ARMY RESEARCH LABORATORY

The Effects of Physical Exertion on Cognitive Performance

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Executive Summary

The goal of this study was to examine the cognitive and physiological performance of soldiers during physical exertion on a treadmill. New technology is being used to develop highly technical equipment for the dismounted soldier. This area of research is important when one considers that soldiers often have to use their equipment to make critical decisions in various tactical situations, often during a high level of physical exertion. The results of this and similar research can be used to ensure that system components are designed to be compatible with the users' cognitive capacity.

Two questions were addressed in this study:

1. Does physical exertion affect cognitive performance?
2. What types of tasks are affected by physical exertion?

This study used a within-subjects design. The independent variables were grade, time, and cognitive task. The dependent variables were accuracy (percent correct), response time (responses per minute), throughput (hits per minute), heart rate, and rating of perceived exertion. There were three levels of grade (0%, 3.5%, and 7.0%), five levels of time (pre-test, 15 minutes, 30 minutes, 45 minutes, and post-test), and four levels of cognitive task (two reaction time tasks, one decision-making task, and one arithmetical task). Participants walked on the treadmill at 1.56 m/sec at each grade. Each experimental trial lasted approximately 60 minutes.

Twelve male subjects recruited from the military population at Aberdeen Proving Ground (APG) participated in this study. The study was fully explained to the participants, and each participant signed a volunteer agreement affidavit (see Appendix A). After signing the affidavit, participants began a series of 12 training sessions to control for any learning effects and to ensure that each participant began the experiment with the same level of training.

The data collection trials took place 17 July through 11 August 2000 at APG. The trials were conducted indoors during daylight hours between 8:00 a.m. and 12:00 p.m. eastern daylight savings time. The participants performed the experimental trials at approximately the same time each day.

Separate analyses of variance (ANOVAs) were conducted for the cognitive and physiological data. A repeated measures ANOVA was conducted on the dependent variables (heart rate and rating of perceived exertion), with the independent variables (grade and time). Another ANOVA was conducted on the dependent variables (accuracy, response time, and throughput), with the independent variables (grade, time, and task).

The level of significance for each analysis was 0.05. Tukey's Honestly Significant Difference Test was used to determine significant differences between the means.

Results of the analysis on the physiological data showed a significant Grade x Time interaction, a significant main effect of grade, and a significant main effect of time for both heart rate and rating of perceived exertion. These results were consistent with those of a progressive walking protocol.

Results of the analysis on the cognitive data indicate a significant main effect of task for the accuracy measure, with the arithmetical task showing significantly more errors than the other tasks. However, the main effect of task lacks any practical significance because it is merely a comparison of error rates for the different tasks. The analysis also showed a significant main effect of time and a significant main effect of task for the response time and throughput measures. The results indicate that there were more responses per minute and more hits per minute over time for all four cognitive tasks, which suggests that arousal may have been facilitating performance.

These results are important to the military community, but further research should be conducted. In this research effort, the participants worked at a relatively low level of physical exertion. A soldier's ability to perform tasks both quickly and accurately may be compromised during high levels of physical stress. Research with higher levels of physical exertion or with an external load may lead to increases in errors and increased response time, which would significantly impact the soldier's performance on the battlefield.

1. Introduction

1.1 Purpose

New technologies are currently being developed for the military to increase the survivability and lethality of soldiers. The development of these technologies has fueled the need to provide the soldier with the capability to access critical mission information at any time and any position on the battlefield. Soldiers typically receive and transmit information via radios, hand signals, and person-to-person voice communications. New technologies, such as wearable computers, provide an alternate means of communication and information sharing. For example, wearable computers are a main component of the Army's Land Warrior and Objective Force Warrior systems and will be used to provide tactical information to the soldier via a helmet- or wrist-mounted display. Many of these technologies require soldiers to use their cognitive resources to receive and process information and make decisions. As a result, concerns have been raised about how these new technologies affect the soldier's capability to perform the cognitive functions necessary in a combat situations that may include high levels of stress and physical exertion that lead to fatigue and may impinge upon the soldiers' ability to process information.

In response to these concerns, the Deputy Under Secretary of Defense for Science and Technology designated cognitive readiness as a critical research focus area. Cognitive readiness is defined as a measure of a system's effects on the war fighter's capabilities to perform mental functions contributing to optimal performance in a combat environment (Fatkin, McNinch, & Blackwell, 1999). In a recent paper about the relationship between human performance, technology, and cognition, Rapmund (2002) emphasized the need to integrate research across scientific disciplines with the goal of understanding the totality of human performance, not just its component parts. The purpose of this research is to address the issue of physical exertion and its effect on cognitive performance (i.e., information processing and problem solving), thereby increasing knowledge in the area of human cognitive performance in environments that include psychological and physical stressors. The information gleaned from this and future research can be used to establish a set of guidelines or standards that can be used in the design of informational displays and decision aids.

1.2 Review of Theoretical Literature

The Hull-Spence drive theory has been used to explain the relationship between performance and physiological arousal. The drive theory (Spence & Spence, 1966) proposes that there is a relationship between anxiety, learning, and performance. The theory states that an increase in arousal (or drive) will increase the likelihood that a learned response will occur. Therefore, increasing the pressure to perform will increase drive and elevate the level of performance. Another facet of the drive theory is that arousal will decrease performance if the behavior is not well learned.

Theories of attention have also been used to help explain how different levels of physical arousal influence attention. Easterbrook (1959) proposed a cue-utilization model, which suggests that changes in physical arousal will result in changes in attention. Easterbrook discusses the phenomenon of "narrowing of attention," which happens as arousal increases. The increase in arousal results in attention being focused on the details of the task that are critical for success. If arousal continues to increase, attention will continue to narrow and performance will deteriorate.

Kahneman (1973) proposes that individuals possess a fixed amount of attentional capacity that can be allocated to process incoming information. Certain types of information processing such as spatial memory, time, and frequency of occurrence happen automatically, whereas other types such as imagery, rehearsal, and mnemonic techniques require deliberate allocation of attention. Nideffer's (1976) attentional control theory, similar to the cue-utilization theory, also proposes that the perceptual narrowing of attention occurs during periods of increased physical arousal. Nideffer's work is popular among sports psychologists and has been used to enhance performance among athletes.

The theories of attention and information processing presented in this literature review were developed to help explain the relationship between physical arousal and motor performance (Landers, 1980; Schmidt, 1982). Attempts have been made to further an understanding of the effects of exercise on cognitive variables (Folkins & Sime, 1981). Some of these research efforts are presented here.

1.3 Review of Empirical Literature

In the empirical literature, conclusions about the effects of physical exertion on cognitive function vary greatly because of the different modes of exercise, exercise severity, and forms of cognitive testing. The research can be separated into four categories: studies that found a beneficial relationship between exertion and cognitive performance, those that found a detrimental relationship, those that found both a beneficial and detrimental relationship, and studies finding no relationship.

A few studies (Burgess & Hokanson, 1964; McGlynn, Laughlin, & Bender, 1977; Hogervorst, Riedel, Jeukendrup, & Jolles, 1988; Lybrand, Andrews, & Ross, 1954; and Gliner, Matsen-Twisdale, Horvath, & Maron, 1979) have found that exercise facilitates performance of cognitive tasks. These studies used various exercise interventions and elicited a low to high level of arousal.

Other studies have found decreased performance of cognitive tasks with physical exertion. Hancock and McNaughton (1986) investigated the effects of physical exertion to the point of fatigue on two visual perception tasks. Results suggest that under the influence of fatigue, an orienteer's ability to perceive visual information is greatly impaired. Fleury and Bard (1987) found that sensory and adaptive behaviors improve with previous physical activity, but cognitive performance is impaired by highly demanding (maximal aerobic) efforts. Weingarten (1973) found a decrement in cognitive task performance during physical exercise. Weingarten suggests that the initial level of physical fitness of subjects may interact with task performance. Subjects with low cardio-respiratory fitness showed decrements in task performance and those with high fitness were able to maintain their performance after strenuous exercise.

Results of previous studies also indicate that physical activity can have beneficial and detrimental effects. Davey (1973) found an inverted "U" relationship between physical exertion and attention. As metabolic activity increased, performance also increased to a point. With further metabolic activity, performance decreased. Gupta, Sharma, & Jaspal, (1974) investigated the influence of physical activity on the performance of mathematical tasks. Results indicated a significant increase in mental work performance when physical activity lasted 2 to 5 minutes and significant decreases in performance when the physical activity lasted 10 to 15 minutes. Paas and Adam (1991) found that exercising on a bicycle ergometer improved performance of a decision task and reduced performance of a perception task.

Zervas (1990) concluded that intensive physical exercise does not impair mental performance. Tomporowski, Ellis, & Stephens, (1987) investigated the effects of running on a treadmill to exhaustion on free recall memory. The results show no differences between the number of words recalled after the strenuous exercise and the number of words recalled by a non-exercise control group. Other studies (Sparrow & Wright, 1993; Sjoberg 1980) used a step-test protocol and found no significant effect of physical exertion on mathematical ability.

The studies cited have provided some information about the effects of physical exertion on cognitive performance. However, the results have been inconclusive. This research is an attempt to shed additional light on the problem, especially in regard to soldiers performing cognitive activities during physical activity.

1.4 Summary of Previous Studies

Table 1 summarizes all the studies previously discussed. It provides a review of the literature found to be relevant to the effects of physical exertion on cognitive task performance. The elements addressed in each of these studies were author(s) and year of publication, type of cognitive task(s), type of exercise intervention, and results.

