult arithmetic problems at the “High” level of mental workload, time and error in performing the mental arithmetic task increased as did ratings of temporal demand, frustration, and workload attributable to a perceived decline in performance; however, subjective ratings of physical demand decreased. Interactions found between terrain difficulty and mental workload indicated that differences in ratings of performance and overall workload scores between the two levels of terrain difficulty decreased significantly between the “No Load” and the “Moderate” level of mental workload, and converged at the “High” level of mental load. Although relationships were found between perceived workload, gait, and performance of the mental arithmetic and hazard avoidance tasks, the analysis did not reveal a significant effect of mental workload on the number of hazards contacted. Some participants tended to contact more hazards at the “High” level of mental workload than at the “No Load” or the “Moderate” levels, as expected. However, other participants tended to contact more hazards at the “Moderate” level of mental load than at either of the two extremes. Still other participants tended to contact more hazards at the “No Load” level of mental workload than at the “Moderate” or the “High” levels. Correlations were found between subjective ratings of workload, mental arithmetic performance, and scores on the AFQT and subtests of the ASVAB related to arithmetic skills, but no relationships were found between test scores and performance of the hazard avoidance task. However, when test scores were used as covariates in the analysis of mental arithmetic performance, the findings revealed that the number of correct responses to the arithmetic problems decreased when the participants were required to avoid hazards. The results of the study may support the belief that the allocation of limited resources will vary based on past experience and other individual differences, and that the amount of resources allocated to a task may be influenced by the difficulty of the task, criteria for performance, and the motivation of the individual.

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CHAPTER 1

INTRODUCTION

1.1 Rationale

Among the many challenges confronting U.S. Army soldiers are increases in mental workload that can cause distraction, reduce awareness of hazards in the immediate environment, and ultimately threaten soldier survival.

Advances in technology have increased the complexity of modern warfare and the decisions soldiers must make to successfully accomplish their missions. New sensors and displays offer to enhance the performance of soldiers by providing them more information about the battlefield. However, the more information the soldier must process, the greater the risk of mental overload. There is concern that greater quantities of information and complex displays and controls might compete for the soldier's attention, reduce awareness of the immediate situation, and conflict with performance of other critical tasks (National Research Council, 1997).

Soldiers perform a number of physical and mental tasks concurrently that can compete for their attentional resources. While moving over hazardous terrain, soldiers must monitor radio transmissions and other information displays, extracting, processing, and acting on information that is critical to their mission. Soldiers must also communicate with the members of their team and others within the battlefield while remaining alert and ready to respond immediately to threats and hazards within their local environment. Soldiers must remain aware of their position with respect to objectives, and other friendly and enemy units. Soldier tasks, such as *Navigation* and *Call for Fire*, require computation of position coordinates, distances, and bearings where even small errors can have serious consequences.

As multiple-resource theory suggests (Navon & Gopher, 1979; Wickens, 1984), when two tasks are performed concurrently, decrements should be expected based on the magnitude of the resource demands and the extent to which the demands of one task overlap the other. Schneider and Shiffrin (1977) contend that two tasks can be performed simultaneously if one of these tasks can be performed automatically. Given this, one might expect that increases in mental workload would have a minimal effect on the performance of a well-learned and somewhat automatic task such as walking, particularly if the terrain being traversed is even and known to be free of obstacles. However, the terrain the soldier travels is often rugged and filled with hidden dangers. For the soldier, the task of walking can be visually intensive, as well as physically and psychologically stressful. Attentional demands and distractions imposed at higher levels of mental workload may result in failure to detect ground hazards or delays in detection that reduce the time available for successful avoidance.

Research suggests that running over uneven terrain or avoiding obstacles while walking requires some level of cognitive effort (Patla, Prentice, Robinson, & Neufield, 1991; Warren, Young, & Lee, 1986). There is also evidence of cognitive involvement in maintaining body stability while standing (Maylor & Wing, 1996; Sos & Toole, 2001). Nonetheless, the level of mental effort involved in adjusting locomotor patterns to avoid obstacles remains uncertain, as does the potential that increases in mental workload will interfere with this process.

Research on the effects of aging and divided attention supports the notion that there is more cognitive involvement in walking than might be expected. Most studies found that performance of a cognitive task while walking affected seniors more so than young adults, but dual-task costs were evident in both age groups (Chen, Schultz, Ashton-Miller, Giordani, Alexander, & Guire, 1996; Guardiera, Bock, & Allmer, 2003; Lajoie, Teasdale, Bard, & Fleury, 1996; Lindenberger, Marsiske, & Baltes, 2000; Li, Lindenberger, Freund, & Baltes, 2001). Among the factors that were believed to have influenced the incidence and extent of the decrements in dual-task performance were the level of difficulty of the walking and cognitive tasks, and the priority assigned to one task over another (Guardiera, Bock, & Allmer, 2003; Li, Lindenberger, Freund, & Baltes, 2001).

Although research on aging indicates that a cognitive task can interfere with walking performance and that walking can interfere with the performance of a cognitive task, it remains uncertain as to whether a cognitive task can interfere with the mobility performance of soldiers. The effects of increases in mental workload on soldier mobility and obstacle avoidance have not been explored. Understanding the impact of mental workload on one of the most basic tasks of the soldier is an important first step in the design and evaluation of tactical information displays.

1.2 Research Objectives

The primary objective of the proposed research was to quantify the effects of increases in mental workload on avoidance of ground hazards while walking. The following were hypothesized for this investigation:

Hypotheses:

When terrain difficulty increases, subjective ratings of workload will increase along with the variability in step length and step rate. As the difficulty of a cognitive task and mental workload increases, time and error in performing the cognitive task will increase along with subjective ratings of workload, the variability in step length and step rate, and the number of hazards contacted.

1.3 Need for the Study

Advances in sensor and display technologies offer to enhance soldier performance by providing more information about the battlefield. However, as the amount of information the soldier must process increases, so does the risk of mental overload.

During a combat mission, dismounted soldiers often walk long distances moving over rugged terrain that is littered with both natural and manmade hazards. Attentiveness to these hazards and other threats within the immediate environment is as important to the survival of the soldier as is his awareness of the situation within the larger battle space.

In the current battlefield, command information is communicated auditorily via radio; however, in the future, more information about the battlefield may be presented to the soldier visually on a head-mounted display (HMD). One of the major concerns related to the use of HMDs has been the potential for losses in local situational awareness caused by obstructions in the visual field of the soldier. Therefore, much of the research has focused on the effects of display design (e.g., HMDs versus handheld displays) and sensory modality (e.g., auditory versus visual display) on local and global situational awareness. Investigation of the effects of increases in mental workload, apart from the visual obstructions and distractions that might be imposed by the display, has been relatively limited.

Although research on the effects of aging has found that performance of a cognitive task while walking can affect the performance of young as well as old adults, it remains uncertain as to whether a cognitive task can impair the mobility performance of soldiers. Determining the effects of increases in mental workload on one of the most fundamental tasks of the soldier is an important first step in the design and evaluation of tactical information displays. Decrements found in mobility performance that are attributable to increases in mental workload will have significant implications for other tasks that rely more heavily on cognitive resources. Keeping mental workload at a manageable level can help the soldier assimilate information, make better decisions, and ultimately improve his effectiveness and survivability.

CHAPTER 2

LITERATURE REVIEW

2.1 Physical Exertion and Performance of Cognitive Tasks

There have been many studies on the effects of physical exertion on cognitive performance, but research on the effects of mental workload on the performance of "physical" or predominantly motor tasks has been limited. Research on the effects of physical exertion on cognitive performance has yielded mixed results (Tomporowski & Ellis, 1986). The findings of some studies indicated a decrease in cognitive performance as a result of physical exercise (Fleury & Bard, 1987; Hancock & McNaughton, 1986; Mihaly, Hancock, Vercruyssen, & Rahimi, 1988; Weingarten, 1973). In other studies, physical exercise appeared to increase cognitive performance (Hogervorst, Riedel, Jeukendrup, & Jolles, 1996; McGlynn, Laughlin, & Bender, 1977). In some studies, cognitive performance at first increased with physical exertion and then began to decrease (Davey, 1973; Gupta, Sharma, & Jaspal, 1974; Salmela & Ndole, 1986). In still other studies, exercise appeared to have no effect (Fleury, Bard, Jobin, & Carriere, 1981; Sparrow & Wright, 1993; Tomporowski, Ellis, & Stephens, 1987; Zervas, 1990). In a study by Krausman, Crowell, and Wilson (2002), physical exercise facilitated performance on reaction time and decision-making tests, but performance on an arithmetic test was degraded.

2.2 Mental Workload and Performance of Physical Tasks

Much of the research on the effects of mental workload on physical tasks has focused on the effects of state or trait anxiety. As with studies on the effects of physical exertion on cognitive performance, experimental methodologies varied and results were mixed. Martens (1971) contended that one of the confounding factors in these studies was the difference in the “degree of motorness” of the motor tasks used. Although some tasks were primarily motor with some cognitive and perceptual involvement, other tasks were mostly perceptual and cognitive by nature and only marginally motor.

2.3 Cognitive Involvement in Walking

Schneider and Shiffrin (1977) contend that two tasks can be performed simultaneously if one of these tasks can be performed automatically. Given this, one might expect that increases in mental workload would have minimal affect on the performance of a somewhat automatic task such as walking, particularly if the terrain being traversed is even and known to be free of obstacles. However, if the ground traveled is uneven or filled with obstacles, the attentional demands of the walking task may increase significantly.

There is some evidence that running over uneven terrain, and avoiding obstacles while walking require some level of cognitive effort (Warren, Young, & Lee, 1986; Patla, Prentice, Robinson, & Neufield, 1991). Warren, Young, and Lee (1986) were among the first to explore visual control of gait while moving over uneven terrain. In their study, they examined movements of participants running on a treadmill on irregularly spaced targets that represented areas that provided secure footing. The researchers found that the participants adjusted their step length to acquire the targets by varying the vertical ground reaction force applied during the stance phase. It was believed that this vertical ground reaction force was controlled by the visual information on time to contact the target. Patla et al. (1991) extended this work in two series of studies on strategies used in avoiding obstacles. In their first series of studies, the researchers examined adjustments in gait that occurred when changing direction to walk around an obstacle. In their second series of studies, they examined gait changes that occurred when choosing to go over an obstacle. In these latter studies, Patla et al. (1991) manipulated cue time to obstacle presentation, the height of the obstacle, and obstacle location. One important finding in the first series of studies was that directional changes in steering around an obstacle had to be planned in the earlier part of the previous step. In the second series of studies, the researchers found that high obstacles and the late cue condition caused some difficulty in successful avoidance compared to conditions with low obstacles and early cues which were relatively error free. The location of the obstacles was found to have no effect.

Patla et al. (1991) concluded that the cognitive aspects of regulations in gait need further investigation.

The extent of cognitive involvement in adjusting locomotor patterns in avoiding obstacles is uncertain, as is the potential that increases in cognitive load will interfere with this process. However, recent research in postural control indicates that even the act of standing still requires some mental effort. Sos and Toole (2002), for example, found that counting backwards by threes while standing interfered with postural reactions in maintaining body stability. Maylor and Wing (1996) found that when young and old adults were asked to stand still while performing a mental arithmetic task, body sway increased in both groups but more so in older adults.

Research on the effects of aging appears to support the notion that there is more cognitive involvement in walking than might be expected. In one study, Lajoie et al. (1996) compared reaction time to an auditory stimulus of young and old adults when sitting, standing with both a wide and narrow support base, and walking. For both age groups, reaction times were faster when sitting than when standing or walking. When standing, the reaction times of older adults were more affected by a decrease in base support than were the reaction times of young adults. Differences were found between young and old adults in gait but neither group changed their gait when the reaction time task was performed while walking.

In another study on aging, Lindenberger et al. (2000) examined memory recall of young, middle-age, and old adults when sitting, standing, or walking on two different tracks that varied in level of difficulty. The researchers found that recall performance was lower when encoding was performed while walking than while sitting or standing. This decrease in recall was more evident in middle-age and old adults than in the younger group. Generally, recall performance was lower when walking on the more difficult track, but the type of track did not have a significant effect on walking while performing the concurrent task. In the dual-task condition, walking speed decreased in all age groups but more so in middle-age and old adults. Walking accuracy decreased in old adults but not in the young and middle-age groups.

Guardiera et al. (2003) found that spelling performance declined in both young and old adults when the spelling task was performed while walking. Performance in holding a cup while walking also declined for both groups but the decline was greater for seniors. In the dual-task condition, researchers found that step velocity and step length decreased for both groups. Step duration increased.

The findings of Li et al. (2001) indicated that memory and walking performance decreased in both young and old adults when the difficulty of the two tasks was increased. When the tasks were made more difficult, older adults tended to focus more on the walking task while younger adults tended to focus more on the memory task.

Although research on the effects of aging has revealed dual-task costs in both young and old adults when a cognitive task is performed while walking, there is insufficient evidence that a cognitive task will interfere with the ability of soldiers to avoid obstacles. Research that might provide more insight in the latter area is limited. Although Chen et al. (1996) found that obstacle contact increased significantly in both young and old adults when their attention was divided by a reaction time task, the latter task involved visual detection of colored lights and thus may have competed for resources similar to those required to perform the obstacle avoidance task. In a study of particular relevance to the present topic, Sampson (1993) measured the effects of standing and walking with and without obstacles on three cognitive choice reaction-time tasks. The latter tasks involved three displays of information that differed in the degree of verbal-spatial mental processing (i.e., spatial, verbal, and numeric) and, theoretically, level of cognitive difficulty. The study was conducted on a treadmill that was configured to simulate four levels of attentional demand related to mobility (i.e., standing only, walking without obstacles, walking with left obstacles only, and walking with left and right obstacles). Significant differences in reaction time were found among all three display-tasks for all walking conditions, and between the standing and each condition of walking-with-obstacles. Walking-without-obstacles, however, seemed to have no more effect on information processing than standing. No significant differences were found between the latter two walking-with-obstacle conditions. In this study, a buzzer was sounded when the participants stepped on a simulated obstacle, but the number of obstacles contacted was not recorded.

2.4 Single and Multiple Resource Theories

There are a number of theories that address the ability of humans to perform two or more tasks concurrently. Some theories suggest that there is a single undifferentiated pool of mental resources available to perform tasks (Craik, 1948; Telford, 1931; Welford, 1952), while other theories propose that there are sets of resources or channels that can be allocated (Navon and Gopher, 1979; Wickens, 1984). In the single-channel theory, the performance of one task might be postponed to focus on another task. Multiple resource theory suggests there are a number of channels used to perform a task. These channels have distinct functions and each channel is limited in capacity. Performance of a task is expected to be affected by the magnitude of the demand on each resource, the efficiency of each resource used in performing the task, and the extent to which two tasks performed concurrently compete for the same resources.

2.5 Human Information Processing and Attention

According to multiple resource theory, a cognitive task which requires verbal-mental resources should not interfere with a task which requires spatial-mental resources. The potential for task conflict is reduced if one task involves the visual modality and the other the auditory. However, attentional capacity for processing information is fixed and limited (Kahneman, 1973), and attentional conflicts can occur that may cause significant disruption in the performance of one or both tasks.

Wickens' model of human information processing stages shown in Figure 1 may provide insight as to where attentional conflicts might occur if a mental arithmetic task and hazard avoidance are performed concurrently.

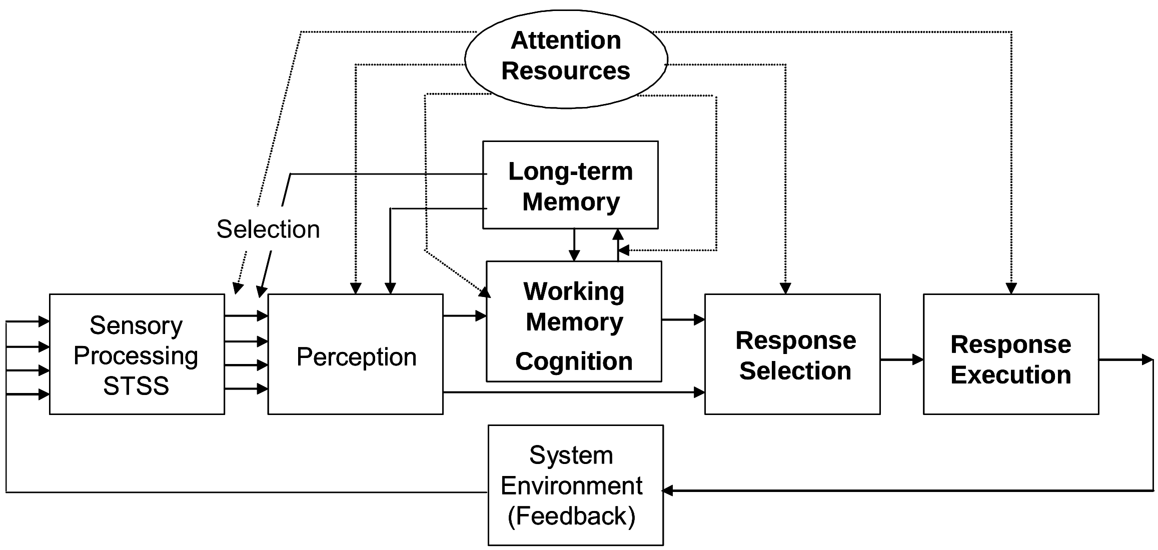

Figure 1. A model of human information processing stages (Wickens, 1984).

According to Wickens' model, raw sensory data are received by the eyes and the ears, and interpreted in the initial stages of information processing. Although these operations involve attention and long-term memory, their performance is somewhat automatic. It is during the cognitive stage that follows where greater demands are placed on resource-limited memory stores and the potential for conflict between the two tasks increases significantly. Solving arithmetic problems and avoiding hazards both employ long- and short-term (working) memory resources and require attention. During cognitive operations, an arithmetic problem may be repeated aloud to assist in retention and-or transformed into a mental image that takes the place of the paper and pencil on which some of us may have become dependent. During this stage of processing, a determination is made about the nature of the arithmetic problem (e.g., subtraction or addition, borrow or carryover). Meanwhile, information about the position and motion of oneself in relation to ground hazards continues to be extracted from the environment toward selection and timing of the avoidance response. In the response selection stage, an answer to the arithmetic problem is chosen along with a strategy for avoiding the hazard (e.g., stepping over or around the hazard, taking one large step or several smaller steps). In the response execution stage the answer to the arithmetic problem is spoken verbally and the chosen method of avoiding the hazard is performed. Although the appropriate hazard avoidance strategy may have been selected, both mental and physical effort must be expended during this stage in processing to coordinate the muscles for controlled motion in successfully executing the strategy.

2.6 Literature Review Summary and Conclusion

There have been many studies on the effects of physical exertion on the performance of cognitive tasks, but research on the effects of mental workload on the performance of physical tasks, such as walking, has been limited. Theory suggests that two tasks can be performed simultaneously if one task can be performed automatically, or if the two tasks do not compete for the same mental resources. Given that walking is a well-learned, predominantly motor task that is somewhat automatic, one might not expect that it would be significantly affected by increases in mental workload.

However, research suggests that there may be more cognitive involvement in walking than one might think. Even the act of standing still has been found to require some mental effort. Studies on changes in gait during locomotion have revealed that some prior planning is involved in acquiring areas that provide secure footing when running over irregular terrain, or steering around obstacles when walking. Research on the effects of aging found that when a cognitive task was performed while walking, the performance of both young and old adults declined on one or both tasks.

When the ground being traveled is uneven and filled with obstacles, the attentional demands of the walking task can increase significantly. According to theories on attention, attentional capacity is fixed and limited. Models of human information processing indicate that when two tasks are performed concurrently, competition for resource-limited memory stores and attention can cause significant disruption in the performance of one or both tasks. In conclusion, it might be expected that for this study, the attentional demands and distractions imposed at higher levels of mental workload will result in failure to detect ground hazards or delays in detection that will degrade the performance of the hazard avoidance task.

CHAPTER 3

METHOD

3.1 Participants

Twelve U.S. Army soldiers participated in this experiment. Ten of the soldiers were male and two were female.* The ranks of the soldiers were Specialist (E-4) through Sergeant First Class (E-7) and they ranged in age from 24 and 43 years (Mean = 34.3) with 2.2 to 23 years in military service (Mean = 13.3).

All participants were required to have passed their most recent physical fitness test (U.S. Department of the Army, 1992) to reduce the probability of any chronic illness or injury that would increase the risk to the participant or bias the data. All read and signed a Volunteer Agreement Affidavit (see Appendix A).

3.2 Apparatus

3.2.1 Treadmill

The treadmill used in this study was a Quinton Q65 (Quinton® Instrument Co.), Series 90, powered by a 3-horsepower A.C. motor (see Figure 2). The walking surface of the treadmill was 165 cm (65 inches) long and 51 cm (20 inches) wide. For this study the walking grade was set to 0% incline. The walking speed was maintained at 1.34 m/sec (3.0 mph) to simulate an infantry road march during daylight hours (U.S. Department of the Army, 1990). The front handrail was removed to avoid any visual obstruction to the front of the treadmill and handrails were provided on each side of the walking surface.

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* The two female participants represented 15.33% of active duty U.S. Army personnel that are female and were based on 2002 U.S. Army statistics.

Markers were located on each handrail approximately 94 cm (37 inches) from the front edge of the walking surface to assist participants in maintaining their position along the length of the treadmill.

Treadmill power and speed were controlled using pushbuttons located on a Controller (Model 640). The controller, shown in Figure 3, incorporates a *Start Belt* button that initiates movement of the belt at a minimum walking speed of 0.67 m/sec (1.5 mph). Speed is increased by pressing the *Increase* button and decreased to the minimum walking speed by pressing the *Decrease* button. A *Stop Belt* button reduces the speed of the belt to a soft stop. For this study, the controller was located to the side of the treadmill where it was operated by the principle investigator.

Figure 2. Treadmill.

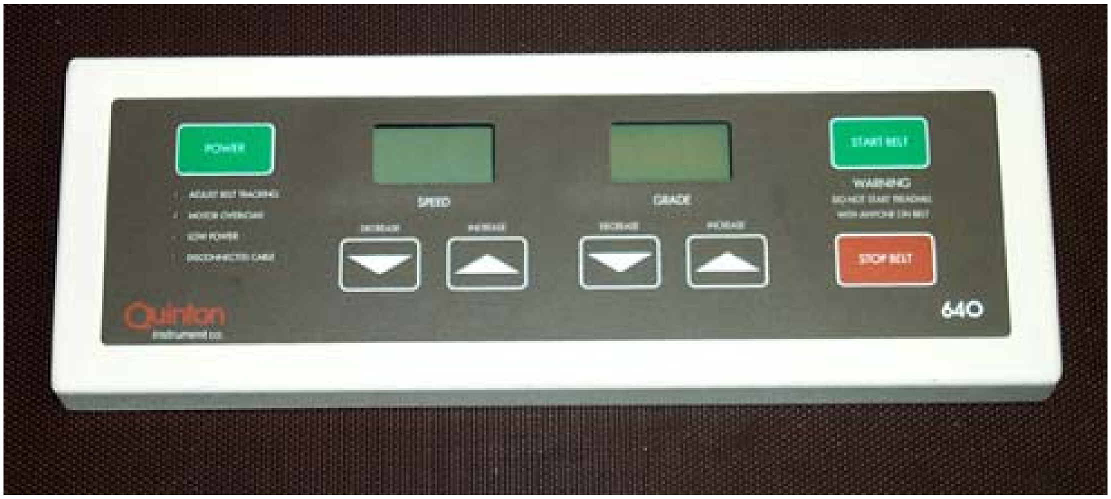

Figure 3. Treadmill controller.

For this study, the treadmill was modified to provide the participant a view of impending ground hazards up to 5 meters forward of his or her walking position (see Figure 4). The modification was modeled after one used by Warren, Young, and Lee (1986) in their study of visual control of step length during running over irregular terrain. The modification consisted of a vinyl belt that was looped around the treadmill belt. The vinyl belt, which was 0.4 m wide and 15 m long, was extended to a tensioner-pulley assembly located 5 meters beyond the front edge of the treadmill. The tensioner-pulley assembly enabled the vinyl belt to turn in unison with the treadmill belt.

A total of 24 simulated ground hazards were painted to the left and right of center at irregular intervals along the length of the vinyl belt as illustrated in Figure 4. The hazards were white and the vinyl belt on which the hazards were painted was a dark olive green. Each hazard was 10 cm wide and 20 cm long. The intervals between hazards varied between 0.9 m to 1.8 m. Two vinyl belts were created with hazards painted on both the top and reverse sides. The spacing between the hazards on each side of the two belts was varied but the number of hazards remained constant.   The two belts provided four different hazard arrangements for use during training and testing.

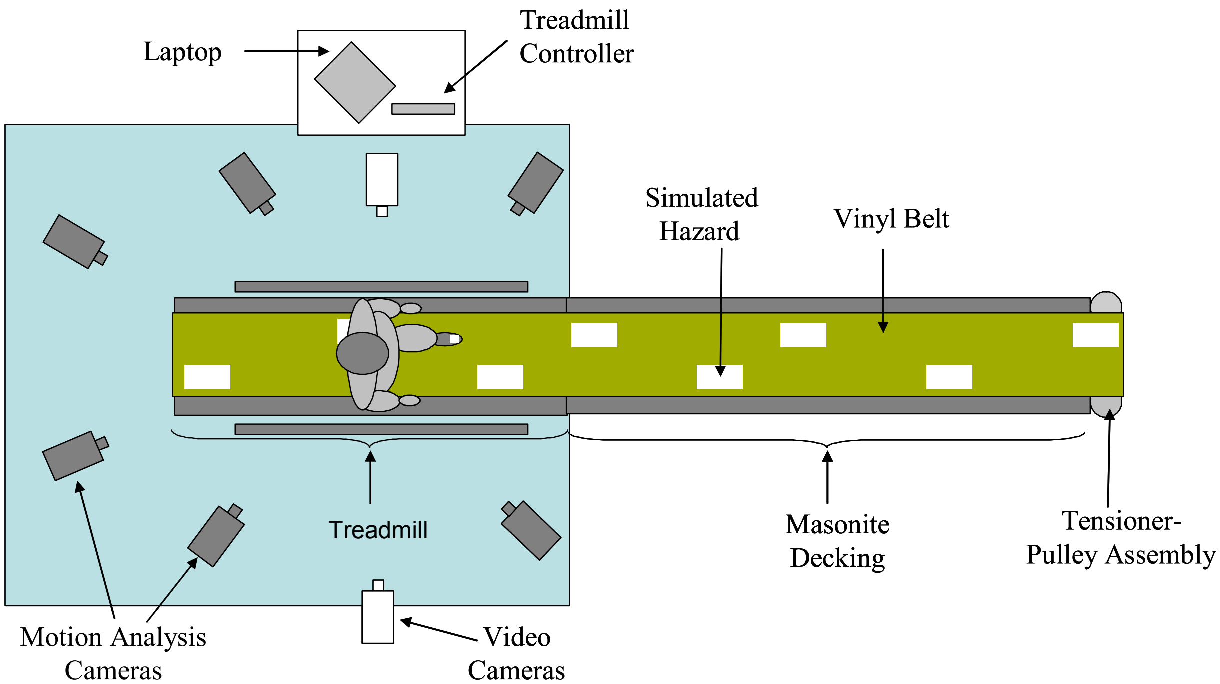

Figure 4. Test setup with modified treadmill and simulated ground hazards.

3.2.2 Motion Analysis System

An opto-electronic motion analysis system was used to obtain measures of step length and step rate. The system which was developed by Motion Analysis Corporation of Santa Rosa, CA consists of six high-resolution video cameras and a real-time motion capture software package (EVaRT 4.0). In this investigation, the motion analysis system was used to capture and track three-dimensional positions of reflective markers located on the heels and toes of the participant's boots (see Figure 5). The three-dimensional position data that were used to calculate step length and step rate were collected at a rate of 30 Hz. The data was filtered using a low-pass Butterworth filter with a cut off frequency of 6 Hz. The accuracy for tracking the marker position was approximately 1.5 ± 0.5 mm.

Figure 5. Reflective markers on boot.

3.2.3 Clothing

All participants wore the standard battle dress uniform (BDU) with combat boots throughout the training and testing periods. The personal armor system for ground troops (PASGT) helmet was also worn when walking on the treadmill.

3.2.4 Arithmetic Task

Mental workload was manipulated by varying the difficulty of arithmetic problems that the participant solved mentally while walking on the treadmill. The arithmetic task involved mental addition and subtraction of two numbers where all answers were greater than 10 but less than 100. This task was based on similar tests of arithmetic and adapted by Scribner and Harper (2001) for auditory presentation. The level of difficulty of the arithmetic problems were based on the number of digits in each of the two numbers to be added or subtracted and the requirement for a carryover or borrow operation (see Figure 6). A “Moderate” level of mental workload involved addition or subtraction of a double-digit and a single-digit number without a carryover or borrow. A “High” level of mental load involved addition or subtraction of two double-digit numbers with and without a carryover or borrow operation. The number of addition and subtraction problems, and the ratio of problems requiring a carryover or borrow to those that did not, remained constant for all runs in which mental workload was applied.

The arithmetic problems were presented auditorily in computer-generated voice messages through a speaker-microphone (Jabra® EarSet) that the participant wore in his or her ear. Presentation of the problems was controlled by a laptop computer using software running in embedded Visual Basic. Sound files of the verbal response of the participant to each arithmetic problem were created. A digital audio editing software program (Sound Forge V4.5) was used to analyze the sound files and determine response times and errors.

Level 2 (Moderate)		Level 3 (High)			
One Double and One Single Digit		Two Double Digits			
Addition	Subtraction	Addition		Subtraction	
(no Carryover or Borrow)		(Carryover)	(no Carryover)	(Borrow)	(no Borrow)
15 + 4 19	15 - 4 11	36 + 15 51	36 + 13 49	36 -19 17	36 - 13 23

Figure 6. Sample arithmetic problems at the "Moderate" and "High" levels of mental workload.

3.2.5 Workload Assessment Technique

The National Aeronautics and Space Administration-Task Load Index (NASA-TLX) was used to obtain subjective measures of the workload experienced by the participant during each run (Hart & Staveland, 1988). The NASA-TLX uses rating scales that provide the researcher information on the extent to which mental, physical, and temporal demands, performance, effort, and frustration contribute to the overall workload experience.

In the administration of the NASA-TLX, a weight is initially obtained for each of the six-workload factors based on the responses of the participant to pair-wise comparisons among these factors. In these comparisons, the six factors are presented in 15 possible pairs and, for each pair, the participant is asked to circle the factor that they perceived contributed more to his or her workload experience. The participant then completes rating scales that provide an estimate of the magnitude of the workload experienced for each factor. Those factors perceived by the participant to have contributed most to his or her workload experience are given more weight in computing an overall workload score. The paired-comparisons worksheets and the workload rating scale are shown in Appendix B.

3.3 Experimental Design

3.3.1 Independent Variables

The design matrix for this study is shown in Table 1. The independent variables were terrain difficulty and mental workload. The study examined two levels of terrain difficulty and three levels of mental workload. The two levels of terrain difficulty were (1) No Hazards and (2) Hazards. The three levels of mental workload were (1) No Load (2) Moderate Load and (3) High Load. There were six combinations of terrain difficulty and mental workload. These six combinations were (A) No Hazards-No Mental Load (B) No Hazards-Moderate Mental Load (C) No Hazards-High Mental Load (D) Hazards-No Mental Load (E) Hazards-Moderate Mental Load and (F) Hazards-High Mental Load. The order of presentation of the six experimental conditions was counterbalanced with a Latin Square design (Table 2).

Table 1. Design Matrix.

		Mental Workload		
		No Load	Moderate Load	High Load
	No Hazards	A	B	C
Terrain				
Difficulty				
	Hazards	D	E	F

Table 2. Counterbalancing Scheme.

Participant	Order of Presentation					
1	A	B	C	D	E	F
2	B	D	A	F	C	E
3	C	A	E	B	F	D
4	D	F	B	E	A	C
5	E	C	F	A	D	B
6	F	E	D	C	B	A
7	A	B	C	D	E	F
8	B	D	A	F	C	E
9	C	A	E	B	F	D
10	D	F	B	E	A	C
11	E	C	F	A	D	B
12	F	E	D	C	B	A

3.3.1.1 Terrain Difficulty

The two levels of terrain difficulty were (1) No Hazards and (2) Hazards. In the "No Hazards" runs, the simulated ground hazards were covered throughout the warm-up period and the 10-minute test run. In "Hazards" runs, the ground hazards were covered during the warm-up period and uncovered 30 seconds prior to the start of the test run. The vinyl belts on which four different hazard arrangements were painted provided one hazard arrangement that was dedicated to the training phase of the study, and three other hazard patterns that counterbalanced among the three test runs that involved hazard avoidance.

3.3.1.2 Mental Workload

The three levels of mental workload were (1) No Load (2) Moderate Load and (3) High Load. In “No Load” runs, the arithmetic task that was used to impose mental workload was not presented. For training and test runs in which mental workload was imposed, a total of six sets of arithmetic problems were created. Each set consisted of 30 arithmetic problems. Three sets were prepared for presentation during runs at the “Moderate” level of mental workload, and another three sets were prepared for runs at the “High” level. One set from among each of the three was reserved for training and the other two sets counterbalanced among test runs. Separate sets of arithmetic problems were prepared for administration during tabletop training sessions prior to testing and during post-test assessments of arithmetic performance.

3.3.2 Dependent Variables

3.3.2.1 Mental Arithmetic

During the study, each participant performed one run in each combination of terrain difficulty and level of mental workload for a total of six runs. Cognitive performance was measured in four of the six runs in which mental workload was imposed via the administration of the mental arithmetic task. During each of these four runs, a total of 30 arithmetic problems were administered. The participant received and responded to each problem through a speaker-microphone that was worn in his or her ear. Sound files of the verbal response of the participant to each arithmetic problem were created. The sound files were analyzed using digital audio editing software to determine (1) the number of correct responses and (2) the time to respond to each arithmetic problem regardless of whether the answer was right or wrong. An incorrect solution to a problem or failure to provide a solution to the problem within the time allotted (i.e., 12 seconds) was scored as an error. Only the first response to the arithmetic problem was scored. Time to respond was measured from the last syllable of the arithmetic problem presented to the first syllable of the solution that the participant provided. If the participant did not provide an answer to the problem, time to respond was scored as 12 seconds.

3.3.2.2 Ground Hazard Avoidance

The number of ground hazards stepped on during a 10-minute run was counted manually by two research personnel who stood on opposite sides of the treadmill. If any part of either of the participant's boots overlapped the hazard by more than 0.5 inches or more, an error was scored. Two video cameras positioned at the left and right sides of the treadmill recorded the position of the participant's boots with respect to the simulated hazards during the hazard avoidance runs. The videos were reviewed independently by a third researcher to verify the counts obtained during the test period. A count of the number of hazards that were contacted by one half or more of either of the participant's boots was also obtained during the video reviews. The first criterion for hazard contact (i.e., 0.5 inches or more of the boot) included errors that were small but capable of triggering explosive hazards, such as landmines, while the second criterion (i.e., half or more of the boot) indicated the proportion of the total count that were more clearly errors in avoidance that could potentially result in loss of balance and falls due to contact with other hazards such as fallen trees or potholes.

3.3.2.3 Gait

Step length and step rate were calculated from the three-dimensional position data collected by the motion analysis system. For each step, step length was computed as the horizontal distance between the right and left toe markers just before toe-off of the left foot. Toe-off was defined as the time at which the toe marker was at its minimum in the z axis. Step lengths were averaged for each of the 10-minute test runs and reported in meters. The time between the right and left toe-off was computed for each step to determine step rate. Step rate was reported as the average number of steps per minute attained during the 10-minute test run.

3.3.2.4 Subjective Workload

The NASA-TLX questionnaire was administered immediately after each 10-minute run in the six experimental conditions. For each condition, an adjusted rating was computed for each of the six different subscales (mental demand, physical demand, temporal demand, performance, effort, and frustration). The adjusted rating on each subscale was obtained by multiplying the weight derived from the comparison of paired workload factors by the raw rating derived from the estimate of the magnitude of each factor. An overall weighted workload score was also computed. The overall workload score was obtained by multiplying the sum of the adjusted ratings on each of the six subscales by the sum of the weights.

3.3.2.5 Armed Services Vocational Aptitude Battery (ASVAB) Scores

Permission was obtained from the participants to access their scores on the Armed Services Vocational Aptitude Battery (ASVAB) and the Armed Forces Qualification Test (AFQT). Scores on the ASVAB and AFQT are used for selection and placement in the Armed Services and served as covariates in the present study. The ASVAB consists of 10 individual tests: General Science (GS), Arithmetic Reasoning (AR), Word Knowledge (WK), Paragraph Comprehension (PC), Numerical Operations (NO), Coding Speed (CS), Mathematics Knowledge (MK), Mechanical Comprehension (MC), and Electronics Information (EI). A score on Verbal Expression (VE) is derived from scores on two of the individual tests: Word Knowledge and Paragraph Comprehension.

The AFQT score is a percentile score based on the population of ASVAB test takers. It is derived from scores on Verbal Expression, Arithmetic Reasoning, and Mathematics Knowledge. In the calculation of the AFQT score, Verbal Expression has twice the weight of scores on Arithmetic Reasoning and Mathematics Knowledge (i.e., AFQT = 2VE + AR + MK).

3.4 Procedures

3.4.1 Training

Consistency in measurement was achieved by ensuring that the same training and testing procedures were followed for all participants and experimental conditions. The training and testing procedures are provided in Table 3.

One participant was trained and tested at a time. The duration of participation was approximately 6.5 hours including breaks for rest and lunch. Each participant wore the standard battle dress uniform (BDU) with combat boots throughout the training and testing periods. The personal armor system for ground troops (PASGT) helmet was also worn when walking on the treadmill.

Each participant was briefed on the purpose of the study, the procedures to be followed throughout training and testing, and the risks involved. After the participant had read and signed a Volunteer Agreement Affidavit (see Appendix A), he or she completed a demographic questionnaire that provided pertinent information about his or her background.