Table 1. Summary of studies performed to assess the effects of exercise on cognition (adapted from Mozrall & Drury, 1996)

Study	Cognitive Task	Exertion	Time	Results
Burgess and Hokanson (1964)	Digit-Substitution Task	Weight lifting and pulling	During	Facilitated performance
Davey (1973)	Brown-Poulton Test	Bicycle ergometer	After	Improved performance with sub-maximal physical exertion. Decreased performance with increasing exercise over longer time periods.
Fleury & Bard (1987)	Peripheral Detection Visual Detection	Treadmill Anaerobic alactacid (20 sec) Anaerobic lactacid (five 90-sec runs) Submaximal aerobic (30 min) Maximal aerobic (exhaustion)	After	Impairment after maximal aerobic condition
Gliner et al. (1979)	Signal detection	Marathon race	After	Facilitated
Gupta et al. (1974)	Arithmetic	Step-ups on 20-inch high bench Five sessions total (no exercise, 2 min, 5 min, 10 min, 15 min)	After	Increased performance – 2- and 5-min exercise. Decreased Performance – 10- and 15-min exercise.
Hancock & McNaughton (1986)	Visual Perception	Treadmill - at or above anaerobic threshold for 25 minutes.	During	Impairment of ability to perceive visual information Short-term memory not affected
Hogervorst et al. (1988)	Choice Reaction Time Test Stroop Color-Word Test Finger-Tapping Test	Bicycle ergometer at 75% of maximal work capacity (Wmax)	After	Increase in speed of performance
Lybrand (1954)	Perceptual Organization	5-mile march with 40-lb load.	After	Facilitated performance
McGlynn et al. (1977)	Line matching	Treadmill – four 3-min stages of exercise Stage 1 – 2.5 mph at 12% grade Stage 2 – 3.4 mph at 14% grade Stage 3 – 4.2 mph at 16% grade Stage 4 – 5.0 mph at 18% grade	During After	Decreased response time, no effect on accuracy No effect
McGlynn et al. (1979)	Line matching	Treadmill – four 3-min stages of exercise Stage 1 – 0.7 m s^{-1} at 10% grade Stage 2 – 1.1 m s^{-1} at 12% grade Stage 3 – 1.52 m s^{-1} at 14% grade Stage 4 – 1.88 m s^{-1} at 16% grade	During After	Decreased response time, no effect on accuracy No effect
Paas and Adam (1991)	Information processing (Perception & Decision)	Bicycle ergometer – endurance and interval protocols	During	Improved performance of decision task. Reduced performance of perception task.
Sjoberg (1980)	Switching of attention Paired associate learning Multiplication	Bicycle ergometer (0%, 25%, 50%, and 75% of VO_{2max} for 30 min)	During	No effect
Sparrow and Wright (1993)	Raven's Matrices and WAIS arithmetic subtest	Bench stepping test	After	No effect
Tomporowski et al. (1987)	Free recall	Treadmill run to voluntary exhaustion	After	No effect
Weingarten et al. (1970)	Raven's Matrices	Treadmill run (60% VO_{2max}) for 10 min.	After	Facilitated performance
Zervas (1990)	Eysenck's tests	40-min intensive exercise session	After	No effect

2. Objectives

The broad goal of this research is to enhance soldier performance by ensuring that system components are designed to be compatible with the users' cognitive capacity. To achieve this goal, the following questions will be addressed. First, does physical exertion affect cognitive task performance? Soldiers perform a multitude of different tasks during a mission, including ones that require cognitive resources. Many of these tasks must be performed while soldiers are physically stressed or during tight time constraints. As a result, it is important to determine the impact of physical exertion on a soldier's ability to receive and process information. The second question is what types of tasks are affected by physical exertion? This information will help us determine what types of tasks the soldier is likely to have trouble performing in a physically stressed state. These two issues are important because they can influence the type and quantity of information being presented to the soldier, ultimately improving the soldier's performance on the battlefield.

Another important goal of this research is to collect data that can be used to develop effective and usable equipment for the military and commercial sectors and to provide useful information that can be integrated into existing human performance models and contribute to the overall body of knowledge regarding this topic.

3. Methodology

3.1 Participants

Twelve male volunteers were recruited from the military population at Aberdeen Proving Ground (APG). Male participants were used because they were available for the duration of the study. The participants did not receive any compensation, other than their normal pay, for participating in the study. All participants were between the ages of 18 and 35 years old and were required to meet the visual requirement of 20/20 vision corrected or uncorrected. Their visual acuity was verified by a Titmus[1] vision tester. Participants were also required to be "fit for duty," which means that they were not on a medical profile list that limits their physical activity because of an injury or illness. In addition, each volunteer was required to read and sign a volunteer agreement affidavit, which has been approved by the U.S. Army Research Laboratory (see Appendix A). A coding scheme was employed to identify the data by participant's number only (e.g., Subject 1) to maintain anonymity. Any pictures or videos taken during the experimental trials were modified so that the participants' name and face cannot be identified.

[1]Titmus® is a registered trademark of Titmus Optical.

3.2 Apparatus

3.2.1 Physiological Equipment

A Quinton Q65, Series 30, Model 640 treadmill was used. It contains a 3-hp AC motor and has an extra long (1.6-meter) running surface that can be used for speeds ranging from 0.67 to 6.7 m/s and on a grade as steep as 25%. Attached to the treadmill is the Model 645 programmable treadmill controller that allows for push-button or automatic operation and can program and store as many as 10 exercise programs. A liquid crystal display shows the current speed and grade. The treadmill is equipped with certain safety features such as a stop button on the front console, which automatically stops the treadmill.

A Polar[2] heart watch was used to measure participant's heart rate. This device consists of a sensor strap that the participant wears around his chest, and a small display that can be worn like a wristwatch. The sensor strap detects the electrical impulses of the heart and transmits the information via telemetry to the heart watch, which displays beats per minute.

Borg's rating of perceived exertion scale (Borg, 1973) was used to assess the participant's subjective level of exertion. This scale is a ratio scale with values ranging from 6 to 20 (see Appendix B). The participant chose the number that most closely represented his level of physical workload.

3.2.2 Anthropometric Equipment

An anthropometer was used to measure the stature of participants. An electronic scale was used to measure weight.

3.3 Cognitive Tasks

The cognitive tasks used in this study are part of the Walter Reed Performance Assessment Battery (WRPAB), a computer-generated and controlled battery consisting of 14 different tasks. The WRPAB has been used to study the effects of sleep deprivation, sustained performance, jet lag, heat stress, and fatigue on cognitive performance. Details about reliability and validity of each of the tasks in the WRPAB are presented in a report published by Perez, Masline, Ramsey, & Urban, (1987).

For this study, 4 of the 14 tasks in the WRPAB were used. These four tasks took approximately 4 minutes to complete. Test items were presented to participants via a 15-inch computer monitor and a computer. Participants responded by pressing one or more keys on an alphanumeric keyboard. For each task, a response or key press initiates the next trial. Brief descriptions of the tasks used for this research are listed in Table 2.

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[2]Polar Vantage XL® is a registered trademark of Polar Electro Oy.

Table 2. Cognitive task descriptions

Task	Description	Number of Trials Presented
Wilkinson Choice Reaction Time	A red square appears in one of four boxes positioned in the center of the computer screen, and the subject presses a corresponding button on the numeric keypad.	50
Serial Addition and Subtraction	A machine-paced mental arithmetical task requiring sustained attention. Two random digits and either a + or - sign are displayed sequentially in the same screen location, followed by a prompt symbol. The subject performs the addition or subtraction and enters the least significant digit of the result. If the answer is a negative number, the subject adds 10 to it and enters the positive single digit remainder. The digits and signs are presented for approximately 250 milliseconds, separated by approximately 200 milliseconds.	50
Serial Reaction Time	A simple reaction time task. A single number from zero to nine is presented in the center of the computer screen and subjects respond by pressing the corresponding number on the numeric keypad.	50
Stroop Task	A series of red, green, or blue words is displayed in the center of the computer screen. Subjects determine the color of the word and press the key on the numeric keypad that corresponds to that color.	48

(adapted from Thorne, Genser, Sing, & Hegge, 1985)

These tasks were chosen because they are representative of some of the critical tasks that an infantry soldier performs. These critical tasks and the corresponding WRPAB task are shown in Figure 1.

Critical Infantry Task		WRPAB Task
Respond to data: give attention to details, perceive form, visually recognize and identify patterns, recall rules, and comprehend their environment	→	Stroop Task Choice Reaction Time Task
Take action based on data: perform quantitative analysis, reason verbally, assess given situations, formulate concepts, plan, and make decisions.	→	Serial Addition and Subtraction Task Stroop Task Serial Reaction Time Task
Create data: make inferences, formulate and validate hypotheses, and solve problems.	→	Serial Addition and Subtraction Task

Figure 1. Infantry tasks and associated tasks from the WRPAB.

Before the experiment began, a cognitive test battery containing all four cognitive tasks was created for each participant. The order of presentation for the cognitive tasks was different for the test batteries. Participants used their cognitive test battery for all experimental trials. During the experiment, participants performed the cognitive test battery five times, the pre-test, at 15-minute intervals (15 minutes, 30 minutes, and 45 minutes), and the post-test.

3.3.1 Scoring

Tasks are scored by the computer on three criteria: (a) accuracy (percent correct), (b) response time (responses per minute; measured from the stimulus presentation until the first valid response), and (c) throughput (hits per minute). Data for each participant are stored on the computer in a separate file and printed before the data analysis. An example of the data is shown in Figure 2.

SERIAL			
	TOTAL	RIGHT	WRONG
N	50	46	4
MEAN	1.299	1.26	1.747
SD	.632	.628	.568
MIN	.484	.484	.938
MAX	3.234	3.234	2.26
	ACCURACY	92	PERCENT
	RESPONSE TIME	46.19	RESPONSES PER MINUTE
	THROUGHPUT	42.49	HITS PER MINUTE

Figure 2. Serial addition and subtraction task data.

3.4 Experimental Design

3.4.1 Independent Variables

This study is a three-factor, within-subjects design. The three independent variables were percent grade, cognitive task, and time of test. The independent variables and levels are shown in Table 3. The grades and cognitive tasks were counterbalanced to control for order effects.

Table 3. Independent variables

Variable Name	Levels
Grade (%)	0% 3.5% 7.0%
Cognitive Task	Wilkinson Reaction Time Serial Addition and Subtraction Serial Reaction Time Stroop
Time of test	Pre-exercise 15 minutes 30 minutes 45 minutes Post-exercise

3.4.2 Dependent Variables

The five dependent variables for this study were accuracy, response time, throughput, heart rate, and ratings of perceived exertion (RPE) (see Appendix B). The measures used for each dependent variable are shown in Table 4.

Table 4. Dependent variables

Dependent Variable	Measure
Accuracy	Percent correct
Response Time	Responses per minute, measured from
Throughput	Hits per minute (Correct per minute)
Heart rate	Beats per minute
Ratings of Perceived Exertion	Borg Scale

3.5 Experimental Procedures

Participants were given a vision screening by a Titmus vision tester to verify that they have 20/20 vision corrected or uncorrected. After passing the vision test, each participant received a short tour of the test area and a short explanation of the purpose of the research. Following the tour, participants read and signed the volunteer agreement affidavit, and any questions they had were answered.