The participant then received practice in performing the mental arithmetic task at the "Moderate" and the "High" levels of mental workload. During training at each of these levels, the participant was presented successive sets of arithmetic problems. Each set consisted of five addition and five subtraction problems that were presented in a random order. Each problem was presented orally, and the participant was asked to provide a verbal response as quickly as possible. The participant was trained to an asymptote in performance at the "Moderate" level of mental workload before receiving training at the "High" level of load. For this study, an asymptote in performance was defined as no greater than a 20% variance in the number of incorrect solutions between each of three successive sets of problems. The procedures followed during training at the “High” level of mental workload were the same as those followed during training at the “Moderate” level. As during training at the “Moderate” level of mental workload, five of the ten problems in each set required addition and five required subtraction.

After training in performing the mental arithmetic task, the participant was briefed on the safety features of the treadmill and procedures to be followed when boarding, walking, and dismounting the treadmill. He or she then received practice in walking on the treadmill at a natural gait, followed by practice in performing the hazard avoidance task. The participant then completed one 3-minute practice session at the “Moderate” and at the “High” level of mental workload at each level of terrain difficulty (i.e., Hazards and No Hazards). During practice and test runs that involved concurrent performance of the mental arithmetic and hazard avoidance tasks, the participant was told to: *“Provide a correct solution to each problem as quickly as possible while at the same time avoiding any foot contact with the simulated ground hazards. Avoiding the hazards, and speed and accuracy in solving the arithmetic problems are equally important.”*

The participant then received instruction and practice in assessing his or her workload experience using the NASA-TLX. This portion of the training included a review of the definitions of each of the six workload factors (i.e., mental demand, physical demand, temporal demand, performance, effort, and frustration) and instruction on completion of the paired comparisons and rating scale sections of the NASA-TLX (see Appendix B).

The participant was then provided a 15-minute rest break during which time the motion analysis system was calibrated. Reflective markers were then affixed to the heels and toes of the participant’s boots. The markers on the heels of each boot were positioned 1.0 inch above the rear sole of the boot and 1.0 inch from the end of the heel. The markers on the toes of each boot were centered 1.5 inches from the front edge of the sole of the boot. When the markers were in place, the participant was asked to board the treadmill to begin his or her first walk in one of the six experimental conditions.

Table 3. Training and Testing Schedule.

TRAINING			
Event	**Duration**	**Time of Day**	**Description**
Informed Consent	30 minutes	8:00-8:30	(1) Briefing on study purpose, procedures, and risks (2) Voluntary Agreement Affidavit (3) Demographic Questionnaire
Mental Arithmetic	30 minutes (estimated)	8:30-9:00	Successive sessions* to asymptote at Moderate and High levels of mental workload *(10 math problems per session)
Treadmill Familiarization	15 minutes	9:00-9:15	(1) Review of safety features (2) Review of boarding, walking, and dismounting procedures (3) Practice walking at both levels of terrain difficulty (i.e., No Hazards and Hazards)
Mental Arithmetic and Hazard Avoidance	15 minutes	9:15-9:30	(1) Check/adjust speaker-microphone (2) One 3-minute practice session at each level of terrain difficulty and mental workload.
Workload Assessment (NASA-TLX)	10 minutes	9:30-9:40	Instruction and practice in assessing workload
BREAK	15 minutes	9:40-9:55	
Instrumentation	5 minutes	9:55-10:00	(1) Affix reflective markers to heels and toes of boots (2) Adjust speaker-microphone
TESTING			
Event	**Duration**	**Time of Day**	**Description**
Run 1	13 minutes	10:00-10:40	*Note:* Each run includes a 3-minute warm-up period and 10 minutes of testing
NASA-TLX	5 minutes		
BREAK	20 minutes		
Run 2	13 minutes	10:40-11:20	
NASA-TLX	5 minutes		
BREAK	20 minutes		
Run 3	13 minutes	11:20-1200	
NASA-TLX	5 minutes		
Instrumentation	5 minutes		Remove reflective markers from heels and toes of boots
LUNCH	1 hour	12:00-1:00	
Instrumentation	10 minutes	1:00-1:10	(1) Affix reflective markers to heels and toes of boots (2) Adjust speaker-microphone
Run 4	13 minutes	1:10-1:50	
NASA-TLX	5 minutes		
BREAK	20 minutes		
Run 5	13 minutes	1:50-2:30	
NASA-TLX	5 minutes		
BREAK	20 minutes		

3.4.2 Testing

During the test period that followed, the participant performed a total of six runs in accordance with the counterbalancing scheme shown in Table 2. Three of the six runs were performed in the morning and three were performed in the afternoon separated by a one-hour lunch break. A rest break of 20 minutes was provided between each of the morning and afternoon runs. Each run was 13 minutes in duration and included a 3-minute warm-up period immediately followed by a 10-minute test run.

Prior to the start of each test run, the participant was informed of the tasks to be performed during that run. The participant was reminded to stay even with the markers located on the handrails at each side of the treadmill. In runs that involved hazard avoidance, the participant was reminded to step over the hazards and not between or around them. In runs where hazard avoidance and mental arithmetic were performed concurrently, it was emphasized that both tasks were of equal importance.

At the start of each run, the investigator initiated movement of the treadmill at the minimum speed of 0.67 m/sec (1.5 mph) by pressing the *Start Belt* button on the control panel. The participant was then asked to step onto the moving belt and walk at a natural gait. While monitoring the participant, the investigator pressed the *Increase* button to gradually increase the walking speed to 1.34 m/sec (3.0 mph). For all runs, the simulated ground hazards remained covered and the participant continued to walk at a set speed for 3 minutes. Two minutes into each warm-up period, step length and step rate were sampled for 5 seconds to ascertain if a change in gait parameters had occurred between runs. In runs that involved hazard avoidance, the hazards were uncovered 30 seconds prior to the end of the warm-up period. In all runs, a tone was presented to the participant to signal the start of the test run.

In runs in which the mental arithmetic task was performed, the tone also indicated that the first arithmetic problem would be presented in 5 seconds. During the 10-minute test period that followed, one arithmetic problem was presented every 20 seconds for a total of 30 problems. After an arithmetic problem had been presented, the participant had 12 seconds to provide an answer. An auditory tone was presented at the end of the 12-second period to indicate that the time to answer the previous arithmetic problem was up and that a new problem would be presented in 5 seconds. The number of arithmetic problems administered during a run remained a constant, as did the number of addition and subtraction problems. The ratio of problems requiring a carryover or borrow to those that did not was the same for all participants and all runs in which a “High” level of mental workload was applied.

At the end of each run, the participant was presented a computer-generated message indicating “Run Complete.” At that time, the investigator slowed the treadmill to the minimum speed and pressed the *Stop Belt* button to bring the treadmill to a soft stop. The participant was then asked to dismount the treadmill and assess his or her workload experience using the NASA-TLX.

3.5 Data Analysis

Subjective ratings of workload on the six subscales of the NASA-TLX (i.e., mental, physical, temporal, performance, effort, and frustration) were subjected to a multivariate analysis of variance (MANOVA) with level of terrain difficulty and mental workload as within-subject effects. Separate analyses of variance (ANOVA) were performed on ratings on each of the six subscales to determine where differences might lie. An ANOVA was also performed on overall workload scores derived from weighted ratings of workload on each of the six subscales. Post hoc comparisons were performed using the least significant difference (LSD) method.

MANOVAs were performed on response times and the number of correct responses in the performance of the mental arithmetic task, and the means and standard deviations in step length and step rate. Separate ANOVAs were performed where main effects were indicated, and the LSD method was used in post hoc comparisons.

ANOVAs were used to examine differences in the number of hazards contacted at each level of mental workload for each of two contact criterion. These criterion included hazards contacted by 0.5 inches or more of either boot and hazards contacted by half or more of either boot. Post hoc analyses were performed if significant main effects of mental workload were found.

Bivariate analyses (Pearsons Correlation Coefficient) were performed to determine if there were any relationships between subjective ratings of workload, performance of the mental arithmetic and hazard avoidance tasks, measures of gait, and scores on the AFQT and two subtests of the ASVAB related to arithmetic skills (i.e., Arithmetic Reason [AR] and Mathematics Knowledge [MK]).

Measures of subjective workload, gait, and performance on the mental arithmetic and hazard avoidance tasks were also subjected to analyses of covariance (ANCOVA). The covariates in these analyses were scores on the AFQT and subtests of the ASVAB (i.e., AR and MK). The AFQT and ASVAB scores of 11 of the 12 participants were available for these and the bivariate analyses described above. The results of the ANCOVAs were reported if they did were different from the results of the ANOVAs.

The alpha level for all the statistical tests was set at 0.05.

CHAPTER 4

RESULTS

4.1 Subjective Workload

4.1.1 Overall Workload Scores

It had been hypothesized that subjective ratings of workload obtained using the NASA-TLX would increase with increases in mental workload and level of terrain difficulty. To test this hypothesis, an ANOVA was performed to assess the effects of mental workload and terrain difficulty on overall workload scores derived from subjective ratings on each of the six subscales of the NASA-TLX (i.e., mental, physical, temporal, performance, effort, and frustration). The LSD method was used in post hoc comparisons.

The results of the ANOVA indicated a significant main effect of both mental workload (F (2, 55) = 35.116, $p < .001$) and terrain difficulty (F (1, 55) = 49.453, $p < .001$).

The mean and standard deviation of overall workload scores at each level of mental workload and terrain difficulty are provided in Appendix C (see Table C1). Figure 7 shows these mean overall workload scores for each level of mental workload across the two levels of terrain difficulty. Post hoc comparisons using the LSD method indicated that overall workload scores were significantly higher at the "High" level of mental workload than at the "Moderate" (Mean Difference = 18.79, $p < .001$) or the "No Load" level (Mean Difference = 29.23, $p < .001$). Overall scores at the "Moderate" level of workload were significantly higher than those at the "No Load" level (Mean Difference = 10.43, $p = .005$).

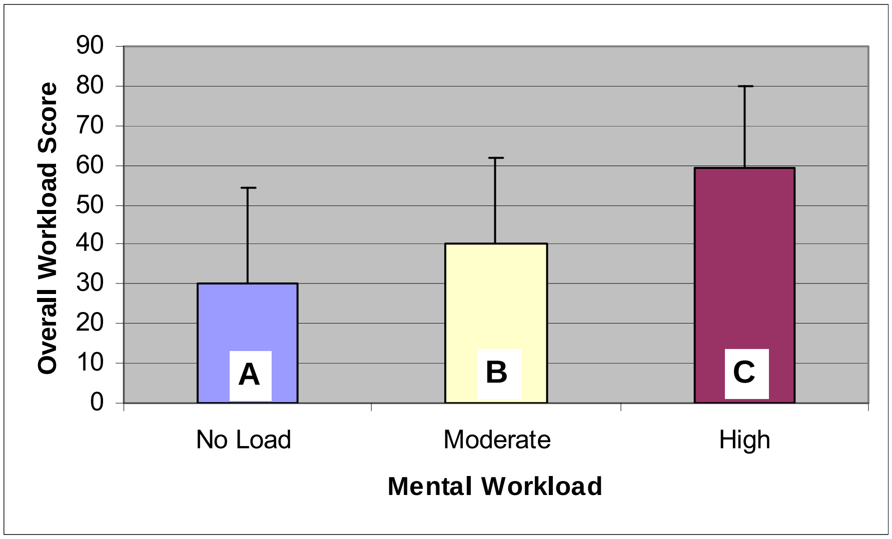

Figure 7. Mean overall workload scores across levels of terrain difficulty.

Figure 8 shows the mean overall workload scores for each level of terrain difficulty across each level of mental workload. Post hoc comparisons indicated that overall workload scores were significantly higher for the "Hazards" level of terrain difficulty than for the "No Hazards" level (Mean Difference = 20.29, $p < .001$).

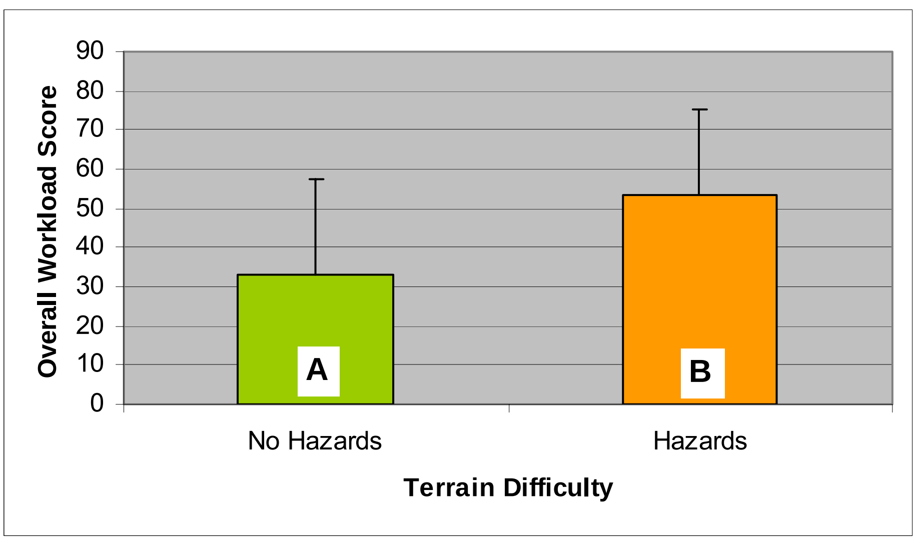

Figure 8. Mean overall workload scores across levels of mental workload.

Although increases in level of mental workload and terrain difficulty were found to influence an increase in overall workload scores, as hypothesized, the ANOVA also revealed a significant interaction between the two factors (F (2, 55) = 3.78, $p = .03$). This interaction suggests that terrain difficulty had different effects on overall workload scores at the two extremes in mental workload (see Figure 9).

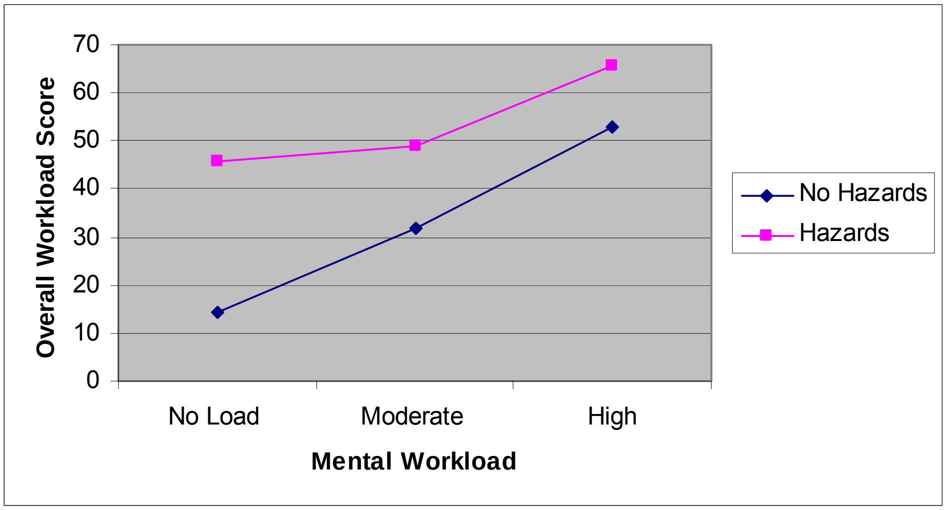

Figure 9. Interaction between terrain difficulty and mental workload on overall workload scores.

4.1.2 Subscale Ratings of Workload

A MANOVA was performed on subjective ratings of workload obtained on the six subscales of the NASA-TLX. The results of this analysis indicated significant main effects of mental workload (Wilks' λ (.294; F (12, 100) = 7.038; $p < .001$) and terrain difficulty (Wilks' λ (.372; F (6, 50) = 14.045; $p < .001$).

ANOVAs indicated significant main effects of mental workload on each of the six subscales of the NASA-TLX: mental demand (F (2, 55) = 32.906, $p < .001$), effort (F (2, 55) = 8.990, $p < .001$), performance (F (2, 55) = 9.862, $p < .001$), frustration (F (2, 55) = 7.075, $p = .002$), temporal demand (F (2, 55) = 4.094, $p = .02$), and physical demand (F (2, 55) = 6.199, $p = .004$). The mean and standard deviation of the ratings on these subscales at each level of mental workload across the two levels of terrain difficulty are provided in Appendix C (see Table C2) and shown in Figures 10 through 15.

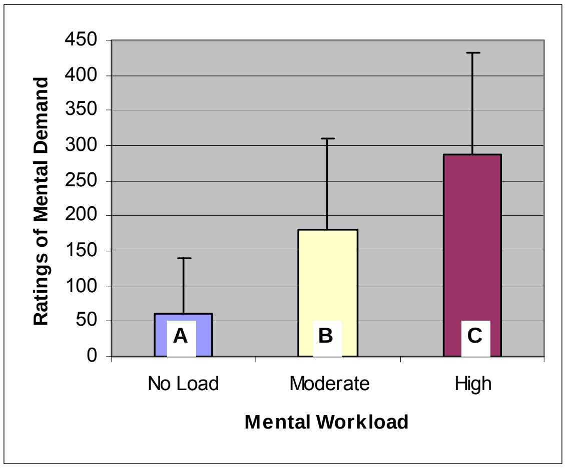

Figure 10. Mean ratings of mental demand across levels of terrain difficulty.

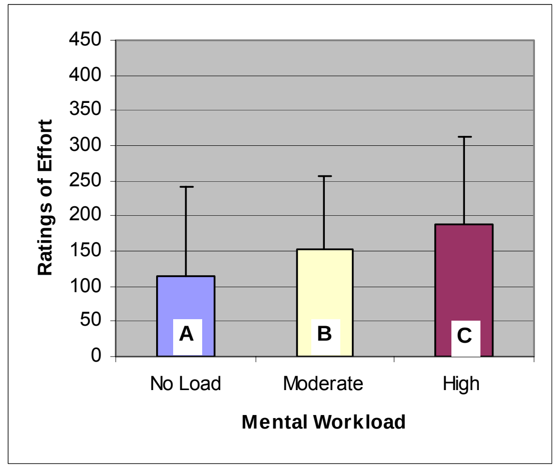

Figure 11. Mean ratings of effort across levels of terrain difficulty.

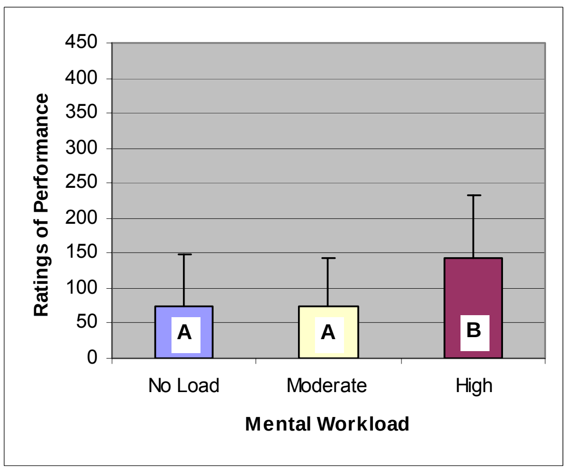

Figure 12. Mean ratings of performance across levels of terrain difficulty.

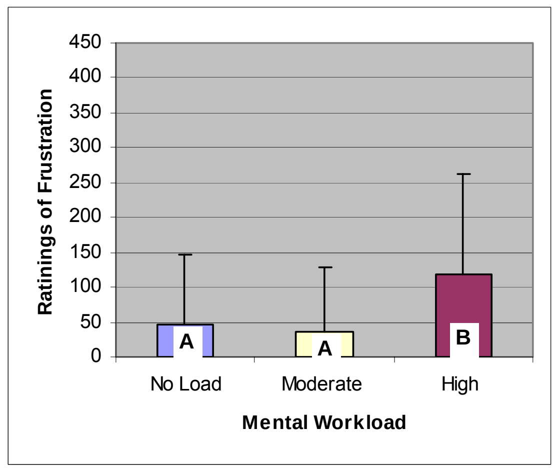

Figure 13. Mean ratings of frustration across levels of terrain difficulty.

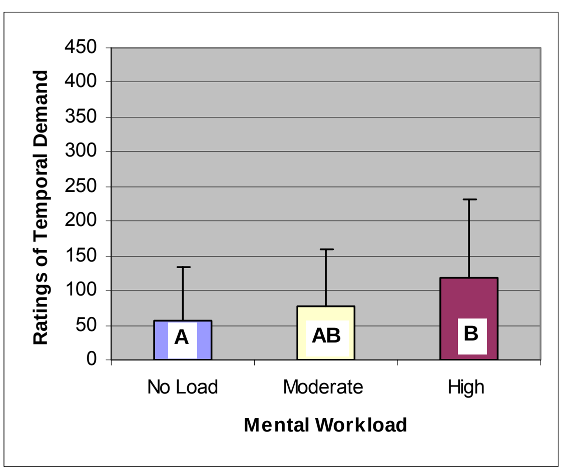

Figure 14. Mean ratings of temporal demand across levels of terrain difficulty.

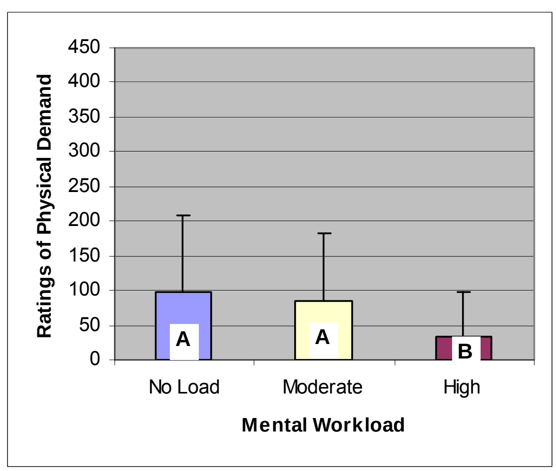

Figure 15. Mean ratings of physical demand across levels of terrain difficulty.

With the exception of ratings on physical demand, ratings of workload generally increased with increases in level of mental workload. As shown in Table 4, post hoc comparisons indicated that mental demand and effort increased significantly from the "No Load" to the "Moderate" and from the "Moderate" to the "High" level of mental load. Subscale ratings of performance and frustration were significantly higher at the "High" level of mental workload than they were at either the "No Load" or the "Moderate" levels; but no significant difference was found between the latter two levels on either of these workload dimensions. The only significant increase in ratings of temporal demand occurred between the "No Load" and the "High" level of mental workload. Increases in mental workload had a different affect on subscale ratings of physical demand. Ratings of physical demand were significantly lower at the "High" level of mental workload than at the "No Load" and the "Moderate" levels, but no significant difference was found between ratings at the "No Load" and the "Moderate" levels of load.

Table 4. Mean Differences Between Levels of Mental Workload in Subscale Ratings of Workload.

Workload Factor	**Mental Workload**	Moderate	High
Mental	No Load	**118.96 (*p* <.001)**	**226.46 (*p* < .001)**
	Moderate		**107.5 (*p* < .001)**
Effort	No Load	**38.75 (*p* =.03)**	**74.38 (*p* < .001)**
	Moderate		**35.63 (*p* = .05)**
Performance	No Load	.00 (*p* =1.00)	**69.58 (*p* < .001)**
	Moderate		**69.58 (*p* < .001)**
Frustration	No Load	-8.33 (*p* = .73)	**73.96 (*p* = .003)**
	Moderate		**82.29 (*p* = .001)**
Temporal	No Load	20.42 (*p* = .34)	**59.58 (*p*= .007)**
	Moderate		39.17 (*p* = .07)
Physical	No Load	-13.13 (*p* =.51)	**-65.42 (*p* =.002)**
	Moderate		**-52.29 (*p* =.01)**

The means and standard deviations of ratings on the six subscales at each level of terrain difficulty across the three levels of mental workload are provided in Appendix C (see Table C3). The results of ANOVAs indicated a significant main effect of terrain difficulty on ratings of physical demand (F (1, 55) = 13.845, p < .001), effort (F (1, 55) = 67.752, p < .001), and performance (F (1, 55) = 11.267, p = .001). As shown in Figures 16 through 18, ratings on each of these subscales were higher at the "Hazards" level of terrain difficulty than at the "No Hazards" level. No significant differences were found between levels of terrain difficulty on subjective ratings of mental demand (F (1, 55) = 2.155; p = .15), temporal demand (F (1, 55) = .125; p = .73), or frustration (F (1, 55) = 3.664; p = .06).

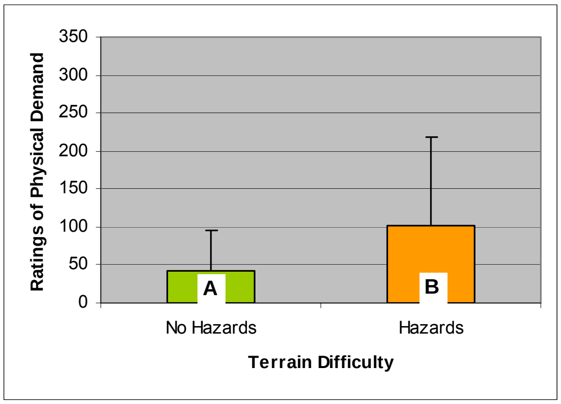

Figure 16. Mean ratings of physical demand across levels of mental workload.

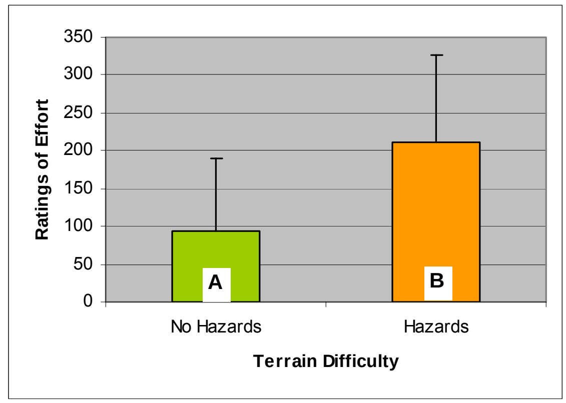

Figure 17. Mean ratings of effort across levels of mental workload.

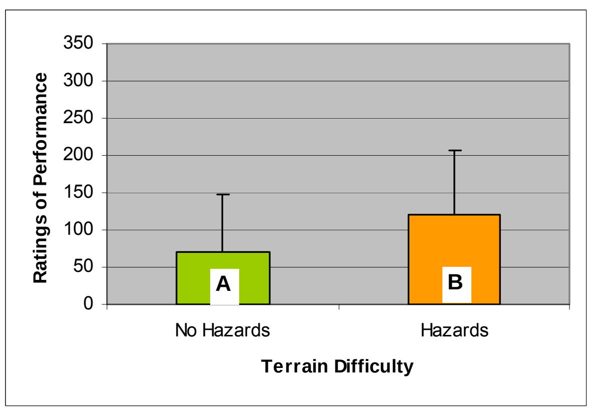

Figure 18. Mean ratings of performance across levels of mental workload.

The analysis also revealed a significant interaction between mental workload and terrain difficulty on ratings of performance (F (2, 55) = 5.430, p = .007). The interaction depicted in Figure 19 suggests that level of terrain difficulty had different effects on the participants' perceptions of how well they performed at the extremes of mental workload which may have influenced the similar interaction that was found in the analysis of overall workload scores.

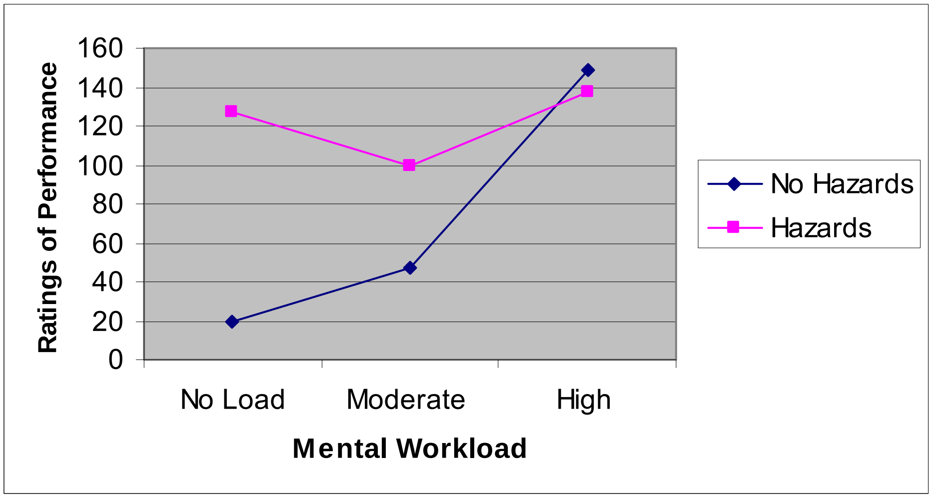

Figure 19. Interaction of mental workload and terrain difficulty on subjective ratings of performance.

4.2 Mental Arithmetic

4.2.1 Time to Respond and the Number of Correct Responses

It had been hypothesized that as the difficulty of the cognitive task and mental workload increased from the "Moderate" to the "High" level by increasing the difficulty of the problems presented, response time and error in the performance of the cognitive task would also increase. To test this hypothesis, a MANOVA was performed to assess the effects of mental workload and terrain difficulty on time to respond to the arithmetic problems and the number of correct responses. Separate ANOVAs were performed where main effects were indicated, and the LSD method was used in post hoc comparisons.

The mean times to respond and the number of correct responses at the "Moderate" and "High" levels of mental workload for each level of terrain difficulty are provided in Appendix C (see Tables C4 and C5). A MANOVA revealed a significant main effect of mental workload (Wilks' λ (.165; F (2, 32) = 81.164; $p < .001$). The results of the ANOVAs indicated main effects of mental workload on both time to respond (F (1, 33) = 159.865, $p < .001$) and the number of correct responses (F (1, 33) = 118.882, $p < .001$). As shown in Figure 20, mean time to respond to the arithmetic problems increased from 1.6 seconds at the "Moderate" level of mental workload to 5.4 seconds at the "High" level of load (Mean Difference = 3.8, $p < .001$). As shown in Figure 21, the number of correct responses decreased from 29 at the "Moderate" level of mental workload to approximately 20 at the "High" level (Mean Difference = 9, $p < .001$).

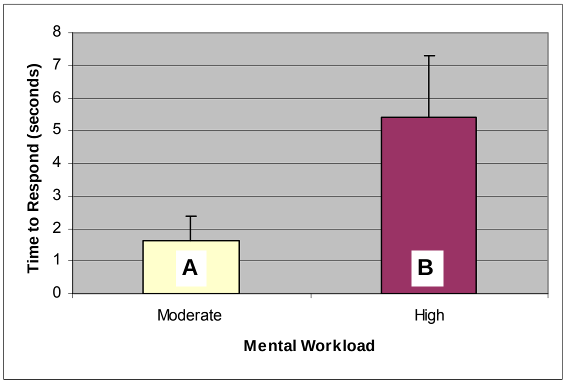

Figure 20. Mean time to respond to arithmetic problems across levels of terrain difficulty.

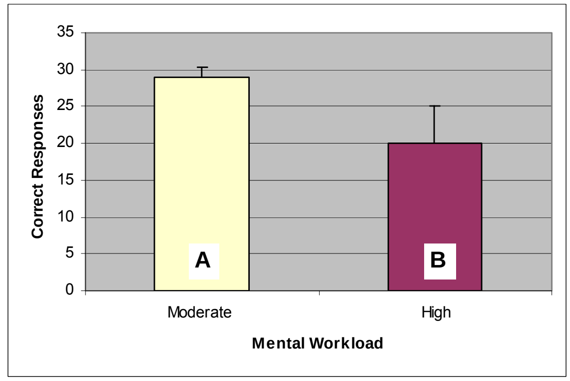

Figure 21. Mean number of correct responses across levels of terrain difficulty.

The results of the MANOVA failed to show a main effect of terrain difficulty at the .05 criterion for significance (Wilks' λ (.834; *F* (2, 32) = 3.184; *p* = .06). However, when scores on the AFQT and subtests of the ASVAB related to arithmetic skills (i.e., AR and MK) were included as covariates in ANCOVAs on time to respond and the number of correct responses to the arithmetic problems, the analysis revealed a significant effect of terrain difficulty on the latter measure (*F* (1, 24) = 6.152, *p* = .02). Pairwise comparisons indicated that the mean number of correct responses decreased from 25 at the "No Hazards" level of terrain difficulty to 23 at the "Hazards" level (Mean Difference = 2, *p* = .02). No significant effect of terrain difficulty was revealed by the ANCOVA on time to respond (*F* (1, 24) = 1.592, *p* = .22). These findings indicate that terrain difficulty had a significant effect on the number of correct responses to the arithmetic problems when mean performance on this measure was adjusted based on scores on tests of arithmetic skills. They suggest that the number of correct responses to the problems may have been influenced by the arithmetic ability of the participants when they were required to perform the mental arithmetic and hazard avoidance tasks concurrently.

4.2.2 Correlations Between Mental Arithmetic Performance and Subjective Ratings of Workload

Bivariate analyses (Pearsons Correlation Coefficient) were performed to determine if there were any relationships between mental arithmetic performance and subjective ratings of workload at the "Moderate" and "High" levels of mental workload at each level of terrain difficulty.

At the "No Hazards" level of terrain difficulty, the results of the analyses indicated a significant relationship between mental demand and time to respond to the arithmetic problems at the "High" level of mental workload ($r = .645$, $p = .02$). A correlation was also found between mental demand and the number of correct responses ($r = -.735$, $p = .006$). These findings indicate that as ratings of mental demand increased at the "High" level of mental workload, the time to respond to the arithmetic problems increased and the number of correct responses decreased. Correlations were also found between overall workload scores at the "High" level of mental workload and both time to respond to the arithmetic problems ($r = .657$, $p = .02$) and the number of correct responses ($r = -.646$, $p = .02$). As for the correlations found between mental demand and mental arithmetic performance, these findings indicate that as overall workload scores increased at the "High" level of mental workload, the time to respond to the arithmetic problems increased and the number of correct responses decreased.

At the "Hazards" level of terrain difficulty, a correlation was found between the number of correct responses to the arithmetic problems at the "Moderate" level of mental workload and ratings of physical demand ($r = -.681$, $p = .02$), temporal demand ($r = -.678$, $p = .02$), effort ($r = -.638$, $p = .03$), and overall workload scores ($r = -.693$, $p = .01$). These findings indicate that ratings of physical demand, temporal demand, effort, and overall workload scores tended to increase as the number of correct responses to the arithmetic problems at the "Moderate" level of mental workload decreased. A relationship was also found between temporal demand and the time to respond to the arithmetic problems at the "High" level of mental workload ($r = .645$, $p = .02$). This finding indicates that ratings of temporal demand tended to increase as the time to respond to the arithmetic problems at the "High" level of mental workload increased.

4.2.3 Correlations Between Mental Arithmetic Performance and Scores on ASVAB Subtests and the AFQT.

Bivariate analyses were performed to determine if there were any relationships between performance of the mental arithmetic task and scores on the AFQT and subtests of the ASVAB that were related to arithmetic skills (i.e., AR and MK). The results of the analyses did not reveal any significant correlations between test scores and time and error in responding to the easier arithmetic problems presented at the "Moderate" level of mental workload. However, as shown in Table 5, significant relationships were found at both levels of terrain difficulty between subtest scores on the AR and time and error in responding to the more difficult problems presented at the "High" level of mental workload. These findings indicate that time and error in responding to the arithmetic problems at the "High" level of mental workload tended to decrease as scores on the AR subtest of the ASVAB increased. Similar relationships were found between AFQT scores and time and error in performing the mental arithmetic task at the "High" level of mental workload but only at the "No Hazards" level of terrain difficulty. The relationship found between subtest scores on the MK and the number of correct responses to the arithmetic problems was also limited to the "No Hazards" level. These findings imply that subtest scores on the AR may be a better predictor of performance on the mental arithmetic task than subtest scores on the MK or scores on the AFQT.

Table 5. Correlations Between Mental Arithmetic Performance and Scores on ASVAB Subtests and the AFQT at the "High" Level of Mental Workload (N = 11)

	No Hazards		Hazards	
ASVAB Scores	Time to Respond	Number Correct	Time to Respond	Number Correct
Arithmetic Reasoning	**-.669, *p* = .02**	**.674, *p* = .02**	**-.715, *p* = .01**	**.743, *p* = .01**
Mathematics Knowledge	-.521, *p* = .10	**.699, *p* = .02**	-.440, *p* = .18	.563, *p* = .07
AFQT Score	**-.695, *p* = .02**	**.691, *p* = .02**	-.585, *p* = .06	.552, *p* = .08

4.2.4 Correlations Between Subjective Ratings of Workload and Scores on ASVAB Subtests and the AFQT

Bivariate analyses were performed to determine if there were any relationships between measures of subjective workload and scores on subtests of the ASVAB and the AFQT for each level of mental workload at the "No Hazards" and "Hazards" levels of terrain difficulty. The results of these analyses indicated significant correlations for all workload measures except for ratings of performance at the "No Hazards" level of terrain difficulty (see Table 6), and ratings of both performance and frustration at the "Hazards" level (see Table 7). Except for correlations found between test scores and ratings of frustration at the "No Hazards" level of terrain difficulty, these relationships indicated that the higher the test scores the lower the ratings of workload. The relationships found between test scores and ratings of frustration at the "No Hazards" level of terrain difficulty suggest that the higher the test scores, the higher the levels of frustration at the "No Load" and "Moderate" levels of mental load. This latter finding may suggest that those with higher test scores may not have been sufficiently challenged at the lower levels of mental load.