Before the participants began the experiment, they were trained in the four cognitive tasks. Participants completed 12 practice sessions (Thorne et al., 1985): the first six sessions, while seated in front of a computer monitor and the last six, while walking on the treadmill. The last six training sessions, conducted while participants walked on the treadmill, helped the participants become comfortable with walking on the treadmill and eliminated the initial awkwardness of walking while performing the tasks. The training was conducted to control for potential learning effects (i.e., a significant improvement in accuracy, response time, and throughput for each of the cognitive tasks) and to ensure that each participant began the experiment with the same level of training. After the participants completed the 12th training session, the data for each of the four tasks were analyzed with t-tests to determine if there were significant differences between the training sessions. The rationale was that subjects could be classified as "trained" when there were no significant differences between the training sessions (see Appendix C). The analysis of the practice sessions indicated that subjects were fully trained, and the participants began the experimental trials (see Figure 3).

The grade used in each treatment condition was determined through counterbalancing as shown in Table 5. In addition, the cognitive tasks were counterbalanced in order to decrease the presence of order effects. The order of presentation of the cognitive tasks is shown in Table 6. This order was also used to create the customized cognitive test battery for each participant, which was used for all experimental trials. During the experiment, participants stood on the stationary treadmill, and their baseline heart rate was recorded. Then, they performed the pre-test. Upon completion of the pre-test, participants began walking on the treadmill at 1.56 meters/second (3.5 mph). Participants walked for a total of 45 minutes. At each 15-minute interval (i.e., 15 minutes, 30 minutes, 45 minutes), the participants' heart rate and RPE score were recorded, and they performed the four cognitive tasks, which took approximately 4 minutes. After completing all four tasks at the 45-minute interval, participants stopped walking and dismounted the treadmill. Their heart rate was monitored and when it returned to baseline, the participants mounted the stationary treadmill and performed the post-test. Upon completion of the post-test, participants dismounted the treadmill and returned the following day to perform the experiment while walking at a different grade. This procedure was followed until each participant performed the experiment at 0%, 3.5%, and 7.0% grades.

Figure 3. Participant walking on the treadmill.

Table 5. Balanced Latin square design for grades

	Subjects 1 & 7	**Subjects 2 & 8**	**Subjects 3 & 9**	**Subjects 4 & 10**	**Subjects 5 & 11**	**Subjects 6 & 12**
Presentation Order of Grades	0% 3.5% 7.0%	3.5% 7.0% 0%	7.0% 0% 3.5%	7.0% 3.5% 0%	0% 7.0% 3.5%	3.5% 0% 7.0%

Table 6. Balanced Latin square design for cognitive tasks

	Subject 1,5,& 9	**Subject 2, 6, & 10**	**Subject 3, 7, & 11**	**Subject 4, 8, &12**
Presentation Order of Cognitive Tasks	1	2	3	4
	2	3	4	1
	4	1	2	3
	3	4	1	2

Key: 1 = Wilkinson Choice Reaction Time Task
2 = Choice Reaction Time Task
3 = Serial Addition & Subtraction Task
4 = Stroop Task

4. Results

Before the actual statistical analysis was performed, a simple descriptive analysis of the data for each of the dependent variables was performed with the SAS[3] statistical analysis package. This review was performed to examine the shape of the distribution and to ensure that the data were entered correctly. The review revealed one potential outlier for response time on the Wilkinson Choice Reaction Time task. A further examination of the data indicated that a recording error had been made. The error was corrected and the data were analyzed. Output from the data analysis is shown in Appendix D.

4.1 Results of Physiological Variables

4.1.1 Heart Rate

The mean values for heart rate are presented in Figures 4 and 5. The results were analyzed with a two-way ANOVA, with repeated measures on both factors (grade and time). The Grade x Time interaction was significant $F\ (8,132) = 7.03, p < .0001$. This interaction is shown in Figure 6. *Post hoc* contrasts using Tukey's Honestly Significant Difference (HSD) Test indicated that heart rate was not affected by grade during the stationary trials (pre and post), but for the walking trials (15, 30, and 45 minutes), heart rate increased significantly with grade. The analysis also revealed a significant main effect of grade, $F\ (2,20) = 23.99, p < .0001$. *Post hoc* contrasts using Tukey's HSD Test found that there are significant differences among all three grades, indicating that participant heart rate increased as grade increased. The analysis also revealed a main effect of time, $F\ (4,132) = 219.14, p < .0001$. *Post hoc* contrasts using Tukey's HSD Test found that there are significant differences between the stationary trials (pre/post) and the walking trials, indicating that heart rate was significantly higher during the walking trials than during the stationary trials.

[3]SAS®, which is not an acronym, is a registered trademark of SAS Institute, Inc.

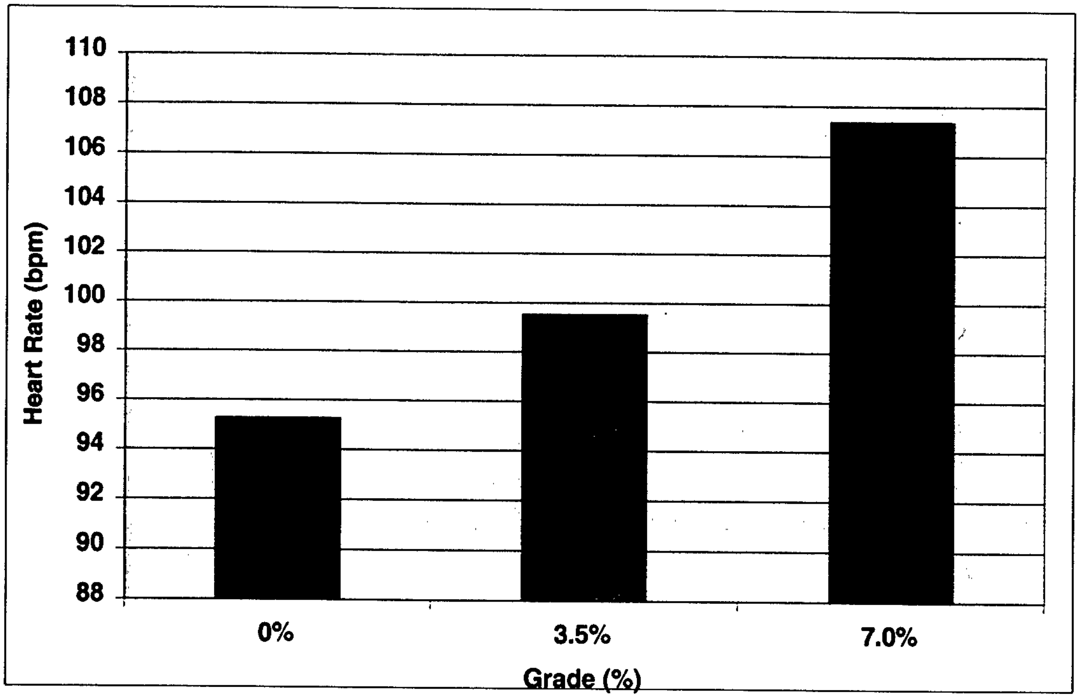

Figure 4. Mean heart rate values for each grade.

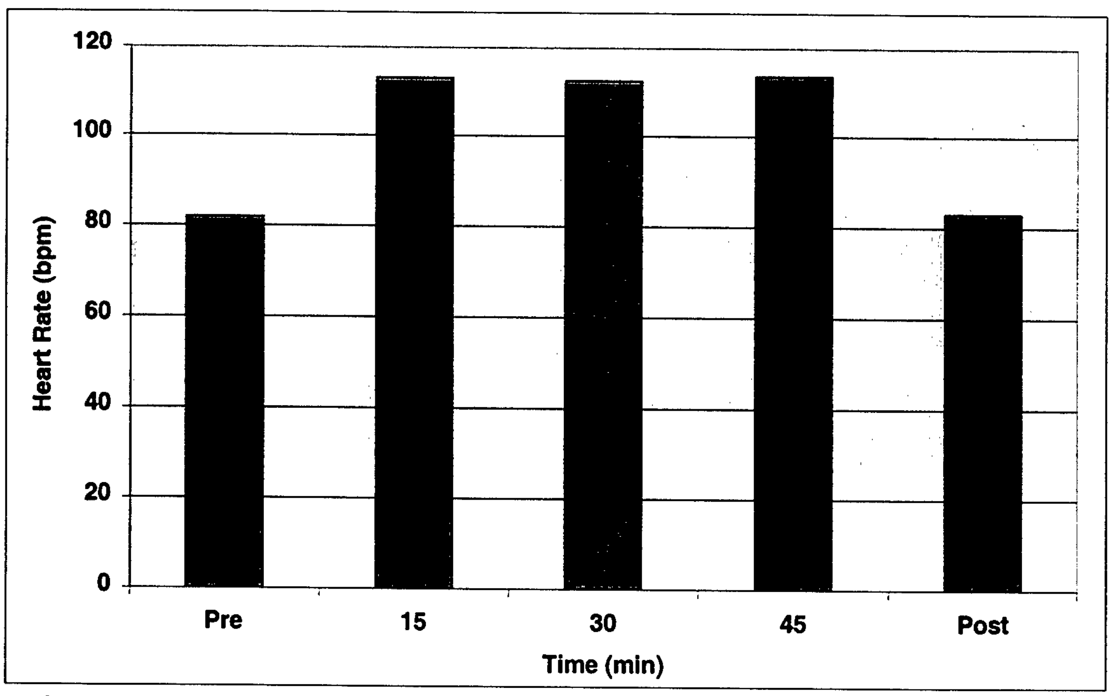

Figure 5. Mean heart rate values for each time.

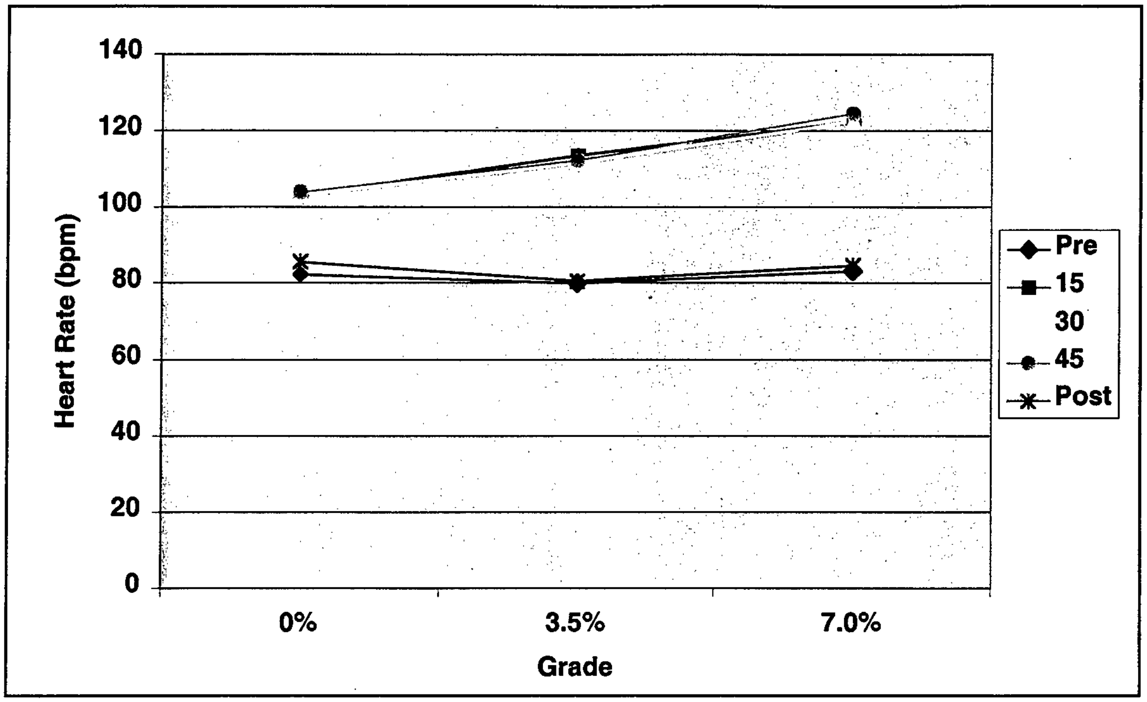

Figure 6. Grade x Time interaction (heart rate).

4.1.2 Rating of Perceived Exertion (RPE)

The mean values for RPE are presented in Figures 7 and 8. The results were analyzed with a two-way ANOVA, with repeated measures on both factors (grade and time). The Grade x Time interaction was significant F (8,132) = 4.94, $p < .0001$. This interaction is shown in Figure 9. *Post hoc* contrasts using Tukey's HSD Test indicate that RPE was not affected by grade during the stationary trials (pre and post), but for the walking trials (15, 30, and 45 minutes), RPE increased significantly as grade increased. The analysis also revealed a significant main effect of grade, F (2,20) = 15.61, $p < .0001$. *Post hoc* contrasts using Tukey's HSD Test found that RPE increased significantly as grade increased. The highest RPE was found at 7.0% grade, the next highest at 3.5% grade, and the lowest at 0% grade. This indicates that participants perceived that they were working harder as the grade increased. The analysis also showed a significant main effect of time F (4,132) = 204.78, $p < .0001$. *Post hoc* contrasts using Tukey's HSD Test found that the RPE was significantly higher for the walking trials (15 minutes, 30 minutes, and 45 minutes) than for the stationary trials (pre-test/post-test). In addition, the RPE was significantly higher at 30 minutes and 45 minutes than at 15 minutes.

4.2 Results of Cognitive Tasks

Individual three-way ANOVAs were performed on the three performance measures: accuracy, response time, and throughput data, with repeated measures on all three factors (grade, time, and task). Results are presented for each of the performance measures.

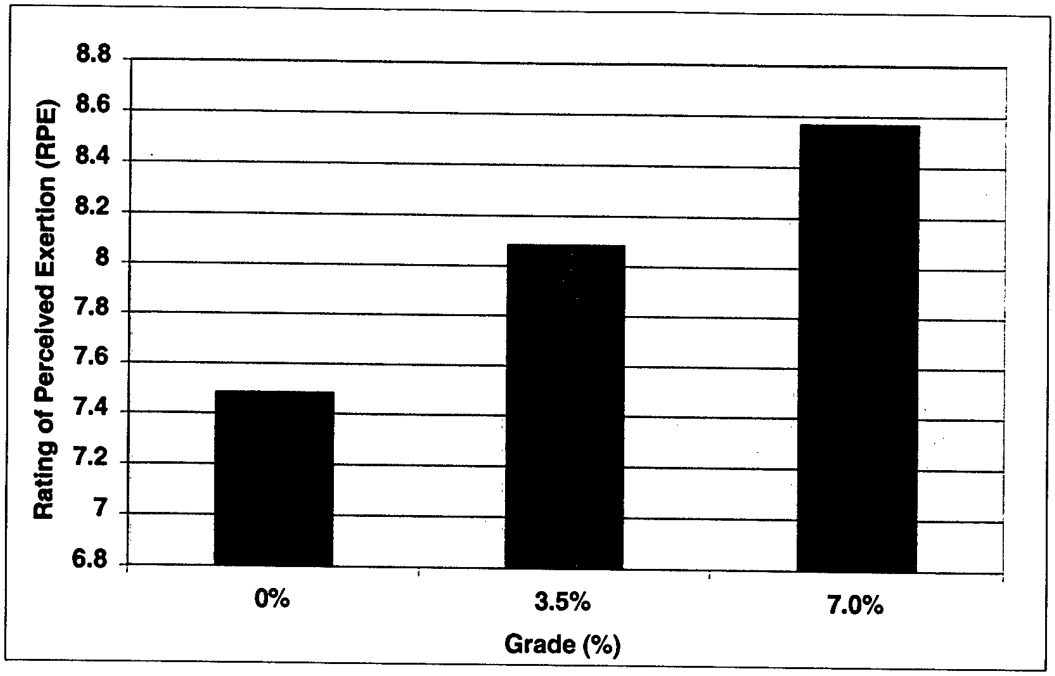

Figure 7. Mean RPE values for each grade.

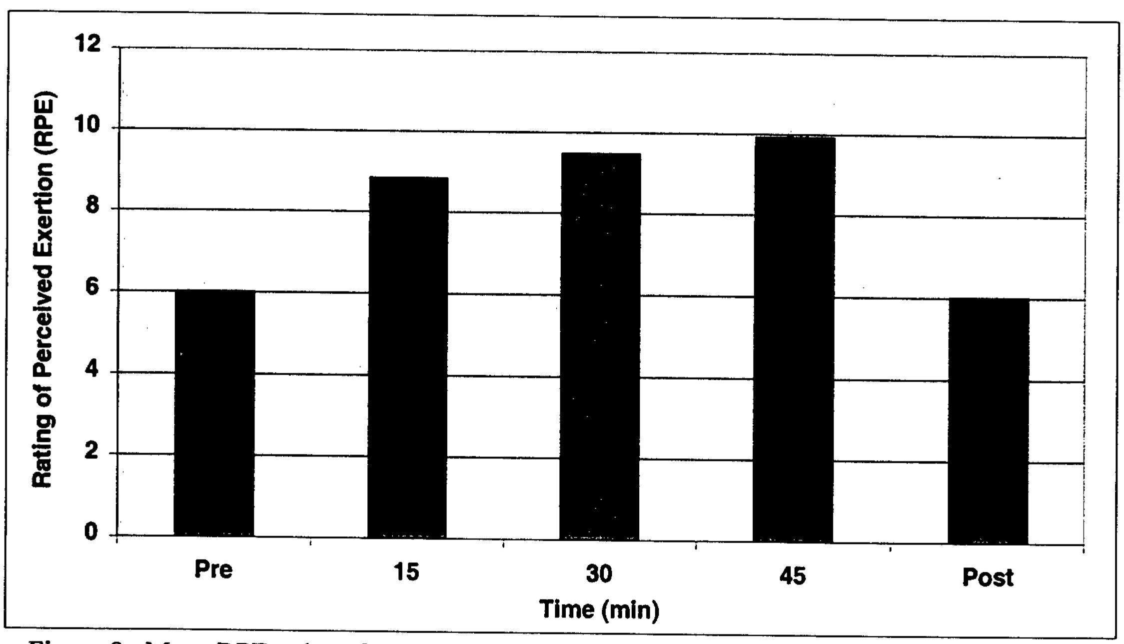

Figure 8. Mean RPE values for each time.

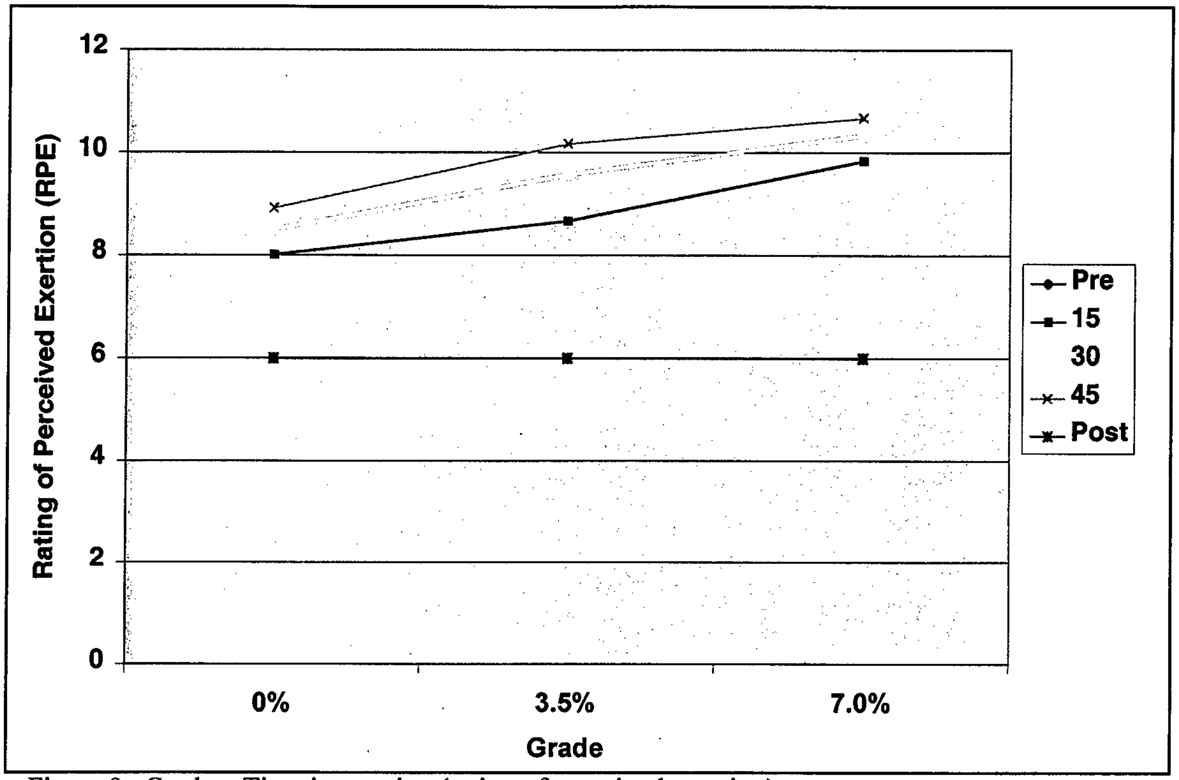

Figure 9. Grade x Time interaction (rating of perceived exertion).