Table 6. Correlations Between Scores on ASVAB Subtests and the AFQT and Subjective Ratings of Workload at the "No Hazards" Level of Terrain Difficulty (N = 11)

		ASVAB Subtests			AFQT
Terrain Difficulty	**Workload Factor***	Mental Workload	Arithmetic Reasoning	Mathematics Knowledge	
No Hazards	Mental	No Load	-.166, *p* = .63	-.577, *p* = .06	-.303, *p* = .37
		Moderate	**-.628, *p* = .04**	-.395, *p* = .23	-.544, *p* = .08
		High	-.575, *p* = .06	-.529, *p* = .10	**-.668, *p* = .03**
	Physical	No Load	**-.600, *p* = .05**	-.302, *p* = .37	-.448, *p* = .17
		Moderate	-.139, *p* = .68	-.074, *p* = .83	-.102, *p* = .77
		High	-.433, *p* = .18	-.262, *p* = .44	-.312, *p* = .35
	Temporal	No Load	-.245, *p* = .47	-.495, *p* = .12	-.429, *p* = .19
		Moderate	**-.813, *p* = .002**	**-.713, *p* = .01**	**-.815, *p* = .002**
		High	-.471, *p* = .14	**-.725, *p* = .01**	**-.614, *p* = .05**
	Effort	No Load	-.308, *p* = .36	-.424, *p* = .19	-.330, *p* = .32
		Moderate	-.382, *p* = .25	-.293, *p* = .38	-.381, *p* = .25
		High	-.555, *p* = .08	**-.624, *p* = .04**	-.585, *p* = .06
	Frustration	No Load	**.676, *p* = .02**	**.766, *p* = .006**	**.805, *p* = .003**
		Moderate	**.639, *p* = .03**	**.648, *p* = .03**	.516, *p* = .10
		High	-.337, *p* = .31	.094, *p* = .78	-.275, *p* = .41
	Overall	No Load	-.430, *p* = .19	-.551, *p* = .08	-.487, *p* = .13
		Moderate	**-.658, *p* = .03**	-.547, *p* = .08	**-.655, *p* = .03**
		High	**-.650, *p* = .03**	-.570, *p* = .07	**-.739, *p* = .009**

* No significant correlations between test scores and ratings of performance.

Table 7. Correlations Between Scores on ASVAB Subtests and the AFQT and Subjective Ratings of Workload at the “Hazards” Level of Terrain Difficulty (N = 11)

		ASVAB Subtests			AFQT
Terrain Difficulty	**Workload Factor***	Mental Workload	Arithmetic Reasoning	Mathematics Knowledge	
Hazards	Mental	No Load	**-.666, *p* = .03**	-.400, *p* = .22	**-.676, *p* = .02**
		Moderate	-.346, *p* = .30	-.288, *p* = .39	-.484, *p* = .13
		High	-.433, *p* = .18	-.502, *p* = .12	-.523, *p* = .10
	Physical	No Load	**-.755, *p* = .007**	-.470, *p* = .15	-.544, *p* = .08
		Moderate	**-.593, *p* = .05**	-.590, *p* = .06	-.567, *p* = .07
		High	-.562, *p* = .07	**-.681, *p* = .02**	**-.652, *p* = .03**
	Temporal	No Load	-.510, *p* = .11	**-.744, *p* = .009**	**-.611, *p* = .05**
		Moderate	**-.765, *p* = .006**	-.548, *p* = .08	**-.601, *p* = .05**
		High	**-.856, *p* = .001**	-.382, *p* = .25	**-.629, *p* = .04**
	Effort	No Load	-.369, *p* = .26	-.463, *p* = .15	-.400, *p* = .22
		Moderate	-.394, *p* = .23	-.486, *p* = .13	-.501, *p* = .12
		High	-.275, *p* = .41	**-.664, *p* = .03**	-.483, *p* = .13
	Overall	No Load	**-.614, *p* = .04**	**-.606, *p* = .05**	**-.630, *p* = .04**
		Moderate	-.578, *p* = .06	**-.620, *p* = .04**	**-.625, *p* = .04**
		High	**-.776, *p* = .005**	**-.775, *p* = .005**	**-.830, *p* = .002**

* No significant correlations between test scores and ratings of performance or ratings of frustration.

4.3 Gait Parameters

4.3.1 Step Length and Step Rate

It had also been hypothesized that increases in mental workload would cause changes in gait parameters, including greater variability in step length and step rate. To test this hypothesis, the means and standard deviations in step length and step rate were subjected to a MANOVA. Separate ANOVAs were performed where main effects were indicated, and the LSD method was used in post hoc comparisons.

Figures 22 and 23 show the means and standard deviations in step length and step rate at each level of mental workload across the two levels of terrain difficulty. Figure 24 and 25 show the means and standard deviations in step length and step rate at each level of terrain difficulty across the three levels of mental workload. These data are also provided in Appendix C (see Tables C6 and C7).

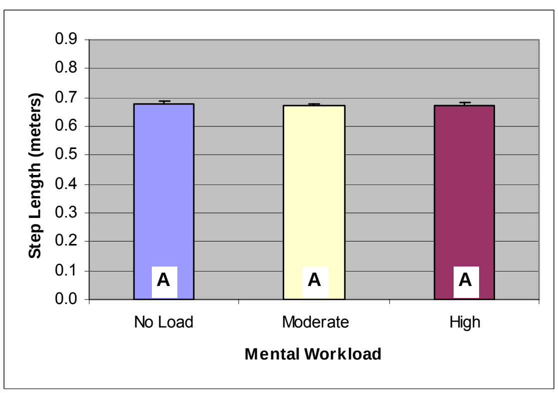

Figure 22. Mean step length across levels of terrain difficulty.

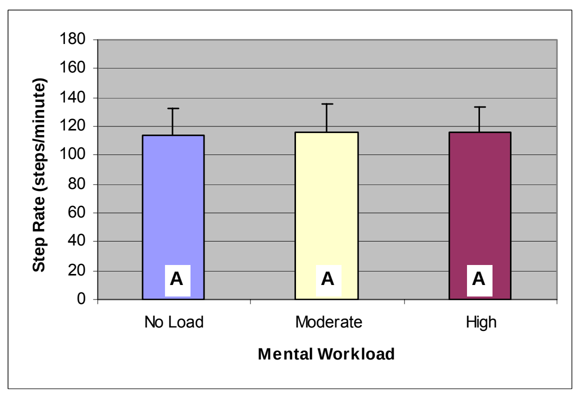

Figure 23. Mean step rate across levels of terrain difficulty.

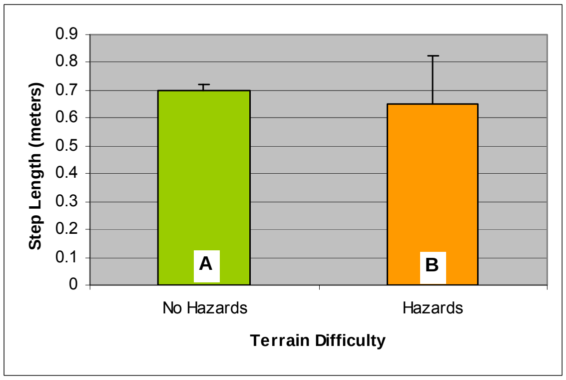

Figure 24. Mean step length across levels mental workload.

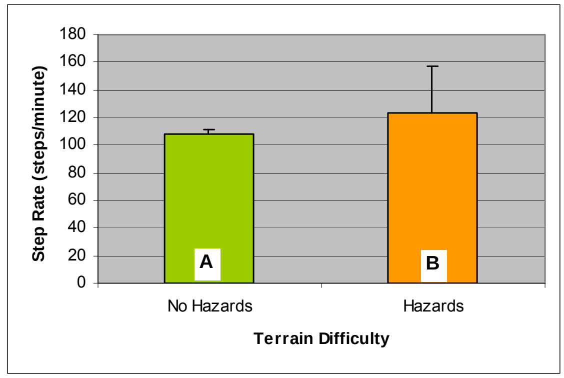

Figure 25. Mean step rate across levels of mental workload.

The results of the MANOVA did not reveal a significant effect of mental workload on the means or the standard deviations of step length or step rate (Wilks' λ (.952; *F* (8, 104) = .325; *p* = .96). However, as might be expected, the analysis did indicate a main effect of terrain difficulty (Wilks' λ (.030; *F* (4, 52) = 427.459; *p* < .001). The results of the ANOVAs that were performed on the means and standard deviations in both step length and step rate indicated that mean step length decreased significantly from .70 meters at the "No Hazards" level of terrain difficulty to .65 meters at the "Hazards" level (*F* (1, 55) = 29.876, *p* < .001). The variability in step length increased from .02 meters at the "No Hazards" level of terrain difficulty to .18 meters at the "Hazards" level (*F* (1, 55) = 1399.643, *p* < .001). The results of the analyses of mean step rate indicated that this measure of gait increased from approximately 107 steps/minute at the "No Hazards" level of terrain difficulty to 124 steps/minute at the "Hazards" level (*F* (1, 55) = 57.151, *p* < .001). The variability in step rate increased from approximately 4 steps/minute at the "No Hazards" level of terrain difficulty to 34 steps/minute at the "Hazards" level (*F* (1, 55) = 147.265, *p* < .001).

4.3.2 Correlations Between Measures of Gait and Subjective Ratings of Workload.

Bivariate analyses were performed to determine if there were any relationships between measures of gait and subjective ratings of workload at each level of mental workload and level of terrain difficulty. At the "No Hazards" level of terrain difficulty, negative correlations were found between mental demand and mean step rate at the "No Load" level of mental workload (r = -.819, p = .001). This finding indicates that when the participant's only task was to walk at a natural gait, ratings of mental demand tended to increase as mean step rate decreased, possibly suggesting some mental involvement in correcting for decreases in step rate to maintain walking speed and position on the treadmill.

At the "Moderate" level of mental workload, the participants perceived an improvement in their performance as mean step rate increased (r = -.819, p = .001). As the variability in step rate increased, frustration levels tended to decrease (r = -.819, p = .001). These latter findings may suggest that the easier arithmetic problems presented at the "Moderate" level of mental workload may have facilitated walking performance and reduced frustration levels by increasing arousal levels.

Correlations were found between subjective ratings of workload and measures of gait at the "Hazards" level of terrain difficulty (see Table 8). These relationships indicate that the participants' ratings of effort tended to increase as mean step rate and the variability in step rate and step length increased at the "No Load" level of mental workload. Ratings of workload attributable to a perceived decline in performance also increased with increases in the variability in step rate and step length. At the "Moderate" level of mental workload, ratings of effort tended to increase as the mean and variability in step rate increased, as at the "No Load" level of mental load. Ratings of physical demand also tended to increase as the variability in step rate increased. At the "High" level of mental load, ratings of physical demand and overall workload scores increased as mean step rate increased. Ratings of mental demand, physical demand, effort, and overall workload scores also tended to increase with increases in the variability in step length and step rate. Generally, these correlations may reflect increases in perceived workload that were associated with the struggle to avoid hazards. However, the increase in the number of relationships found between subscale ratings of workload and measures of gait at the "High" level of mental workload, may suggest some degree of conflict between the mental arithmetic and hazard avoidance tasks.

Table 8. Correlations Between Subjective Ratings of Workload and Gait at the "Hazards" Level of Terrain Difficulty.

	No Load				Moderate				High			
	Step Length		**Step Rate**		**Step Length**		**Step Rate**		**Step Length**		**Step Rate**	
Workload Factor*	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Mental	*r* = -.197 *p* =.54	*r* = -.209 *p* =.52	*r* =.101 *p* =.75	*r* = -.208 *p* =.52	*r* = .170 *p* =.60	*r* = -.205 *p* =.52	*r* = -.247 *p* =.44	*r* = -319 *p* =.31	*r* = -.431 *p* =.16	***r* =.827** ***p* =.001**	*r* =.537 *p* =.07	***r* =.627** ***p* =.03**
Physical	*r* =.172 *p* =.59	*r* =.449 *p* =.14	*r* =.132 *p* =.68	*r* =.356 *p* =.26	*r* = -.220 *p* =.49	*r* =.008 *p* =.98	*r* =.339 *p* =.28	***r* =.705** ***p* =.01**	*r* = -.534 *p* =.07	***r* =.568** ***p* =.05**	***r* =.700** ***p* =.01**	***r* =.855** ***p* <.001**
Effort	*r* = -.341 *p* =.28	***r* =.695** ***p* =.01**	***r* =.594** ***p* =.04**	***r* =.816** ***p* =.001**	*r* = -.481 *p* =.11	*r* =.247 *p* =.39	***r* =.617** ***p* =.03**	***r* =.722** ***p* =.008**	*r* = -.447 *p* =.15	*r* =.483 *p* =.11	*r* =.514 *p* =.09	***r* =.655** ***p* =.02**
Performance	*r* =.052 *p* =.87	***r* =.672** ***p* =.02**	*r* =.144 *p* =.66	***r* =.690** ***p* =.01**	*r* =.013 *p* =.97	*r* =.419 *p* =.18	*r* =.001 *p* =.10	*r* =.000 *p* =.10	*r* =.093 *p* =.77	*r* = -.339 *p* =.28	*r* = -.150 *p* =.64	*r* = -.271 *p* =.39
Overall	*r* = -.239 *p* =.45	*r* =.426 *p* =.17	*r* =.408 *p* =.19	*r* =.510 *p* =.09	*r* = -.208 *p* =.52	*r* =.085 *p* =.79	*r* =.286 *p* =.37	*r* =..460 *p* =.13	***r* = -.600** ***p* =.04**	***r* =.582** ***p* =.05**	***r* =.636** ***p* =.03**	***r* =.663** ***p* =.02**

* No significant correlations were found between gait and subjective ratings of temporal demand or frustration.

4.3.3 Correlations Between Measures of Gait and Mental Arithmetic Performance

Bivariate analyses were performed to determine if there were any relationships between measures of gait and performance of the mental arithmetic task. No correlations were found between gait and arithmetic performance at the "No Hazards" level of terrain difficulty. However, when the participants were required to avoid hazards while performing the mental arithmetic task at the "Moderate" level of mental workload, the variability in step length tended to decrease as time to respond to the arithmetic problems increased ($r = -.662$, $p = .02$). This finding may suggest that the more time participants took in responding to the arithmetic problems, the less likely they were to make the alterations in step length needed to avoid the irregularly spaced hazards. No relationships were found between the variability in step length and time or error in responding to the more difficult problems at the "High" level of mental workload ($r = -.536$, $p = .07$).

4.4 Hazard Avoidance

4.4.1 Number of Hazards Contacted

The primary hypothesis in this investigation was that as the difficulty of the cognitive task and mental workload increased, performance of the hazard avoidance task would be degraded as measured by the number of hazards contacted. To test this hypothesis, an ANOVA was performed on the number of ground hazards contacted by 0.5 inches or more of either of the participants' boots. A second ANOVA was performed on the number of hazards contacted by a minimum of one half of either of the participant's boots. The mean number of hazards contacted at each level of mental workload by hazard contact criterion is provided in Appendix C (see Table C8) along with a breakdown of these data by participant. The scores of the participants on the AFQT and ASVAB subtests (i.e., AR and MK) are also included.

The mean number of ground hazards contacted by 0.5 inches or more of the participant's boots at each level of mental workload is shown in Figure 26. The results of the ANOVA did not reveal a significant main effect of mental workload on the number of hazards contacted (F (2, 22) = .586, p = .57).

The mean number of hazards contacted by half or more of the participant's boots at each level of mental workload is shown in Figure 27. Here too, the ANOVA did not reveal a significant effect of mental workload (F (2, 22) = .952, p = .40).

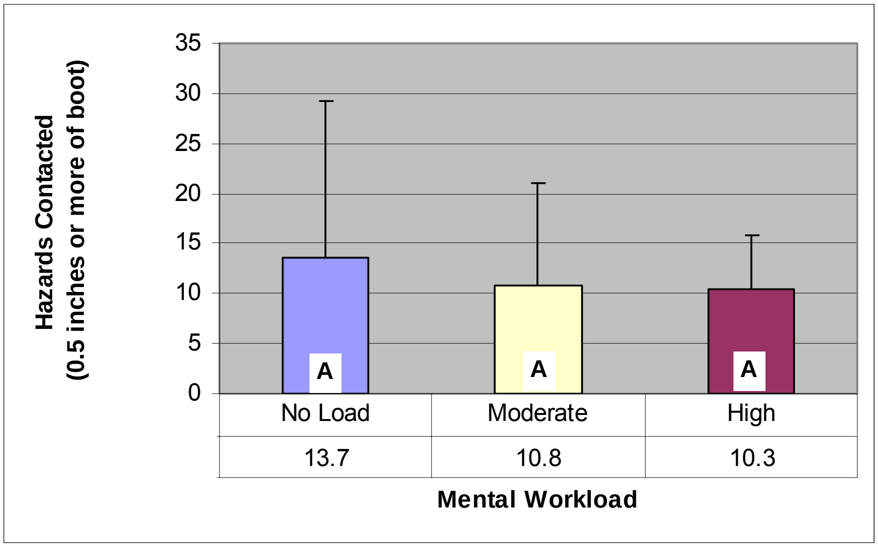

Figure 26. Mean number of hazards contacted by 0.5 inches or more of either of the participant's boots at each level of mental workload.

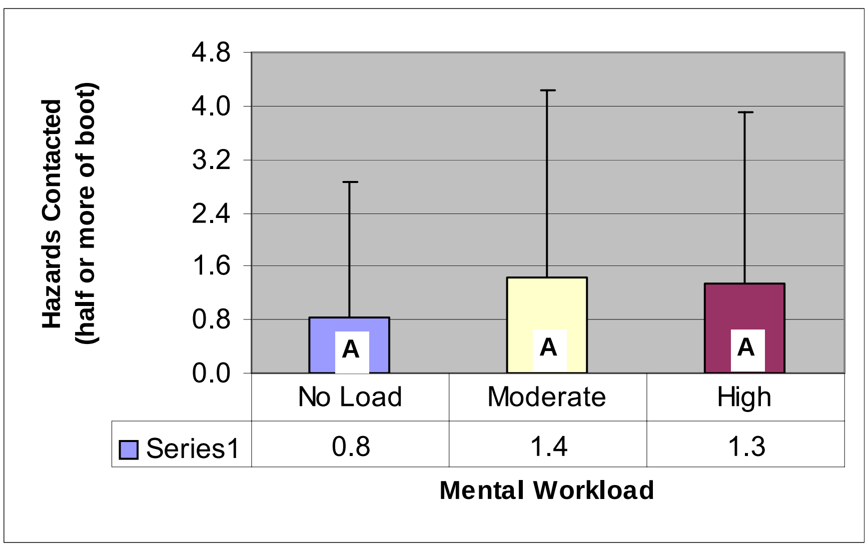

Figure 27. Mean number of hazards contacted by a minimum of one-half of either of the participant's boots at each level of mental workload.

4.4.2 Correlations Between the Number of Hazards Contacted and Subjective Ratings of Workload.

Bivariate analyses were performed to determine if there were any relationships between the number of hazards contacted by 0.5 inches or more of the participants' boots and subjective ratings of workload at each of the three levels of mental workload. The results of the analysis indicated a significant correlation between the number of hazards contacted at the "Moderate" level of mental workload and subjective ratings of effort (r = .635, p = .03) and overall workload scores (r = .681, p = .02). These findings indicate that as the number of hazards contacted by the tip or more of the participants' boots increased at the "Moderate" level of mental load, ratings of effort expended and overall workload scores also tended to increase. No correlations were found between subjective ratings of workload and the number of hazards contacted at the either the "Low" or the "High" levels of mental workload. Bivariate analyses were also performed to determine if there were any relationships between the subjective ratings of workload and number of hazards contacted by a minimum of one-half of either of the participants' boots. The results of this analysis indicated a significant correlation between the number of hazards contacted at the "Moderate" level of mental workload and subjective ratings of performance (r = .811, p = .001). This finding indicates that as the number of hazards contacted by half or more of either boot increased at the "Moderate" level of mental load, the participants perceived a decline in their performance. Here too, no correlations were found between the number of hazards contacted at either the "Low" or the "High" levels of mental workload and perceptions of workload.