4.2.1 Accuracy

Mean values for the accuracy measure are shown in Figure 10. The results of the three-way ANOVA indicate a significant main effect of Task F (3,644) = 49.50, $p < .0001$. No main effect of grade or time was found. The resulting main effect of task is not practically significant because it merely shows that different error rates are associated with the four tasks. Therefore, no further *post hoc* test was conducted.

4.2.2 Response Time

Mean values for the response time measure are shown in Figure 11. The results of the three-way ANOVA indicate a significant main effect of Time F (4,624) = 5.40, $p = 0.0005$. *Post hoc* contrasts using Tukey's HSD Test found that there were significantly more responses per minute at 45 minutes and during the post-test than during the pre-test. The results of the ANOVA also indicate a main effect of task F (3,624) = 1417.67, $p < 0.0001$. *Post hoc* contrasts using Tukey's HSD Test found that there were significant differences in the number of responses per minute for all the cognitive tasks. The choice reaction time task showed the most responses per minute, the Stroop task the next highest, the serial reaction time, the next highest, and the addition and subtraction task had the fewest responses per minute.

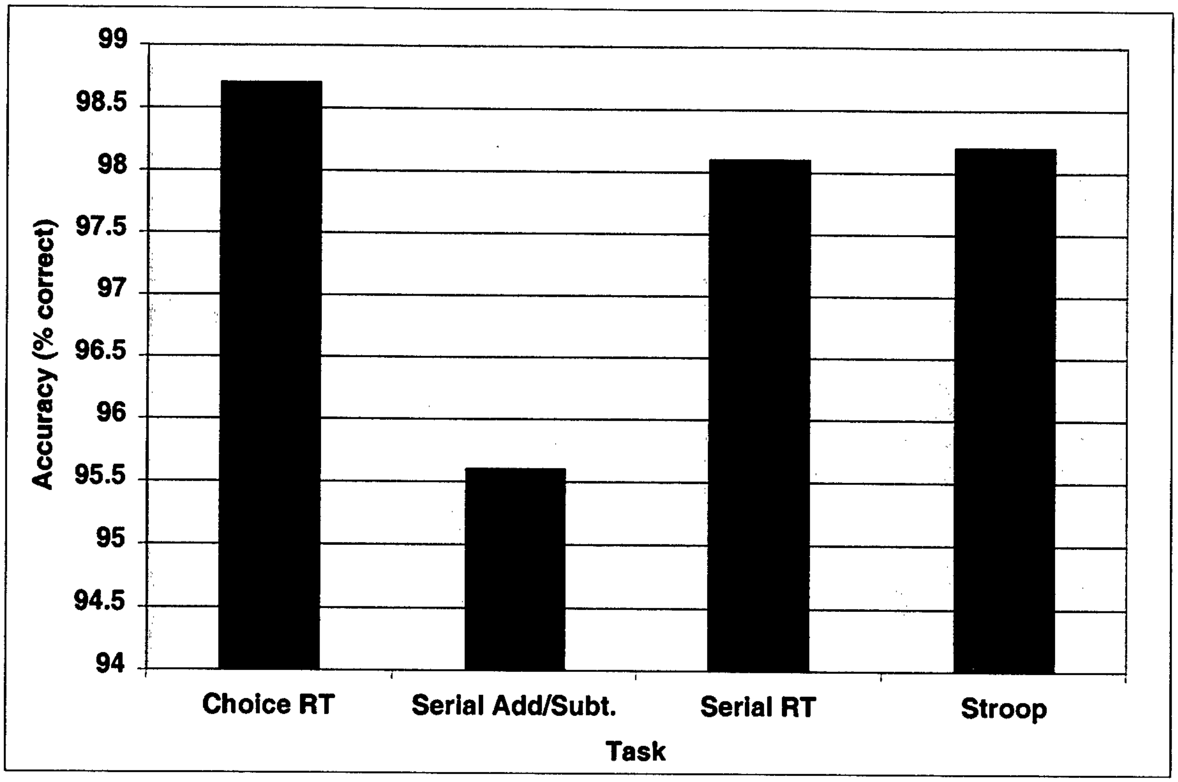

Figure 10. Mean accuracy values for the cognitive tasks.

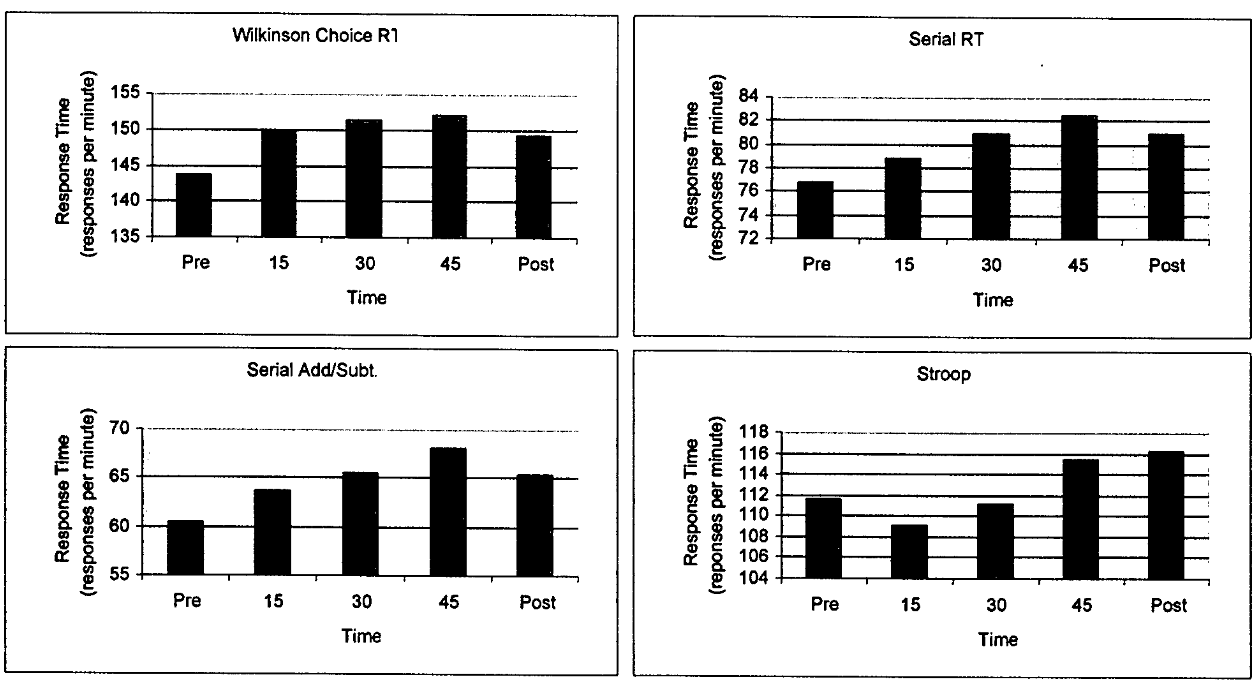

Figure 11. Mean response time values for the cognitive tasks.

4.2.2.1 Throughput

Mean values for the throughput measure are shown in Figure 12. The analysis revealed a significant main effect of time $F(4,624) = 3.50, p = .0077$ for all four tasks. *Post hoc* contrasts using Tukey's HSD Test found that there were significantly more hits per minute at 45 minutes than for the pre-test. The results of the ANOVA also indicate a main effect of task $F(3,624) = 1487.19, p < .0001$. *Post hoc* contrasts using Tukey's HSD Test found that the responses per minute were significantly different for all the cognitive tasks. The choice reaction time task showed the most hits per minute, the Stroop task the next highest, the serial reaction time, the next highest, and the addition and subtraction task had the fewest hits per minute.

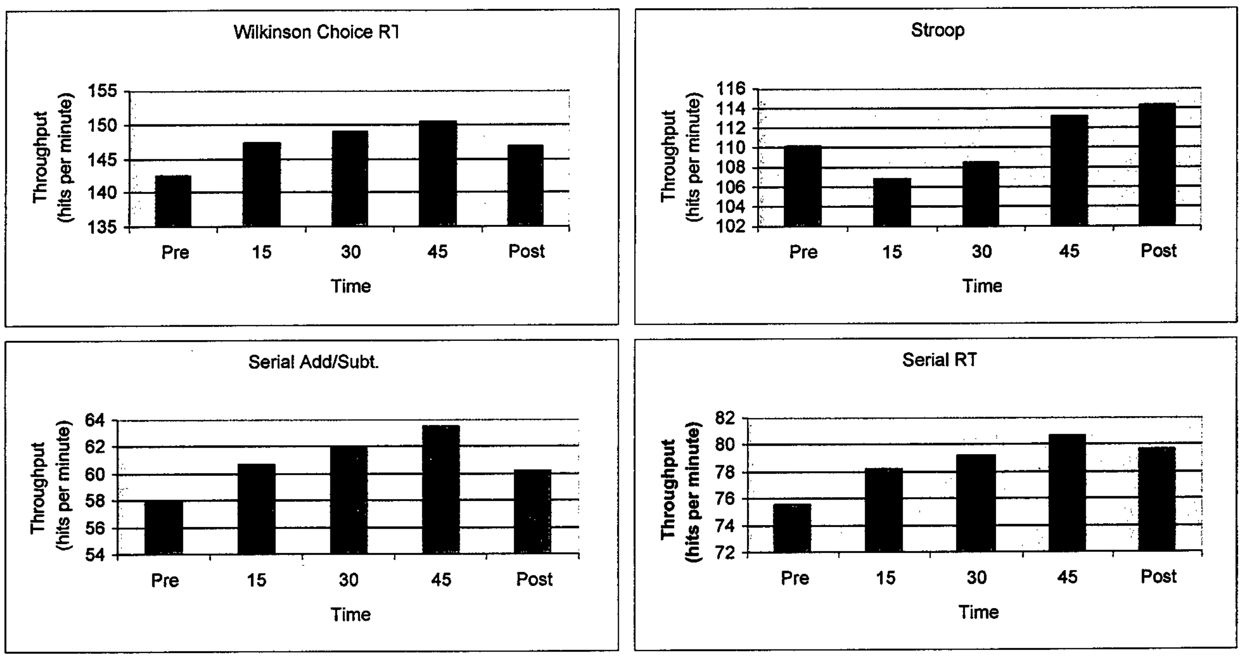

Figure 12. Mean throughput values for the cognitive tasks.

5. Discussion

As mentioned at the beginning of this report, the main objective of this research was to examine the effect of physical exertion on cognitive performance. In order to achieve this objective, specific questions were investigated. These questions are now presented in more detail, followed by the findings based on the results of the various analyses.

The first question that was investigated was whether physical exertion affects cognitive performance. The job of the infantry soldier requires considerable physical work while he or she is involved in critical decision making. As new technologies (e.g., wearable computers) permeate the soldier's everyday activities, the combined cognitive and physical demands are an important concern.

The results of the analysis for the physiological data show that both heart rate and rating of perceived exertion increased with grade and time (see Figures 4, 5, 7, and 8). These results are consistent with Borg (1973) and are expected as participants had to work harder as the grade increased.

An initial review of the results of the cognitive tasks (see Figures 11 and 12) implies that there is a statistically significant difference in response time and throughput. The results indicate that the physical exertion may have facilitated performance of the response time and throughput measures for all four cognitive tasks. This finding is consistent with those of McGlynn et al. (1977), McGlynn, Laughlin, and Rowe (1979), Paas and Adam (1991), and Gliner et al. (1979). One interesting finding is the difference in responses time and throughput for the pre-test and post-test. The experimental procedures allowed for time between the last walking trial and the post-test. This was to allow the participant's heart rate to return to baseline. It was originally thought that a possible explanation could be that we did not allow sufficient time for the heart rate to return to baseline, and this may have contributed to the differences in the responses time and throughput for the pre-test and post-test conditions. However, when we review the results of the heart rate analysis, it is clear that there were no significant differences in heart rate for the pre-test and post-test conditions. Therefore, it is possible that the participants were experiencing some residual arousal even after their heart rate had returned to baseline (Baradell & Klein, 1993).

Overall, results of the cognitive data analysis indicate that the physical exertion did have an effect on cognitive task performance. However, task accuracy was not affected by the physical exertion in this study, especially for the serial addition and subtraction task, considering that this task seemed to require a greater degree of information processing than the other tasks (see Table 2). This can be seen by examining the number of responses per minute and hits per minute for the serial addition and subtraction task (see Figures 11 and 12). It would be interesting to see if accuracy of cognitive tasks, including those that require more information processing, would be affected during a period of physical exertion that was more intense or of longer duration. In this study, the participants worked at a relatively low level of physical exertion, which is reflected in the heart rate and RPE values. The mean heart rate did not exceed 110 beats per minute (see Figures 4 and 5) and the mean RPE (see Figures 7 and 8) score did not exceed 10 on a 20-point scale. Perhaps we would start to see more errors at high levels of physical exertion over a longer period. Most studies that have been performed have looked at moderate to high levels of exertion for a short duration of time; very few have investigated the effects of low, moderate, or high levels of exertion over a long duration (Mozrall & Drury, 1996).

The second question this study tried to answer was what types of tasks are affected by physical exertion? The results show that there were significant differences in performance for all four cognitive tasks. As discussed previously, response time decreased and throughput increased over time. These findings indicate that the two reaction time tasks, the information processing task, and the decision-making task were all impacted by the physical exertion. In this research effort, the participants worked at a relatively low level of physical exertion. A soldier's ability to perform tasks quickly and accurately may be compromised during higher levels of physical stress. For example, the inverted U theory (Davey, 1973), discussed in the literature review section, suggests that arousal can actually enhance performance to an optimum level. Once arousal peaks beyond the optimum level, performance falls off rapidly. This should be explored in research using higher levels of physical exertion, which may lead to increases in errors and increased response time, which could significantly impact the soldier's performance on the battlefield.

6. Conclusions

The purpose of this research was to examine the effects of different levels of physical exercise on cognitive performance. As wearable computer technology progresses, so does the amount of information that can be delivered to the soldier.

This can become a serious problem when a soldier must receive, process, and respond to information during high levels of physical stress. The results indicate that physical exertion impacts physiological and cognitive performance. In this study, heart rate and rating of perceived exertion increased as exercise became more strenuous. The results of the cognitive tasks are consistent with others found in the literature (McGlynn, Laughlin, & Bender, 1977 and McGlynn et al., 1979). We found an increase in throughput and a decrease in response time for all four cognitive tasks, which indicates that soldier tasks such as performing quantitative analysis, solving problems, and recalling rules and procedures (see Figure 1) were influenced by the physical exertion. These are important findings and will be incorporated into future research.

7. Recommendations

This research has helped to fill the data gap regarding the effects of physical exertion on cognitive performance; however, future research is still needed. One area that should be explored is the effect of moderate to heavy physical exertion over a longer duration. Other factors that should be investigated include external load and environmental factors, since both of these can affect the level of physical exertion. In addition, it may prove helpful to group tasks according to their function (e.g., decision making, psychomotor) in order to generalize these results to other situations.

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Appendix A: Volunteer Agreement Affidavit

	Army Research Laboratory, Aberdeen Proving Ground, MD	
Title of Research Project:	Effects of Physical Exertion on Cognitive Performance.	Log No.:
Principal Investigator:	Andrea Krausman	Phone No. (com): (410) 278-5814
Location of Investigation:	Building 518, APG, MD	

Description of the study

You have been asked to participate in a study that will help identify if physical exercise effects your ability to do different cognitive tasks. During this study, you will perform different cognitive tasks as you walk on a treadmill. This area of research is important especially in jobs where operator roles are expanding and many tasks require increased cognitive processing as well as physical demands. This type of research can provide useful information about workload so that tasks can be redesigned or reallocated and serious mistakes or injuries can be prevented.

Two days before the test you will come to the lab and you will be trained on the cognitive tasks. The cognitive tasks you will perform are choice reaction time, serial reaction time, addition and subtraction, and the stroop task. During some of the training sessions you will sit in a chair in front of a computer monitor and perform the cognitive tasks. For others, you will walk on the treadmill and perform the cognitive tasks simultaneously. There will be a total of twelve training sessions. You will also complete a vision screening test to make sure that you have 20/20 vision (normal or corrected).

On the test day you will come to the lab and your baseline heart rate will be recorded. You will take a 5-minute cognitive pretest before you exercise. Following the cognitive test, you will mount the treadmill and begin the walking trial. You will walk on the treadmill for 30 minutes at one of the following levels: 1.56 m/s (3.5 mph) at 0%, 3.5%, or 7.0% grade After 15 minutes of walking on the treadmill you will answer the cognitive tasks. You will be asked for an RPE score at the end of each trial. You will repeat the same procedure at 30 minutes and 45 minutes. Following the last set of cognitive tasks at 45 minutes, you will dismount the treadmill and your heart rate will be monitored. When it returns to baseline, you will take a 5-minute cognitive posttest. This will complete the testing for that day. The approximate time for one trial is one hour. You will return to the lab two more times to complete the other two trials.

During the testing, you may be photographed or videotaped but your identity will not be revealed.

Risks

Because it is physical exercise, fast walking can uncover or worsen pre-existing heart problems such as impaired blood flow to the heart muscle and irregular beats. It is doubtful that voluntary exercise can cause problems without pre-existing heart disease or underlying heart defect. Since you are physically fit and active, and have been medically cleared for exercise testing, you are unlikely to have problems with your heart or circulatory system. Should you develop symptoms of any medical problems, testing will be stopped immediately and the ambulance service will be notified. There is also a risk of stumbling or falling on the treadmill causing bodily harm. A member of the research team will be sitting close to you to provide immediate assistance should this occur. Exercise mats will be placed around the treadmill so that if you do fall, you will not get hurt. There is also a stop button that you may press if you begin to stumble, feel unstable, or you begin to experience problems or discomfort while walking on the treadmill.

Testing will occur only during normal duty hours when emergency medical services are available within ten minutes of the test site from the Ambulance Services, Building 2200, Aberdeen Proving Ground which can be accessed by dialing 911. There will be a working telephone in the testing area so that ambulance service can be contacted if necessary. Personnel and investigators present at the testing site will be able to provide CPR and basic first aid. Prior to the beginning of each test, the principal investigator will provide the supporting medical facility with the number of participating volunteers and the test commencement and completion times. If emergency medical services become unavailable at any time during testing, all procedures will be stopped. Testing will commence again only if services become available within a reasonable amount of time and the principal investigator determines that continuation of testing is warranted.

Other risks include muscle fatigue, soreness, and blisters. Please notify the experimenter if you experience any of these symptoms.

Benefits

This research will provide the Army Research Laboratory with information regarding how well people can perform cognitive tasks before, during, and after strenuous exercise. This research has the potential to help people in occupations that require people to perform mental and physical work simultaneously.

Confidentiality

All data collected from your participation will be confidential. It will be published in an anonymous format.

Points of contact

For answers to pertinent questions about the study, the study participant's rights, or a study-related injury to the participant contact Andrea Krausman, Army Research Laboratory, AMSRL-HR-MB, APG, MD, (410) 278-5814 or DSN 298-5814.

Participant's rights

a. Your participation is voluntary.

b. Refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled.

c. You may discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled.

Compensation.

You will not be compensated for your participation other than your normal duty pay.

Cautions

a. You should thoroughly read the consent form before signing.

b. You should alert the test administrator of any physical ailments previous to the test, not included on your medical records, that could affect your performance, as well as, endanger your health.

c. You should alert the test administrator of any physical ailments that you may have resulted from the test and seek medical attention, if necessary.

d. Should early data show results that would cause the test administrator to alter the study, you will have the right to withdraw.

e. Approximately 12 participants will be involved in the study. A maximum of one participant will be tested at on time.

f. You may ask about, and be given, only your individual results.

g. The required time to complete the study will be approximately three hours (one hour per trial, per day) plus two days for training on the cognitive tasks.