4.4.3 Correlations Between the Number of Hazards Contacted and Mental Arithmetic Performance.

Bivariate analyses were performed to determine if there were any relationships between the number of hazards contacted and performance of the mental arithmetic task at the "Moderate" and "High" levels of mental workload. The results of the analyses revealed a significant correlation between the number of hazards contacted by 0.5 inches or more of the participants' boots at the "Moderate" level of load and the number of correct responses to the arithmetic problems (r = -.780, p = .003). A similar relationship was found for hazards contacted by half or more of the participants' boots (r = -.700, p = .01). These findings indicate that as the number of correct responses to the arithmetic problems increased, the number of hazards contacted at the "Moderate" level of mental workload tended to decrease. As with correlations found between mental arithmetic performance and the variability in step length, these findings might suggest that the easier the arithmetic problems were to solve, the less likely they were to interfere with performance of the hazard avoidance task. No correlations were found between the number of hazards contacted and performance of the mental arithmetic task at the "High" level of mental load.

4.4.4 Correlations Between the Number of Hazards Contacted and Gait

Bivariate analyses were performed to determine if there were any relationships between the number of hazards contacted and measures of gait at each level of mental workload. No significant relationships were found between hazards contacted and gait at the "No Load" or the "High" level of mental workload. However, correlations were found at the "Moderate" level of mental workload between the number of hazards contacted by 0.5 inches or more of the participants' boots and the variability in both step length (r = .627, p = .03) and step rate (r = .796, p = .002). A correlation was also found between the number of hazards contacted by a minimum of half the boot and the variability in step rate (r = .670, p = .02), but no relationship was found for the variability in step length (r = .432, p = .16). The increases in the variability in gait with increases in the number of hazards contacted support the observation that incidents of hazard contact were often followed by a spasm of corrective maneuvers.

4.4.5 Correlations Between the Number of Hazards Contacted and Scores on ASVAB Subtests and the AFQT

Bivariate analyses were performed to determine if there were any relationships between the number of hazards contacted at each level of mental workload and scores on ASVAB subtests and the AFQT. The analyses did not reveal any significant relationships for either criteria of hazard contact at any of the three levels of mental workload.

4.4.6 Exploratory Analyses

The variability among participants in the number of hazards contacted at each level of mental workload was high. Some participants appeared to contact more hazards at the "No Load" level of mental workload than at the "Moderate" or the "High" levels, while others appeared to contact more hazards at the "Moderate" level than at either of the other two levels. There were also participants who tended to contact more hazards at the "High" level of mental workload than at the "No Load" or the "Moderate" levels, as expected.

Table 9 shows the number of hazards contacted by participant at each level of mental workload by 0.5 inches or more of the boot, the percent difference between the two highest counts of hazard contact for each participant, and the grouping of participants based on the level of mental workload at which they contacted the most hazards. The mean number of hazards contacted by each participant group at each level of mental workload is illustrated in Figure 28.

Table 9. Participant Grouping Based on Level of Workload and Hazards Contacted.

Group	Hazards Contacted* No Load	Moderate	High	Percent Difference**
1	(4)	(1)	1	300
	(57)	(35)	20	63
	(24)	5	(10)	140
	(23)	6	(9)	156
2	(12)	(23)	4	92
	1	(16)	(5)	220
	(13)	(17)	13	31
3	1	(1)	(7)	600
	(10)	8	(12)	20
	(8)	4	(11)	38
	(6)	5	(16)	167
	5	(8)	(16)	100

* Tip (0.5 inch) or more of the toe or heel of the boot.
** Percent of difference between the two higher counts hazard contact.

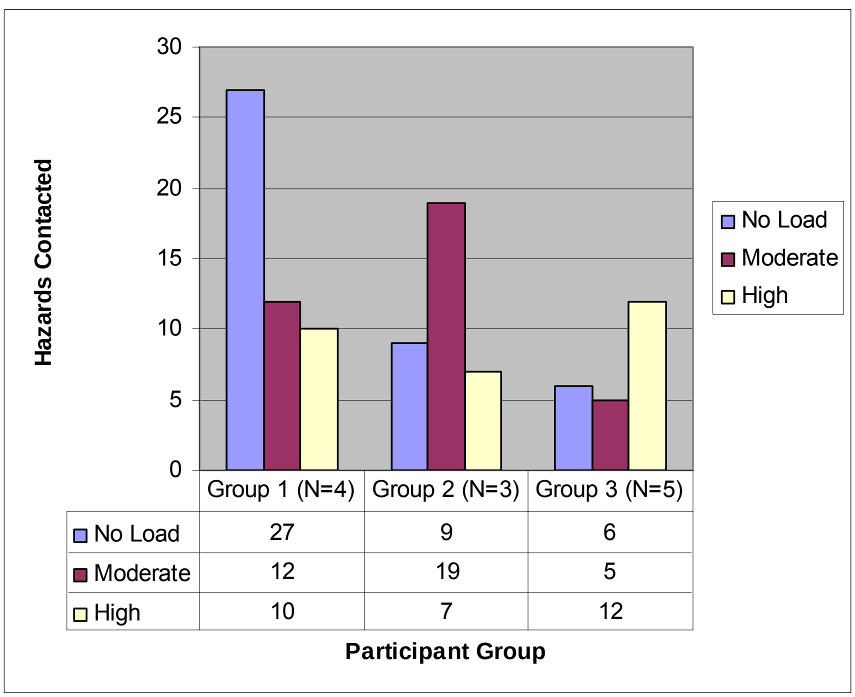

Figure 28. Mean number of hazards contacted by participant group at each level of mental workload.

A repeated measures MANOVA was performed to determine if there were any significant differences between participant groups in the number of hazards contacted by 0.5 inches or more of the participants' boots. The analysis was a mixed, two-factor design with level of mental workload as a within-subject factor and participant group as a between-subject factor. The analysis did not reveal a main effect of mental workload (Wilks' λ (.742; F (4, 6) = .523; p = .72) or group (Wilks' λ (.727; F (4, 16) = .691; p = .61); however, a significant interaction was found between group and level of mental workload (Wilks' λ (.038; F (8, 12) = 6.171; p = .003).

The mean scores on subtests of the ASVAB (i.e., AR and MK) and the AFQT of participants in each of the three groups are illustrated in Figure 29. A MANOVA was performed to determine if there were any significant differences between the test scores of the participant groups. The scores of one participant in Group 1 were not available for this analysis. The results of the MANOVA indicated a significant difference in test scores between groups (Wilks' λ (.146; F (6, 12) = 3.238; p = .04). As shown in Table 10, post hoc analyses revealed that the participants in Group 1 scored higher on the AR, MK, and the AFQT than the participants in Group 2 and 3, but no significant differences were found between the test scores of participants in the latter two groups.

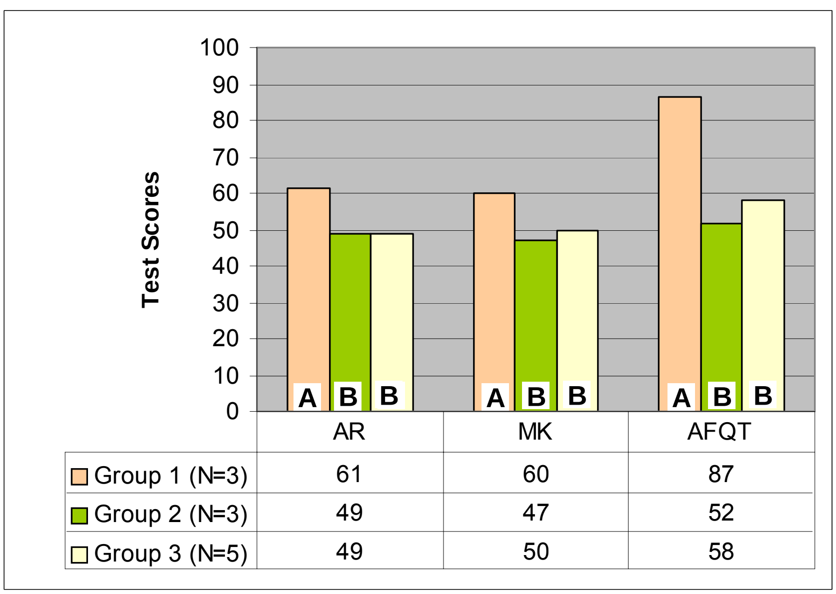

Figure 29. Participant grouping and scores on subtests of the ASVAB and the AFQT (N = 11).

Table 10. Mean Differences in Scores on the AR, MK, and AFQT Between Groups.

Test	**Group**	2	3
AR	1	**12.33** ***p* = .04**	**12.13** ***p* = .03**
	2		-.200 *p* = .97
MK	1	**13.00** ***p* = .02**	**9.80** ***p* = .04**
	2		-3.20 *p* = .45
AFQT	1	**35.00** ***p* = .001**	**28.87** ***p* = .002**
	2		-6.13 *p* = .38

CHAPTER 5

DISCUSSION

The primary purpose of this research was to test the hypothesis that the ability of soldiers to avoid ground hazards would be degraded by increases in mental workload. The 12 soldiers who participated in the study completed six 10-minute walks on a treadmill at two levels of terrain difficulty ("No Hazards" and "Hazards") and three levels of mental workload ("No Load", "Moderate" load, and "High" load).

Mental workload was increased from the "No Load" to a "Moderate" level by requiring the participants to perform a mental arithmetic task while walking. Mental workload was then increased from the "Moderate" to a "High" level of load by increasing the difficulty of the arithmetic problems. The NASA-TLX was used to obtain subjective ratings of workload after each walk in each of the six combinations of mental workload and terrain difficulty.

It had been hypothesized that subjective ratings of workload would increase from the "No Load" to the "Moderate" level of mental workload when the participants were required to perform the walking and mental arithmetic tasks concurrently. It was also anticipated that when the difficulty of the arithmetic problems was increased at the "High" level of mental load that time and error in performing the mental arithmetic task would increase along with the participants' workload experiences. Increases in workload were expected based on theory that as the difficulty of a task is increased more mental resources would be required to perform the task (Norman & Bobrow, 1975). The difficulty of a task and the time pressure associated with performing it are considered major contributors to operator workload (Navon & Gopher, 1979; Wierwille, 1988; Wickens, 1989; Hendy, Liao, & Milgram, P., 1997).

In accordance with these hypotheses, the results of the present study indicated that subjective ratings of mental demand and effort increased with each increase in mental workload imposed by the mental arithmetic task. When the participants were confronted with the more difficult arithmetic problems at the "High" level of mental workload, time and error in performing the mental arithmetic task increased as did ratings of frustration and workload attributable to a perceived decline in performance. These findings are similar to those of DiDomenico (2003) who measured the effects of four levels of mental load on performance of a weight-lifting task and subjective ratings of workload obtained using the NASA-TLX. The four levels of mental workload included a "No Load" level and three levels of increases in the difficulty of a mental arithmetic task. As in the present investigation, increases in the difficulty of the arithmetic problems resulted in decreases in the performance of the mental arithmetic task and increases in subjective ratings of mental demand and workload associated with a perceived decline in performance. Scribner and Harper (2001) used the Subjective Workload Assessment Technique (SWAT) in their assessment of the effects of mental workload on the shooting performance of soldiers. The researchers used a mental arithmetic task similar to the one used in the present investigation to increase the level of mental load. They too found a decrease in performance of the mental arithmetic task and an increase in perceived workload as the difficulty of the arithmetic problems was increased.

In the current study, ratings of physical demand and effort obtained across the three levels of mental workload increased significantly when the participants were required to avoid hazards, as did the participants' perceptions of a decline in their performance. However, ratings of physical demand obtained across the two levels of terrain difficulty appeared to decrease at the "High" level of mental workload. This latter effect may be related to an interaction found between mental workload and terrain difficulty on ratings of performance which may have also influenced a similar interaction that was found for overall workload scores. Generally, the participants perceived a decline in their performance as the level of mental workload increased. However, differences in ratings of performance between the two levels of terrain difficulty decreased significantly between the "No Load" and the "Moderate" levels of mental workload and, at the "High" level of mental load, performance ratings at the two levels of terrain difficulty converged. It is believed that the mental demand associated with solving the more difficult arithmetic problems at the "High" level of mental workload may have diminished the participants' perceptions of the demands imposed by the hazard avoidance task and dominated the participants' workload experience at both levels of terrain difficulty.

Other investigations have reported similar interactions. Scribner and Harper (2001) found that differences in ratings of workload using the SWAT decreased significantly between single (mental arithmetic only) and dual-task conditions (mental arithmetic and shooting) as mental workload was increased (see Figure 30). Here too, the researchers believed that the more difficult arithmetic problems presented at the "High" level of mental load dominated the workload experience.

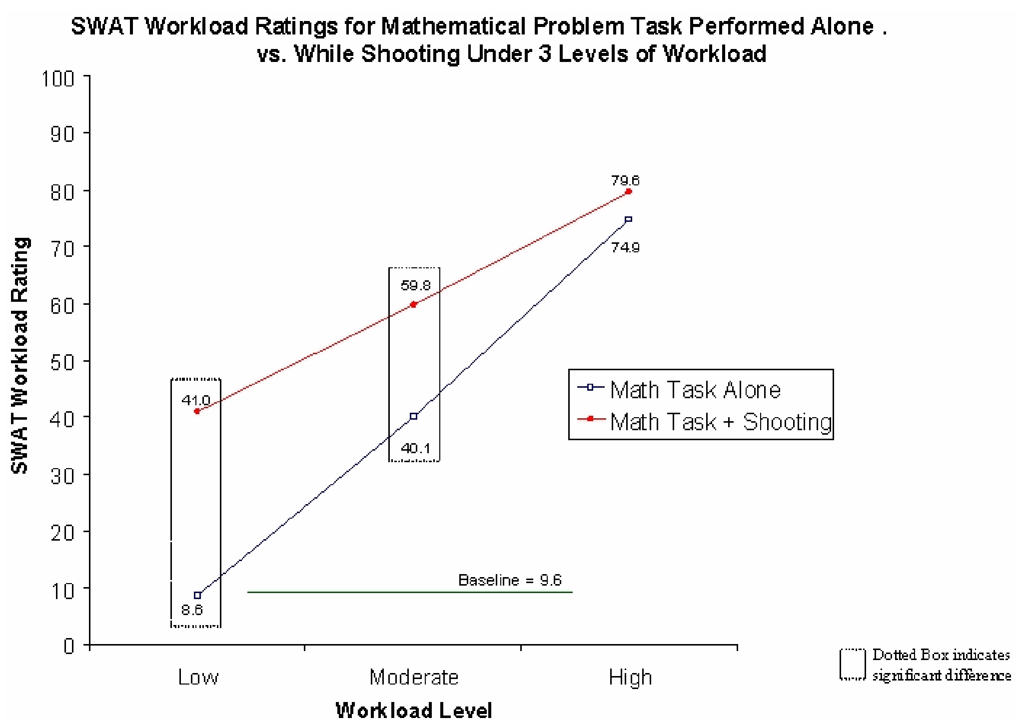

Figure 30. SWAT ratings for arithmetic task under single- and dual-task conditions at three levels of workload (Scribner & Harper, 2001)

DiDomenico (2003) used the Visual Analog (VA) Scale to obtain subjective ratings of workload in her investigation of the effects of mental workload, visual feedback, and postural stances on objective and subjective measures of postural stability. Her findings indicated an interaction between mental workload and postural stance where the difference in perceptions of mental workload between postural stances was found to be significantly less at the “High” level of mental workload. At the “High” level of mental load, the participants perceived that they were more stable during the more difficult postural stances, but less stable at the same level of load during the easier stances. Some participants indicated that when the mental arithmetic task was performed while maintaining the more difficult postural stance, the amount of attention they allocated to maintaining balance decreased. Some of these individuals reported that they felt more stable even though measures of sway were found to increase. These findings may suggest a shift in the allocation of resources from maintaining postural stability to maintaining performance of the more difficult cognitive task. The findings might also suggest that as the attentional demands of a cognitive task increase, an individual may become less aware of the workload imposed by a physical task and to declines in their performance. The implications of the distractions that a cognitive task might cause and the associated distortions in perception are that the individual may not make the necessary adjustments to maintain their performance of the physical task and that he or she may also become less sensitivity to cues that can lead to injury, including the physical stresses and strains that might be imposed by the physical task (Davis, Marras, Heaney, Waters, & Gupta, 2002).

Although walking is a highly automated activity and less likely to be disrupted by a cognitive task than other activities that are less automated (Brown & Carr, 1989), such as shooting or weight lifting, walking over complex terrain and avoiding hazards still requires attention, timing, and balance. Studies have shown that whether a task involves walking or merely standing still, the more balance the task requires, the more attention the task demands (Lajoie et al., 1996, Maylor & Wing, 1996). According to theory, attentional capacity is fixed and limited (Kahneman, 1973) and, if capacity is exceeded, performance will degrade. Models of human information processing indicate that when two tasks are performed concurrently, competition for resource-limited memory stores and attention can cause significant disruption in one or both tasks (Wickens & Hollands, 2000). Therefore, it was hypothesized for this investigation that increases in mental workload imposed by the mental arithmetic task would cause distractions and delays in executing the hazard avoidance response that would lead to instances of imbalance and perturbations in gait that would be reflected in an increase in the variability in step length and step rate. Similarly, it had also been hypothesized that as the difficulty of the mental arithmetic task and mental workload increased, performance in the avoidance of ground hazards would be degraded as measured by the number of hazards contacted. Support for this latter hypothesis was provided by the results of research on the effects of aging that had found decrements in the performance of both young and old adults when walking and cognitive tasks were performed concurrently (Guardiera et al., 2003; Li et al., 2001; Lindenberger et al., 2000).

In this study, the distance between hazards that the participants were asked to avoid ranged from 0.9 to 1.8 meters, whereas the average step length of the participants as measured at the "No Hazards" level of terrain difficulty was approximately 0.7 meters. In some instances, the participants could take one large step to avoid a hazard but, in many cases, a few smaller steps were needed. Thus, as expected, the requirement to avoid hazards had a significant effect on gait. At the "Hazards" level of terrain difficulty, step length decreased and step rate increased at all levels of mental workload. Both measures of gait increased in variability as the participants continuously adjusted the length and rate of their steps to avoid the irregularly spaced hazards**.** As the number of hazards contacted increased, so did the variability in step length and step rate. However, contrary to hypothesis, the results of this study did not indicate a significant effect of mental workload on the gait parameters that were measured. The means and standard deviations in step length and step rate remained relatively constant at each level of mental load.