Disposition of Volunteer Agreement Affidavit

The principal investigator will retain the original signed Volunteer Agreement Affidavit and forward it to the chair of the Human Use Committee after the investigation. If you wish, the test administrator will provide you with a copy. If requested, the principal investigator shall provide an additional copy of this signed Volunteer Agreement Affidavit either to the medical records custodian for inclusion in your medical treatment record (**AR 40-66**, para **6-2f**) or when no medical custodian is identified, to you for inclusion in your primary physician's file.

Any published data will not reveal your identity. Your participation in this evaluation is voluntary. If you choose not to participate in this evaluation, or later wish to withdraw from any portion of it, you may do so without penalty. No administrative sanctions can be taken against military or civilian personnel for choosing not to participate as human subjects.

The furnishing of your social security number and home address is mandatory and necessary for identification and locating purposes 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 study. Information derived from this study will be used to document the study, to implement medical programs, to adjudicate claims, and for the mandatory reporting of medical conditions as required by law. Information may be furnished to Federal, State, and local agencies. Collection of this information is authorized by **10 USC 3013, 44 USC 3101**, and **10 USC 1071-1087**. Under the provisions of **AR 40-38** and **AR 70-25**, volunteers are authorized all necessary medical care for injury or disease which is the proximate result of their participation in this study.

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

PRINTED NAME OF VOLUNTEER	DATE	SOCIAL SECURITY NUMBER	DATE OF BIRTH	
SIGNATURE OF VOLUNTEER	PERMANENT ADDRESS OF VOLUNTEER			
TYPED NAME OF TEST ADMINISTRATOR				
SIGNATURE OF TEST ADMINISTRATOR	**MILITARY**: DO YOU REQUEST A COPY OF THIS VOLUN AGREEMENT AFFIDAVIT TO BE FORWARDED TO THE CUSTODIAN OI MEDICAL RECORDS? **CIVILIAN**: DO YOU REQUEST A SECOND COPY FOR YC YOUR PRIMARY PHYSICIAN?		YES	NO

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

Chair, Human Use Committee
Army Research Laboratory
Human Research & Engineering Directorate
Aberdeen Proving Ground, MD 21005-5425

(OR)

Office of the Chief Counsel
Army Research Laboratory
2800 Powder Mill Road
Adelphi, MD 20783-1197

Appendix B: Borg Scale

The Borg Scale for Ratings of Perceived Exertion
(Borg, 1972)

6	No exertion at all
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

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Appendix C: Analysis of Training Data

Paired-samples t-test between successive training sessions for cognitive tasks

Task	Training Session Number (Accuracy)										
	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12
Wilkinson Choice Reaction	0.16	0.17	0.17	0.05	0.52	1.00	0.39	1.00	0.66	0.75	0.41
Serial Reaction	0.12	0.02	1.00	1.00	0.09	0.21	0.63	0.08	0.39	0.29	0.53
Serial Add and Subtraction	0.01	0.64	0.32	0.80	0.75	0.19	0.13	0.43	0.18	0.08	0.84
Stroop	0.05	0.78	0.03	0.21	0.39	1.00	0.37	1.00	0.99	0.55	0.49

Task	Training Session Number (Response Time)										
	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12
Wilkinson Choice Reaction	0.00	0.05	0.57	0.08	0.29	0.36	0.07	0.46	0.58	0.14	0.75
Serial Reaction	0.63	0.45	0.14	0.58	0.59	0.92	0.10	0.79	0.11	0.98	0.55
Serial Add and Subtraction	0.00	0.05	0.82	0.76	0.19	0.00	0.99	0.22	0.59	0.08	0.81
Stroop	0.11	0.09	0.20	0.73	0.02	0.96	0.68	0.59	0.73	0.13	0.84

Task	Training Session Number (Throughput)										
	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12
Wilkinson Choice Reaction	0.00	0.11	0.80	0.03	0.35	0.43	0.06	0.48	0.55	0.15	0.62
Serial Reaction	0.37	0.14	0.21	0.64	0.80	0.71	0.34	0.71	0.10	0.78	0.75
Serial Add and Subtraction	0.00	0.07	0.88	0.72	0.14	0.00	0.52	0.28	0.80	0.98	0.41
Stroop	0.07	0.09	0.13	0.61	0.03	0.98	0.56	0.61	0.13	0.18	0.66

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Appendix D: Output From SAS

Physiological Data Analysis – Heart Rate (HR)

The SAS System
The Mixed Procedure
Model Information

Data Set	WORK.PHYS2
Dependent Variable	HEART RATE
Covariance Structure	Variance Components
Estimation Method	REML
Residual Variance Method	Profile
Fixed Effects SE Method	Model-Based
Degrees of Freedom Method	Satterthwaite

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Grade	2	20	23.99	<.0001
Time	4	132	219.14	<.0001
Grade*Time	8	132	7.03	<.0001

Differences of Least Squares Means

Effect	Grade	Time	Grade	Time	Adj P
Grade	1		2		0.0635
Grade	1		3		<.0001
Grade	2		3		0.0007
Time		1		2	<.0001
Time		1		3	<.0001
Time		1		4	<.0001
Time		1		5	0.9539
Time		2		3	0.9955
Time		2		4	0.9979
Time		2		5	<.0001
Time		3		4	0.9578
Time		3		5	<.0001
Time		4		5	<.0001
Grade*Time	1	1	1	2	<.0001
Grade*Time	1	1	1	3	<.0001
Grade*Time	1	1	1	4	<.0001
Grade*Time	1	1	1	5	1.0000
Grade*Time	1	1	2	1	1.0000
Grade*Time	1	1	2	2	<.0001
Grade*Time	1	1	2	3	<.0001
Grade*Time	1	1	2	4	<.0001
Grade*Time	1	1	2	5	1.0000
Grade*Time	1	1	3	1	1.0000

Grade*Time	1	1	3	2	<.0001
Grade*Time	1	1	3	3	<.0001
Grade*Time	1	1	3	4	<.0001
Grade*Time	1	1	3	5	1.0000
Grade*Time	1	2	1	3	1.0000
Grade*Time	1	2	1	4	1.0000
Grade*Time	1	2	1	5	<.0001
Grade*Time	1	2	2	1	<.0001
Grade*Time	1	2	2	2	0.0723
Grade*Time	1	2	2	3	0.3004
Grade*Time	1	2	2	4	0.2018
Grade*Time	1	2	2	5	<.0001
Grade*Time	1	2	3	1	<.0001
Grade*Time	1	2	3	2	<.0001
Grade*Time	1	2	3	3	<.0001
Grade*Time	1	2	3	4	<.0001
Grade*Time	1	2	3	5	<.0001
Grade*Time	1	3	1	4	1.0000
Grade*Time	1	3	1	5	<.0001
Grade*Time	1	3	2	1	<.0001
Grade*Time	1	3	2	2	0.0670
Grade*Time	1	3	2	3	0.2848
Grade*Time	1	3	2	4	0.1898
Grade*Time	1	3	2	5	<.0001
Grade*Time	1	3	3	1	<.0001
Grade*Time	1	3	3	2	<.0001
Grade*Time	1	3	3	3	<.0001
Grade*Time	1	3	3	4	<.0001
Grade*Time	1	3	3	5	<.0001
Grade*Time	1	4	1	5	<.0001
Grade*Time	1	4	2	1	<.0001
Grade*Time	1	4	2	2	0.1285
Grade*Time	1	4	2	3	0.4412
Grade*Time	1	4	2	4	0.3165
Grade*Time	1	4	2	5	<.0001
Grade*Time	1	4	3	1	<.0001
Grade*Time	1	4	3	2	<.0001
Grade*Time	1	4	3	3	<.0001
Grade*Time	1	4	3	4	<.0001
Grade*Time	1	4	3	5	<.0001
Grade*Time	1	5	2	1	0.9969
Grade*Time	1	5	2	2	<.0001
Grade*Time	1	5	2	3	<.0001
Grade*Time	1	5	2	4	<.0001
Grade*Time	1	5	2	5	0.9995
Grade*Time	1	5	3	1	1.0000
Grade*Time	1	5	3	2	<.0001
Grade*Time	1	5	3	3	<.0001
Grade*Time	1	5	3	4	<.0001
Grade*Time	1	5	3	5	1.0000
Grade*Time	2	1	2	2	<.0001
Grade*Time	2	1	2	3	<.0001
Grade*Time	2	1	2	4	<.0001
Grade*Time	2	1	2	5	1.0000
Grade*Time	2	1	3	1	0.9994
Grade*Time	2	1	3	2	<.0001
Grade*Time	2	1	3	3	<.0001

Grade*Time	2	1	3	4	<.0001
Grade*Time	2	1	3	5	0.9699
Grade*Time	2	2	2	3	1.0000
Grade*Time	2	2	2	4	1.0000
Grade*Time	2	2	2	5	<.0001
Grade*Time	2	2	3	1	<.0001
Grade*Time	2	2	3	2	0.2018
Grade*Time	2	2	3	3	0.1898
Grade*Time	2	2	3	4	0.0324
Grade*Time	2	2	3	5	<.0001
Grade*Time	2	3	2	4	1.0000
Grade*Time	2	3	2	5	<.0001
Grade*Time	2	3	3	1	<.0001
Grade*Time	2	3	3	2	0.0416
Grade*Time	2	3	3	3	0.0383
Grade*Time	2	3	3	4	0.0042
Grade*Time	2	3	3	5	<.0001
Grade*Time	2	4	2	5	<.0001
Grade*Time	2	4	3	1	<.0001
Grade*Time	2	4	3	2	0.0723
Grade*Time	2	4	3	3	0.0670
Grade*Time	2	4	3	4	0.0084
Grade*Time	2	4	3	5	<.0001
Grade*Time	2	5	3	1	0.9999
Grade*Time	2	5	3	2	<.0001
Grade*Time	2	5	3	3	<.0001
Grade*Time	2	5	3	4	<.0001
Grade*Time	2	5	3	5	0.9909
Grade*Time	3	1	3	2	<.0001
Grade*Time	3	1	3	3	<.0001
Grade*Time	3	1	3	4	<.0001
Grade*Time	3	1	3	5	1.0000
Grade*Time	3	2	3	3	1.0000
Grade*Time	3	2	3	4	1.0000
Grade*Time	3	2	3	5	<.0001
Grade*Time	3	3	3	4	1.0000
Grade*Time	3	3	3	5	<.0001
Grade*Time	3	4	3	5	<.0001

Physiological Data Analysis – Rating of Perceived Exertion (RPE)

The SAS System
The Mixed Procedure
Model Information

Data Set	WORK.PHYS2
Dependent Variable	RPE
Covariance Structure	Variance Components
Estimation Method	REML
Residual Variance Method	Profile
Fixed Effects SE Method	Model-Based
Degrees of Freedom Method	Satterthwaite

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Grade	2	20	15.61	<.0001
Time	4	132	204.78	<.0001
Grade*Time	8	132	4.94	<.0001

Differences of Least Squares Means

Effect	Grade	Time	Grade	Time	Adj P
Grade	1		2		0.0153
Grade	1		3		<.0001
Grade	2		3		0.0544
Time		1		2	<.0001
Time		1		3	<.0001
Time		1		4	<.0001
Time		1		5	1.0000
Time		2		3	0.0080
Time		2		4	<.0001
Time		2		5	<.0001
Time		3		4	0.1330
Time		3		5	<.0001
Time		4		5	<.0001
Grade*Time	1	1	1	2	<.0001
Grade*Time	1	1	1	3	<.0001
Grade*Time	1	1	1	4	<.0001
Grade*Time	1	1	1	5	1.0000
Grade*Time	1	1	2	1	1.0000
Grade*Time	1	1	2	2	<.0001
Grade*Time	1	1	2	3	<.0001
Grade*Time	1	1	2	4	<.0001
Grade*Time	1	1	2	5	1.0000
Grade*Time	1	1	3	1	1.0000
Grade*Time	1	1	3	2	<.0001
Grade*Time	1	1	3	3	<.0001
Grade*Time	1	1	3	4	<.0001
Grade*Time	1	1	3	5	1.0000
Grade*Time	1	2	1	3	0.9690
Grade*Time	1	2	1	4	0.2547
Grade*Time	1	2	1	5	<.0001

Grade*Time	1	2	2	1	<.0001
Grade*Time	1	2	2	2	0.8479
Grade*Time	1	2	2	3	0.0013
Grade*Time	1	2	2	4	<.0001
Grade*Time	1	2	2	5	<.0001
Grade*Time	1	2	3	1	<.0001
Grade*Time	1	2	3	2	<.0001
Grade*Time	1	2	3	3	<.0001
Grade*Time	1	2	3	4	<.0001
Grade*Time	1	2	3	5	<.0001
Grade*Time	1	3	1	4	0.9942
Grade*Time	1	3	1	5	<.0001
Grade*Time	1	3	2	1	<.0001
Grade*Time	1	3	2	2	1.0000
Grade*Time	1	3	2	3	0.1347
Grade*Time	1	3	2	4	0.0005
Grade*Time	1	3	2	5	<.0001
Grade*Time	1	3	3	1	<.0001
Grade*Time	1	3	3	2	0.0169
Grade*Time	1	3	3	3	<.0001
Grade*Time	1	3	3	4	<.0001
Grade*Time	1	3	3	5	<.0001
Grade*Time	1	4	1	5	<.0001
Grade*Time	1	4	2	1	<.0001
Grade*Time	1	4	2	2	1.0000
Grade*Time	1	4	2	3	0.8479
Grade*Time	1	4	2	4	0.0360
Grade*Time	1	4	2	5	<.0001
Grade*Time	1	4	3	1	<.0001
Grade*Time	1	4	3	2	0.3698
Grade*Time	1	4	3	3	0.0075
Grade*Time	1	4	3	4	0.0002
Grade*Time	1	4	3	5	<.0001
Grade*Time	1	5	2	1	1.0000
Grade*Time	1	5	2	2	<.0001
Grade*Time	1	5	2	3	<.0001
Grade*Time	1	5	2	4	<.0001
Grade*Time	1	5	2	5	1.0000
Grade*Time	1	5	3	1	1.0000
Grade*Time	1	5	3	2	<.0001
Grade*Time	1	5	3	3	<.0001
Grade*Time	1	5	3	4	<.0001
Grade*Time	1	5	3	5	1.0000
Grade*Time	2	1	2	2	<.0001
Grade*Time	2	1	2	3	<.0001
Grade*Time	2	1	2	4	<.0001
Grade*Time	2	1	2	5	1.0000
Grade*Time	2	1	3	1	1.0000
Grade*Time	2	1	3	2	<.0001
Grade*Time	2	1	3	3	<.0001
Grade*Time	2	1	3	4	<.0001
Grade*Time	2	1	3	5	1.0000
Grade*Time	2	2	2	3	0.2547
Grade*Time	2	2	2	4	0.0009
Grade*Time	2	2	2	5	<.0001
Grade*Time	2	2	3	1	<.0001
Grade*Time	2	2	3	2	0.0721

Grade*Time	2	2	3	3	0.0005
Grade*Time	2	2	3	4	<.0001
Grade*Time	2	2	3	5	<.0001
Grade*Time	2	3	2	4	0.8986
Grade*Time	2	3	2	5	<.0001
Grade*Time	2	3	3	1	<.0001
Grade*Time	2	3	3	2	1.0000
Grade*Time	2	3	3	3	0.7060
Grade*Time	2	3	3	4	0.1347
Grade*Time	2	3	3	5	<.0001
Grade*Time	2	4	2	5	<.0001
Grade*Time	2	4	3	1	<.0001
Grade*Time	2	4	3	2	0.9998
Grade*Time	2	4	3	3	1.0000
Grade*Time	2	4	3	4	0.9834
Grade*Time	2	4	3	5	<.0001
Grade*Time	2	5	3	1	1.0000
Grade*Time	2	5	3	2	<.0001
Grade*Time	2	5	3	3	<.0001
Grade*Time	2	5	3	4	<.0001
Grade*Time	2	5	3	5	1.0000
Grade*Time	3	1	3	2	<.0001
Grade*Time	3	1	3	3	<.0001
Grade*Time	3	1	3	4	<.0001
Grade*Time	3	1	3	5	1.0000
Grade*Time	3	2	3	3	0.9690
Grade*Time	3	2	3	4	0.4100
Grade*Time	3	2	3	5	<.0001
Grade*Time	3	3	3	4	0.9994
Grade*Time	3	3	3	5	<.0001
Grade*Time	3	4	3	5	<.0001

Cognitive Task Data Analysis – Accuracy (ACC)

The Mixed Procedure

Model Information

Data Set	WORK.COG2
Dependent Variable	ACC
Covariance Structure	Variance Components
Estimation Method	REML
Residual Variance Method	Profile
Fixed Effects SE Method	Model-Based
Degrees of Freedom Method	Satterthwaite

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Grade	2	644	0.56	0.5727
Time	4	644	1.69	0.1505
Grade*Time	8	644	0.68	0.7090
Task	3	644	49.50	<.0001
Grade*Task	6	644	0.87	0.5193
Time*Task	12	644	0.40	0.9630
Grade*Time*Task	24	644	0.75	0.7980

Differences of Least Squares Means

Effect	Task	Task	Adj P
Task	1	2	<.0001
Task	1	3	0.3259
Task	1	4	0.2548
Task	2	3	<.0001
Task	2	4	<.0001
Task	3	4	0.9992

Cognitive Task Data Analysis – Response Time (RT)

The Mixed Procedure
Model Information

Data Set	WORK.COG2
Dependent Variable	RT
Covariance Structure	Variance Components
Estimation Method	REML
Residual Variance Method	Profile
Fixed Effects SE Method	Model-Based
Degrees of Freedom Method	Satterthwaite

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Grade	2	20	1.44	0.2600
Time	4	624	5.04	0.0005
Grade*Time	8	624	0.44	0.8992
Task	3	624	1417.67	<.0001
Grade*Task	6	624	0.56	0.7656
Time*Task	12	624	0.61	0.8350
Grade*Time*Task	24	624	0.24	0.9999

Differences of Least Squares Means

Effect	Time	Task	Time	Task	Adj P
Time	1		2		0.5821
Time	1		3		0.0652
Time	1		4		0.0004
Time	1		5		0.0170
Time	2		3		0.7710
Time	2		4		0.0615
Time	2		5		0.4764
Time	3		4		0.5674
Time	3		5		0.9902
Time	4		5		0.8438
Task		1		2	<.0001
Task		1		3	<.0001
Task		1		4	<.0001
Task		2		3	<.0001
Task		2		4	<.0001
Task		3		4	<.0001

Cognitive Task Data Analysis – Throughput (TP)

The SAS System
The Mixed Procedure

Model Information

Data Set	WORK.COG2
Dependent Variable	TP
Covariance Structure	Variance Components
Estimation Method	REML
Residual Variance Method	Profile
Fixed Effects SE Method	Model-Based
Degrees of Freedom Method	Satterthwaite

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Grade	2	20	1.88	0.1789
Time	4	624	3.50	0.0077
Grade*Time	8	624	0.32	0.9590
Task	3	624	1487.19	<.0001
Grade*Task	6	624	0.78	0.5847
Time*Task	12	624	0.69	0.7621
Grade*Time*Task	24	624	0.28	0.9998

Differences of Least Squares Means

Effect	Time	Task	Time	Task	Adj P
Time	1		2		0.7933
Time	1		3		0.2538
Time	1		4		0.0045
Time	1		5		0.1146
Time	2		3		0.8958
Time	2		4		0.1235
Time	2		5		0.7021
Time	3		4		0.5810
Time	3		5		0.9956
Time	4		5		0.8105
Task		1		2	<.0001
Task		1		3	<.0001
Task		1		4	<.0001
Task		2		3	<.0001
Task		2		4	<.0001
Task		3		4	<.0001

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13. ABSTRACT *(Maximum 200 words)*

This study examined the cognitive and physiological performance of soldiers as they exercised on a treadmill at various grades. Twelve soldiers walked at 1.56 m/sec on three grades, 0%, 3.5%, and 7.0%. The cognitive tasks performed by the soldiers were taken from the Walter Reed Performance Assessment Battery. The tasks chosen for this study included two reaction time tasks, an arithmetic task, and a decision-making task. Three measures were used to evaluate performance of the cognitive tasks: accuracy (percent correct), response time (responses per minute), and throughput (hits per minute). The physiological variables were heart rate and rating of perceived exertion. The findings of the research strongly support the fact that physical exertion does impact cognitive performance. Results indicate that the physical exertion facilitated performance of the two reaction time tasks and the decision-making task. Performance of the arithmetic task was degraded. The physiological results were compatible with those of progressive exercise.

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