For the most part, the relationships found at the "Hazards" level of terrain difficulty between increases in subjective ratings of workload and increases in the means and standard deviations of step length and step rate reflect changes in workload associated with the struggle to avoid hazards. Nonetheless, the number of relationships found between increases in subscale ratings of workload and changes in gait doubled at the

"High" level of mental load. The correlations found at the "Moderate" level of mental load appeared to signal the onset of some conflict between tasks. As time to respond to the arithmetic problems increased at the "Moderate" level of load, the variability of step length tended to decrease. As the number of hazards contacted increased, errors in performing the mental arithmetic task and ratings of effort tended to increase. Time to respond to the arithmetic problems increased with increases in ratings of temporal demand at the "High" level of mental workload, but no other relationships were found at this level.

Despite the increases in perceived workload and correlations found between these increases and degradations in the performance of the mental arithmetic and hazard avoidance tasks, the analysis did not reveal an effect of mental workload on the number of hazards contacted. Although the additional effort expended by some participants with each increase in level of mental load may have helped to curtail a significant increase in hazard contact, there are a number of other factors that may have contributed to this unexpected failure in rejecting the null hypothesis.

In this investigation, the timing and intensity of the hazard avoidance and the mental arithmetic tasks may not have been sufficient to produce the anticipated interference between tasks and competition for attentional resources. The available response time (ART) to the hazards and the time intervals between presentations of the cognitive task were longer than in other studies that had successfully demonstrated an increase in failure rates in avoiding obstacles when a cognitive task was performed concurrently (Chen et al., 1996; Weerdesteyn, Schillings, Van Galen, & Duysens, 2003). As defined in these latter investigations, the ART is the time between the presentation of an obstacle to the time at which the foot contacts the obstacle when no attempts are made to avoid it. Chen et al. (1996) found significant degradations in obstacle avoidance performance with an ART of 350 ms, but no degradations were found when the ART was increased to 450 ms. Weerdesteyn et al. (2003) measured kinematic parameters of gait and performance of an obstacle avoidance and a cognitive task under single- (obstacle avoidance only) and dual-task situations (obstacle avoidance and cognitive task). They too varied the time available to respond to the obstacles. The researchers varied the ARTs by inserting the obstacles in the walking path of participants at three different phases in the gait cycle (i.e., midswing, early stance, and late stance). They hypothesized based on neuromotor noise theory (Van Galen & Van Huygevoort, 2000; Van Gemmert & Van Galen, 1997, 1998) that the dual-task load would increase limb stiffness resulting in a decrease in horizontal swing velocity and an increase in failures in avoiding obstacles, particularly under time-critical conditions. Weerdesteyn et al. (2003) found that more obstacles were contacted during the dual-task condition but only when a short response time was available (maximum 300 ms). All contacts with the obstacles were by the toe and caused by an insufficient shortening of the pre-crossing stride. The researchers did not believe that the total length of the swing trajectory influenced the differences between the single- and dual-task conditions in the number of obstacles contacted because no differences were found in maximum toe heights.

In the current study, participants could view the oncoming hazards up to 5 meters forward of their walking position, but most claimed that their focus was on those hazards that entered the walking surface of the treadmill approximately 2 feet (.61 m) from their position. Given this and a treadmill speed of 3 mph, the time available to respond to a more imminent hazard was approximately 454 ms, exceeding the ART found to affect performance of the obstacle avoidance task in the studies described above. Longer available response times in the performance of the physical task together with longer time intervals between the presentation of the arithmetic problems may have facilitated better timesharing between tasks. Weerdesteyn et al. (2003) used an auditory Stroop task that involved a more rapid presentation of stimuli to which the participant was to respond as quickly as possible. Scribner and Harper (2001) found a significant effect of mental workload on the shooting performance of soldiers by using a mental arithmetic task similar to that employed in the present investigation. However, the time to respond to the arithmetic problems in this latter investigation was limited to 4 seconds and the time interval to the presentation of the next problem was 1 second. Although the participants in the present study were told to provide a correct solution to each problem as quickly as possible, they were allowed up to 12 seconds to provide a response and the time interval to the presentation of the next problem was 5 seconds. In the 12 seconds available to respond to an arithmetic problem, participants had a number of opportunities to switch their attention from one task to the other. It might also be expected that the more quickly and easily an arithmetic problem could be solved, the more time and attention would be available for performing the hazard avoidance task. Indeed, a relationship was found between increases in performance of the mental arithmetic task and decreases in the number of hazards contacted; however, this relationship occurred only at the “Moderate” level of mental workload and only for the number of correct responses. This suggests that some participants may have been able to dedicate fewer resources in deriving a correct solution to the easier arithmetic problems presented at the “Moderate” level of mental load and therefore could allocate more resources to avoiding hazards. It might further imply that differences among participants in their ability to perform the mental arithmetic task may be among the factors that contributed to the high variability in number of hazards contacted at the three levels of mental load.

The introduction of the arithmetic task at the “Moderate” level of mental workload, and the increase in the difficulty of the arithmetic problems at the “High” level, appeared to have different effects on the participants’ performance of the hazard avoidance task. Some participants tended to contact more hazards at the “High” level of mental workload than at either the “No Load” or the “Moderate” levels of load, as was expected. However, other participants tended to contact more hazards at the “Moderate” level of mental load than at either of the two extremes. Most surprising were those participants who contacted more hazards at the “No Load” level of mental workload where their only task involved hazard avoidance.

In the present study, it had been observed that mental arithmetic came easier to some participants than to others. When one soldier was asked why he was so good at mental arithmetic, he explained that his work at a tool company, prior to joining the Army, involved estimating the number of items in bins. It was there that he received a lot of practice in mental addition and subtraction. A few soldiers, who appeared to experience more difficulty in performing the arithmetic task, alluded to their need to visualize the problems. One soldier was observed to take his position on the treadmill with pen to hand and jokingly exclaim "O.K. Now I'm ready!" The soldier added that he would not normally solve an arithmetic problem mentally. If he did not have a piece of paper, he would write it on his hand. If he did not have a pen, he would write it on the ground with his finger.

The comments of the participants provided in debriefing sessions that followed testing also revealed differences in the participants' perceptions of the difficulty of the arithmetic task and the effects the task had on the number of hazards they contacted. Some participants thought that the mental arithmetic task caused distraction and errors in hazard avoidance, while others believed that the mental arithmetic task had a more positive effect. Some participants claimed that when their only task was hazard avoidance, their "mind tended to drift to other things." They believed that the mental arithmetic task helped them to "focus better on avoiding the hazards." One of the participants in this latter group claimed that the mental arithmetic task "woke up his brain." It was found that, on average, these participants scored 19% higher than the other participants on subtests of the ASVAB related to arithmetic skills (i.e., AR and MK). Their AFQT scores were an average 36% higher. The participants in this group had achieved faster times with fewer errors in responding to the more difficult problems presented at the "High" level of mental workload. However, it was also these participants who tended to contact more hazards at the "No Load" level of mental workload than at the higher levels.

The results of bivariate analyses indicated that increases in time and error in solving the more difficult arithmetic problems presented at the "High" level of mental load were related to lower scores on the AR subtest of the ASVAB at both levels of terrain difficulty, but increases in ratings of temporal demand when solving the more difficult problems were only related to lower test scores when participants were required to avoid hazards. No relationships were found between test scores and the number of hazards contacted. However, when mean performance on the mental arithmetic task was adjusted based on scores on tests of arithmetic, the analysis revealed that the number of correct responses to the arithmetic problems decreased when the participants were required to avoid hazards. The analysis did not reveal a significant effect of terrain difficulty on time to respond. These findings may suggest that those with lower test scores dedicated more time and attention to avoiding hazards than to deriving a correct solution to the arithmetic problems.

It is believed that differences among participants in arousal levels may have influenced changes in attentional capacity at the three levels of mental workload and changes in their allocation of resources between the mental arithmetic and hazard avoidance tasks. According to Yeh and Wickens (1988), the amount of resources an individual allocates to a task will be influenced by the difficulty of the task, the criteria for performance, and the motivation of the individual. Wickens and Hollands (2000) also noted that although the resource demand may at times be related to the skill level of the individual, the resource allocation policy of the individual is almost totally related to their skills.

Kahneman (1973) theorized that the amount of attention available and the allocation of attention to different tasks could be affected by arousal levels which vary within and between individuals. If the arousal level is too low or too high, attention capacity would be reduced. As shown in Figure 31, the inverted-U hypothesis suggests that increases in arousal will progressively improve performance to some optimum point beyond which further increases in arousal will result in a decline in performance (Yerkes and Dodson, 1908).

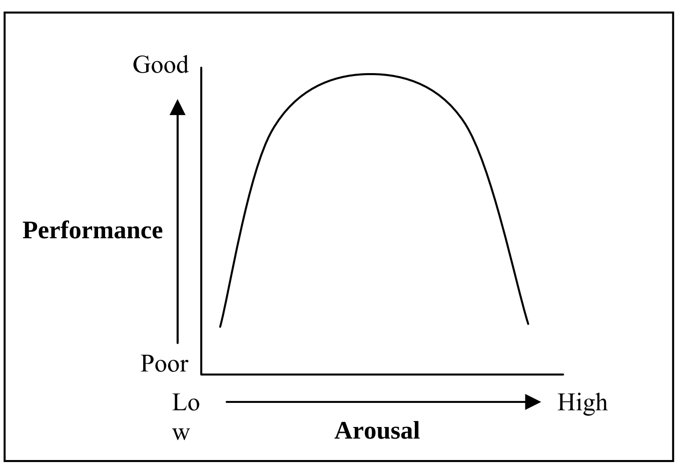

Figure 31. Yerkes-Dodson inverted-U hypothesis.

Yerkes and Dodson (1908) also believed that the performance of an easy task might be enhanced by a moderate level of arousal, but the same level of arousal might degrade the performance of a more difficult task (see Figure 32).

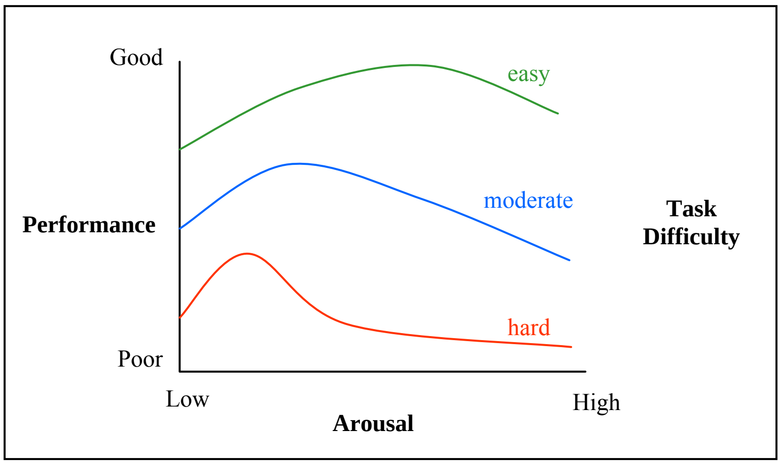

Figure 32. Effects of arousal and task difficulty on performance (Yerkes & Dodson, 1908).

It would appear that for those who tended to contact more hazards at the "No Load" level of mental workload, the arousal level may have been too low and, thus, attentional capacity was reduced. The comments of these participants suggest that when their only task was to avoid hazards, they were underloaded or "bored." For them, the mental arithmetic task served to arouse and refocus their attention on avoiding hazards rather than cause distraction. These participants were more skilled in performing mental arithmetic than the other participants, achieving faster times and fewer errors in solving the more difficult problems presented at the "High" level of mental workload without an increase in the number of hazards contacted over the "Moderate" level of load. The attentional capacity of those who were less skilled at mental arithmetic may have been reduced at the "High" level of mental workload where the arousal level was too high. For some of these participants, this reduction in capacity may have tended to increase the number of hazards contacted at the "High" level of mental load. However, for other participants, the number of hazards contacted at the "High" level of mental load appeared to decrease from the "Moderate" level of load to that achieved at the "No Load" level. This may merely suggest that these participants shifted more of their available resources from the mental arithmetic to the task of avoiding hazards at the "High" level of mental load.

Neither the hazard avoidance nor mental arithmetic task was designated to be a primary or secondary task in this study. Rather, it had been emphasized to the participants during both the training and testing periods that avoiding hazards and speed and accuracy in responding to the arithmetic problems were all of equal importance. Most participants believed that this was an appropriate policy and one that they could easily adopt. However, in order to adhere to this policy, the participants needed to maintain an awareness of changes in their performance so that they could shift resources to one or the other task as needed. The interactions found between mental workload and terrain difficulty on subjective ratings of workload indicated that this may have become more difficult to do at the "High" level of mental workload where the participants' perceptions of how well they performed appeared to be influenced more by increases in the difficulty of the mental arithmetic task and less by the task of avoiding hazards.

CHAPTER 6

CONCLUSIONS

6.1 Summary

As expected, subjective ratings of mental demand and effort increased across the two levels of terrain difficulty with each increase in mental workload imposed by the mental arithmetic task. When the difficulty of the arithmetic problems increased from the "Moderate" to the "High" level of mental load, time and error in performing the mental arithmetic task increased along with subjective ratings of frustration and workload associated with a perceived decline in performance. Temporal demands were only perceived to increase between the "No Load" and the "High" level of mental workload. Although ratings of physical demand measured across the three levels of mental workload increased when the participants were required to avoid hazards, ratings of physical demand measured across the two levels of terrain difficulty decreased when the participants were confronted with the more difficult arithmetic problems at the "High" level of mental load. As might be expected, the participants' perceptions of how well they performed at the "No Load" level of mental load were influenced by the requirement to avoid hazards. However, at the "High" level of mental load, perceptions of workload associated with a decline in performance were dominated by the mental arithmetic task. Correlations between increases in subjective workload, changes in gait, and degradations in performance of the mental arithmetic and hazard avoidance tasks suggested some degree of task conflict but most of these relationships were found to occur at the "Moderate" level of mental workload. The variability among participants in the number of hazards contacted at each level of mental workload was high and, contrary to hypothesis, the results of this study did not indicate a significant effect of mental workload on the avoidance of ground hazards. It is believed that the inconsistency in the effects of mental load on the performance of the hazard avoidance task was related to differences among the participants in arithmetic skills, levels of arousal, and motivation which, in turn, may have affected differences in their attentional capacity and shifts in the allocation of resources.

6.2 Limitations

6.2.1 Optical Flow

Differences in optical flow between walking on actual terrain and walking on a treadmill pose a threat to the external validity of the present study. Optical flow provides information about the direction and speed of movement (Warren & Hannon, 1988). It is believed to influence gait regulation (Konczak, 1994) and provide information for changes in stride length and braking (Lee, Lishman, & Thomson, 1982). There is some evidence that restrictions in peripheral vision in the overall optical flow can affect braking time in avoiding a hazard (Bardy & Laurent, 1989).

6.2.2 Potential Errors in Collection and Processing of Gait Data

Exact measurement of gait often presents a significant challenge where errors can occur during the data collection and reduction process. Gait data obtained using some measurement techniques may be more variable than data obtained using other methods. As the variability of the data increases so does the difficulty of the data reduction process and the potential for errors. In this study, for example, step length was computed as the horizontal distance between the right and left toe markers at toe-off. Toe-off was defined as the time at which the left toe marker was at its minimum in the z axis. A computer program provided an initial identification of the points at which a minimum was achieved by the left and the right toe markers in the z-axis. The investigator reviewed these points and made corrections to the point of toe off identified by the program as needed. It was observed that the point of toe off was more consistent and well defined with little fluctuation around the minimum in the z axis when the participants walked at a natural gait. However, when the participants were required to avoid hazards, the variability of the data around the minimums appeared to increase considerably resulting in a greater number of false “hits.” A less variable and more accurate measurement of step length and step rate may have been obtained by using a treadmill instrumented with a force plate. It should also be noted, given the findings of Weerdesteyn et al. (2003), that the gait parameters measured in the present study may have been less sensitive to increases in mental workload than other measures of gait.

6.2.3 Timing and Intensity of Mental Arithmetic and Hazard Avoidance Tasks

Any conclusions to be drawn from the findings of this study must take into account the timing and intensity of the tasks performed. In the present investigation, the time available to respond to the hazards and time intervals between presentations of the arithmetic problems were longer than in other studies that had successfully demonstrated an increase in obstacle contact when a cognitive task was performed concurrently (Chen et al., 1996; Weerdesteyn et al., 2003). Although the participants in the present study were told to provide a correct solution to each arithmetic problem as quickly as possible, they were allowed up to 12 seconds to provide a response and the time interval to the presentation of the next problem was 5 seconds. In the 12 seconds available to respond to an arithmetic problem, the participants may have had a number of opportunities to switch their attention from one task to the other. The timeline of the presentation of the hazards and the mental arithmetic problems and, thus, the extent to which the two tasks occurred concurrently were not captured in this study.

6.2.4 Individual Differences and Resource Allocation Policy

Differences among participants in the performance of the hazard avoidance task at the “Moderate” and “High” levels of mental workload may be more reflective of differences in arithmetic skills and decisions in the allocation of resources between tasks than the effects of increases in mental workload. Resources may have been allocated to one or the other task based on the difficulty of the task, the probability of success in performing the task, and the risk the task was perceived to pose. In other investigations, researchers found that participants performed better on the secondary task than they did on the primary task. The researchers believed that participants may have assigned priority to the secondary task because the primary task did not present a potential threat (Shumway-Cook, Woollacott, Kerns, & Baldwin, 1997; Weerdesteyn et al., 2003). As in these latter studies, the hazard avoidance task did not pose a risk to the participants. The ground hazards were painted on the walking surface of the treadmill which was flat. The hazards were unlikely to cause the participant to trip and did not pose any danger to the participant if stepped on. In the present investigation, some participants may have allocated more attention to the mental arithmetic task because contact with the hazards did not present a threat. Other participants may have shifted more attention to the hazard avoidance task at the "High" level of mental workload, anticipating a greater likelihood of success in avoiding hazards than in correctly solving the more difficult arithmetic problems.

The soldiers' choices in the allocation of resources during this study and their performance of the hazard avoidance task may not be the same in combat. In the battlefield, soldiers must remain attentive not only to the ground on which he or she is walking but also to other threats that might lie in the surrounding terrain. The attention a soldier might allocate to walking or performing a cognitive task will be influenced by a number of factors. These factors include the ruggedness of the terrain, the likelihood that ground hazards exist, the proximity of the enemy, and the importance of the cognitive task to the success of the mission. The threats to soldiers in combat are real. The physical and psychological stresses that they must endure may only magnify the effects of increases in mental workload.

6.2.5 Sample Size

Post-test power analyses were performed using the general test statistic for two populations (Neter, Kutner, Nachtsheim, & Wasserman, 1996) to determine the adequacy of the sample size for the present investigation. Two power analyses were performed. One power analysis employed the means and standard deviations of the number of hazards contacted in the "Hazards-No Load" and the "Hazards-High" load conditions.

The second power analysis employed the means and standard deviations of time to respond to the mental arithmetic problems for the “No Hazards-High” load and the “Hazards-High” load conditions. Specifying that $\alpha = .05$, the results indicate that approximately 120 participants would be needed to detect differences in the number of hazards contacted with risks of a Type I error of 0.05 and a Type II error of < 0.03 (Power > 0.7). Twenty-four (24) participants would be needed to detect differences in time to respond to the mental arithmetic problems with risks of a Type I error of 0.05 and a Type II error of < 0.03 (Power > 0.7). Therefore, based on these analyses, it appears that a sample size of 12 participants was not sufficient for the current investigation.

6.3 Recommendations

6.3.1 Display Design

There are many factors that will determine the ability of a soldier to timeshare effectively between two tasks. In the present study relationships were found between scores on tests of arithmetic, time and error in responding to the more difficult arithmetic problems, and perceived workload. The results of the study also indicated that performance of the hazard avoidance task may be degraded in states of underload as well as in states of overload. Among those factors that can have a major influence on the difficulty of a cognitive task, workload, and dual-task performance is the manner in which a cognitive task is presented. The following are recommended for the display of information that is used in the performance of a cognitive task:

- Information displays should be capable of being tailored to meet the mission requirements and critical information needs of the soldier.
- Periodic alerts and warnings may be useful in reminding soldiers of hazardous terrain conditions.
- Alternative sensory modalities for the display of information should be considered to reduce the potential for task conflict and competition between tasks for cognitive resources.

- Displays that adapt to changes in the cognitive state of the observer should be explored.

6.3.2 Future Research

Drifts in attention in states of underload, or inappropriate allocation of resources in states of overload, can be equally dangerous. They are concerns that are not only relevant to the performance of a somewhat automatic task, such as walking, but also to other tasks that are less well learned but sometimes perceived to require an equally limited amount of thought (e.g., driving). Understanding those factors that might cause underload or, perhaps, complacency in some individuals and overload in others can help in the assignment of tasks and responsibilities that can improve individual and team performance. Such knowledge can also help in the development of tools and techniques for maintaining workload and performance at optimum levels.

Future studies on the effects of mental workload on ground hazard avoidance should examine the effects of available response times in performing the hazard avoidance task as well as increases in mental workload. The effects of different restrictions in time to respond to the cognitive task that is used to impose mental load should also be explored. Understanding the effects of these variables on workload and the avoidance of ground hazards will help to expand the application of the findings.

Other methods for assessing the effects of mental workload on hazard avoidance should be explored. Research is being conducted by the University of Maryland in collaboration with the U.S. Army Research Laboratory that may offer a promising new approach. This research examines neural and biological processes and how these processes influence attentional and motor control mechanisms when performing tasks under stress. In this research it is hypothesized that an individual's ability to regulate arousal can improve the efficiency of cognitive processing and the consistency of performance.

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APPENDIX A

Volunteer Agreement Affidavit

VOLUNTEER AGREEMENT AFFIDAVIT:
ARL-HRED Local Adaptation of DA Form 5303-R. For use of this form, see AR 70-25 or AR 40-38

The proponent for this research is:	**U.S. Army Research Laboratory** **Human Research and Engineering Directorate** **Aberdeen Proving Ground, MD 21005**

Authority:	Privacy Act of 1974, 10 U.S.C. 3013, [Subject to the authority, direction, and control of the Secretary of Defense and subject to the provisions of chapter 6 of this title, the Secretary of the Army is responsible for, and has the authority necessary to conduct, all affairs of the Department of the Army, including the following functions: (4) Equipping (including research and development), 44 USC 3101 [The head of each Federal agency shall make and preserve records containing adequate and proper documentation of the organization, functions, policies, decisions, procedures, and essential transactions of the agency and designed to furnish the information necessary to protect the legal and financial rights of the Government and of persons directly affected by the agency's activities]
Principal purpose:	To document voluntary participation in the Research program.
Routine Uses:	The SSN and home address will be used for identification and locating purposes. Information derived from the project will be used for documentation, adjudication of claims, and mandatory reporting of medical conditions as required by law. Information may be furnished to Federal, State, and local agencies.
Disclosure:	The furnishing of your SSN and home address is mandatory and necessary to provide identification and to contact you if future information indicates that your health may be adversely affected. Failure to provide the information may preclude your voluntary participation in this data collection.

Part A • Volunteer agreement affidavit for subjects in approved Department of Army research projects

Volunteers are authorized medical care for any injury or disease that is the direct result of

participating in this project (under the provisions of AR 40-38 and AR 70-25).

Title of Research Project:	Title: Effects of Increases in Mental Workload on Avoidance of Ground Hazards	
Human Use Protocol Log Number:	ARL-20098-03008	
Principal Investigator(s):	Monica M. Glumm, ARL-HRED	Phone: (410) 278-5986 E-Mail: mglumm@arl.army.mil
Associate Investigator(s)	Angela C. Boynton, ARL-HRED Harrison P. Crowell, ARL-HRED	Phone: (410) 278-5927 E-Mail: aboynton@arl.army. mil Phone: (410) 278-9528 E-Mail: philip@arl.army. mil
Location of Research:	ARL-HRED, Bldg 459, Room 323, Aberdeen Proving Ground, MD	

Dates of Participation:	Data Collection Period: 1 February – 1 August 2003 Duration of Your Participation: 1 Day (8 hours)

Part B • To be completed by the Principal Investigator
Note: Instruction for elements of the informed consent provided as detailed explanation in accordance with
Appendix C, AR 40-38 or AR 70-25.

Purpose of the Research

The purpose of this study is to examine the effects of increases in mental workload on avoidance of ground hazards while walking. In this study, the amount of mental workload will be determined by the difficulty of mathematical problems that you will solve mentally while walking.

Procedures

The study will be conducted at the U.S. Army Research Laboratory (Building 517) at Aberdeen Proving Ground, MD. The duration of your participation in this study is expected to be one 8-hour day. During this period we will ask you to take six 13-minute walks on a treadmill. There will be a 20-minute rest break between walks. A lunch break of one hour will be provided between the first three and the last three walks. For each of the six walks, the speed of the treadmill will be set to 3 miles per hour and the incline at 0%. During one of these walks we will ask you to walk on the treadmill at a normal gait. During another walk we will ask you to walk on the treadmill and avoid stepping on simulated ground hazards that will enter your path. During the other four walks we will ask you to perform some mental addition and subtraction while you are walking on the treadmill. During two of these four walks, there will be simulated ground hazards for you to avoid. For the other two walks, no ground hazards will be presented. One math problem will be presented every 20 seconds. The math problems will be presented to you auditorily through a small speaker-microphone that you will wear in your ear. Each math problem will require you to add or subtract two numbers. We will ask that you provide a correct solution to each math problem as quickly as possible. We will measure the time it takes you to solve each problem, and the number of problems you solve correctly. If you do not solve the math problem in a specified period of time, it will be counted as a wrong answer. In this study, we will also measure the number of ground hazards you step on. Not stepping on any hazards is as important as quickly and accurately solving the math problems. One is as important as the other. Your step length and step rate will be measured using a motion analysis system and video cameras that track the position of small markers that we will place on the heels and toes of your boots. (These markers can be easily removed and will not damage your boots.) After each walk, we will ask you to rate the amount of workload you experienced during that walk. You will receive training and practice in walking on the treadmill, avoiding the simulated hazards, and performing the mental math task prior to the test period.

Benefits

You will receive no benefits from participating in this study, other than the personal satisfaction of supporting research to minimize the potential effects of increases in mental workload on soldier performance.

Risks

The risks to you in this study include slips and falls that might occur while you are boarding, dismounting, or walking on the treadmill. The floor around the treadmill will be covered with gymnastic mats to cushion any falls, and you will be asked to wear a PASGT helmet during all walks on the treadmill. The ground hazards that you will be asked to avoid are simulated. They are painted on the surface that you will walk on. They pose no hazard if stepped on and should not cause you to trip. For this study, the treadmill will be set for a walking speed of 3 mph (i.e., a 20 minute/mile) that simulates an infantry road march during daylight hours. The distance you will walk in this study is less than the distance you would walk in a standard training road march. During each of the six 13-minute walks on the treadmill, you will travel 0.75 miles for a total distance of 4.5 miles. By comparison, a standard training road march is 7.5 miles. In this study, a 20-minute rest break will be provided between each walk. For your safety, it is important that you be in good health and report any discomforts or changes in feelings of wellness to the investigator. The mental math task that you will perform will be presented auditorily through a combination speaker-microphone that you will wear in your ear. The ear insert will either be replaced or cleaned with alcohol between participants. You will be asked to set the speaker volume to a level that is comfortable for you. Under no conditions will you be exposed to hazardous sound levels. Sound levels will not exceed maximum allowable limits (85dBA for eight hours continuous exposure) as set forth by U. S. Army regulations (U. S. Army Pamphlet 40-501 [U. S. Army, 1998] requirements).

Confidentiality

All data and information obtained about you will be considered privileged and held in confidence. Photographic or video images of you taken during this study will not be identified with any of your personal information (name, rank, or status). This consent form and other documents containing personal information will be secured in a locked file cabinet. You will be assigned a number for data collection purposes. As a member of a military service, complete confidentiality cannot be promised because information bearing on your health may be required to be reported to appropriate medical or command authorities. In addition, applicable regulations note the possibility that the U.S. Army Medical Research and Materiel Command (MRMC-RCQ) officials may inspect the records.

Compensation

As a soldier in the U.S. Army you cannot receive any additional pay for participating in this study.

Disposition of Volunteer Agreement Affidavit

The Principal Investigator will retain the original signed Volunteer Agreement Affidavit and you will be provided a photocopy. A photocopy will also be forwarded to the Chair of the Human Use Committee after the data collection.

Obtaining of ASVAB Scores

IF YOU ARE AN ACTIVE DUTY ENLISTED MILITARY VOLUNTEER, we would like to obtain your Armed Services Vocational Aptitude Battery (ASVAB) scores for potential data analysis. The ASVAB scores would be used strictly for research purposes. The results of any such analyses would be presented for the group of participants as a whole; and no names will be used. With your permission, we will obtain these scores by sending a copy of this signed consent form along with your Social Security Number to the Defense Manpower Data Center (DMDC) in Seaside, CA where ASVAB scores may be obtained from their databases in Arlington, VA or Seaside, CA. If you do not wish your ASVAB scores to be released to the principal investigator, you will still be allowed to participate in the research.

If you would like to participate in this research, please sign one of the following statements, and then complete the information requested at the end of this form:

I **DO AUTHORIZE** you to obtain my ASVAB scores. ______________________________
(Your Signature)

I **DO NOT AUTHORIZE** you to obtain my ASVAB scores. ___________________________
(Your Signature)

Contacts for Additional Assistance

If you have questions concerning your rights on research-related injury, or if you have any complaints about your treatment while participating in this research, you can contact:

Chair, Human Use Committee
U.S. Army Research Laboratory
Human Research and Engineering Directorate
Aberdeen Proving Ground, MD 21005
(410) 278-5919 or (DSN) 298-5919

OR

Office of the Chief Counsel
U.S. Army Research Laboratory
2800 Powder Mill Road
Adelphi, MD 20783-1197
(301) 394-1070 or (DSN) 290-1070

I do hereby volunteer to participate in the research project described in this document. I have full capacity to consent and have attained my 18th birthday. The implications of my voluntary participation, duration, and purpose of the research project, the methods and means by which it is to be conducted, and the inconveniences and hazards that may reasonably be expected have been explained to me. I have been given an opportunity to ask questions concerning this research project. Any such questions were answered to my full and complete satisfaction. Should any further questions arise concerning my rights or project related injury, I may contact the **ARL-HRED Human Use Committee Chairperson at Aberdeen Proving Ground, Maryland, USA by telephone at 410-278-5919 or DSN 298-5919.** I understand that any published data will not reveal my identity. If I choose not to participate, or later wish to withdraw from any portion of it, I may do so without penalty. I understand that military personnel are not subject to punishment under the Uniform Code of Military Justice for choosing not to take part as human volunteers and that no administrative sanctions can be given me for choosing not to participate. I may at any time during the course of the project revoke my consent and withdraw without penalty or loss of benefits. However, I may be required (military volunteer) or requested (civilian volunteer) to undergo certain examinations if, in the opinion of an attending physician, such examinations are necessary for my health and well being.

Your signature below indicates that you: (1) are at least 18 years of age, (2) have read the information on this form, (3) have been given the opportunity to ask questions and they have been answered to your satisfaction, and (4) have decided to participate based on the information provided on this form.

Printed Name Of Volunteer ***(First, MI., Last)***	
Social Security Number (SSN)	***Permanent Address Of Volunteer***
Date Of Birth ***(Month, Day, Year)***	
Today's Date ***(Month, Day, Year)***	***Signature Of Volunteer***
Signature Of Administrator	

APPENDIX B

National Aeronautics and Space Administration-Task Load Index (NASA-TLX)

RATING SCALE DEFINITIONS

Title	Endpoints	Descriptions
MENTAL DEMAND	Low/High	How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	Low/High	How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	Low/High	How much time pressure did you feel due to the rate or pace at which the task or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
PERFORMANCE	Perfect/Failure	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
EFFORT	Low/High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
FRUSTRATION LEVEL	Low/High	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Effort

or

Performance

Temporal Demand

or

Frustration

Temporal Demand

or

Effort

Physical Demand

or

Frustration

Performance

or

Frustration

Physical Demand

or

Temporal Demand

Physical Demand

or

Performance

Temporal Demand

or

Mental Demand

Frustration

or

Effort

Performance

or

Mental Demand

Performance

or

Temporal Demand

Mental Demand

or

Effort

Mental Demand

or

Physical Demand

Effort

or

Physical Demand

Frustration

or

Mental Demand

RATING SCALE SHEET

MENTAL DEMAND

Low **High**

PHYSICAL DEMAND

Low **High**

TEMPORAL DEMAND

Low **High**

PERFORMANCE

Good **Poor**

EFFORT

Low **High**

FRUSTRATION

Low **High**

APPENDIX C

Means and Standard Deviations

Table C1. Mean and Standard Deviation of Overall Workload Scores at Each Level of Mental Workload and Terrain Difficulty.

	Mental Workload							
	No Load		Moderate		High		*Total*	
Terrain Difficulty	Mean	SD	Mean	SD	Mean	SD	Mean	SD
No Hazards	14.32	11.68	31.92	19.48	52.81	23.73	33.01	24.36
Hazards	45.57	23.41	48.83	20.82	65.53	16.34	53.31	21.70
Total	29.94	24.12	40.38	21.53	59.17	20.96	43.16	25.08

Table C2. Mean and Standard Deviation of Subscale Ratings of Workload at Each Level of Mental Workload.

	Mental Workload							
	No Load		Moderate		High		*Total*	
Workload Factor	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Mental	60.63	79.86	179.58	131.44	287.08	144.27	175.76	151.92
Physical	98.13	110.71	85.00	96.68	32.71	64.00	71.94	95.58
Temporal	57.50	75.18	77.92	81.44	117.08	113.64	84.17	93.72
Performance	73.13	75.24	73.13	70.97	142.71	89.38	96.32	84.52
Effort	114.17	126.62	152.92	104.04	188.54	123.86	151.87	120.85
Frustration	45.42	101.61	37.08	92.02	119.38	141.71	67.29	118.24

Table C3. Mean and Standard Deviation of Subscale Ratings of Workload at Each Level of Terrain Difficulty.

	Terrain Difficulty			
	No Hazards		Hazards	
Workload Factor	Mean	SD	Mean	SD
Mental	159.03	165.48	192.50	137.33
Physical	42.08	54.25	101.81	117.27
Temporal	81.11	86.34	87.22	101.71
Performance	71.53	77.31	121.11	85.16
Effort	92.92	96.46	210.83	114.77
Frustration	48.47	96.67	86.11	135.22

Table C4. Mean and Standard Deviation of Time to Respond to Arithmetic Problems Presented at the Moderate and High Levels of Mental Workload at Each Level of Terrain Difficulty.

	Mental Workload					
	Moderate		High		*Total*	
Terrain Difficulty	Mean	SD	Mean	SD	Mean	SD
No Hazards	1.53	0.74	5.47	2.03	3.50	2.51
Hazards	1.68	0.79	5.31	1.82	3.50	2.31
Total	1.61	0.75	5.39	1.89	3.50	2.38

Table C5. Mean and Standard Deviation of Number of Correct Solutions to Arithmetic Problems Presented at the Moderate and High Levels of Mental Workload at Each Level of Terrain Difficulty.

	Mental Workload					
	Moderate		High		*Total*	
Terrain Difficulty	Mean	SD	Mean	SD	Mean	SD
No Hazards	29.58	0.52	20.92	4.70	25.25	5.50
Hazards	28.50	1.73	19.00	5.49	23.75	6.28
Total	29.04	1.37	19.96	5.89	24.50	5.89

Table C6. Mean and Standard Deviation of Step Length and Step Rate at Each Level of Mental Workload.

	Mental Workload							
	No Load		Moderate		High		*Total*	
Gait Parameter	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Step Length (Mean)	0.68	0.058	0.67	0.052	0.675	0.068	0.675	0.059
Step Length (SD)	0.097	0.084	0.101	0.086	0.096	0.082	0.098	0.083
Step Rate (Mean)	114.28	13.18	116.36	14.35	115.52	16.16	115.39	14.44
Step Rate (SD)	18.46	20.41	19.43	19.78	17.81	19.05	18.57	19.49

Table C7. Mean and Standard Deviation of Step Length and Step Rate at Each Level of Terrain Difficulty.

	Terrain Difficulty					
	No Hazards		Hazards		*Total*	
Gait Parameter	Mean	SD	Mean	SD	Mean	SD
Step Length (Mean)	0.701	0.024	0.649	0.072	0.675	0.059
Step Length (SD)	0.018	0.004	0.177	0.029	0.098	0.083
Step Rate (Mean)	107.12	3.40	123.66	16.45	115.39	14.44
Step Rate (SD)	3.62	0.474	33.51	17.62	18.57	19.49

Table C8. Number of Hazards Contacted at Each Level of Mental Workload and Participants' Scores on ASVAB Subtests and the AFQT.

	Hazard Contact Criterion 1				**Hazard Contact Criterion 2**				**Test Scores**		
Participant	No Load	Moderate	High	*Total*	No Load	Moderate	High	*Total*	AR*	MK*	AFQT
1	0	2	0	2	13	17	13	43	55	52	58
2	0	0	0	0	4	1	1	6	64	64	89
3	0	2	0	2	12	23	4	39	48	48	53
4	0	1	2	3	8	4	11	23	55	54	63
5	1	1	0	2	1	16	5	22	44	41	44
6	0	0	1	1	1	1	7	9	51	42	54
7	7	10	8	25	57	35	20	112	57	53	76
8	0	0	0	0	24	5	10	39	63	63	95
9	0	0	0	0	10	8	12	30	51	49	57
10	2	0	0	2	23	6	9	38			
11	0	0	0	0	6	5	16	27	36	51	45
12	0	1	5	6	5	8	16	29	53	55	70
Mean	0.8	1.4	1.3	3.6	13.7	10.8	10.3	34.8	52.5	52.0	64.0
SD	2.0	2.8	2.6	7.0	15.6	10.2	5.5	26.9	8.0	7.3	16.8

* ASVAB subtests of Arithmetic Reasoning (AR) and Mathematics Knowledge (MK).