2005

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Recommended Citation

Goodson, Annie J., "Effect of Supplemental Feeding on Cognitive Function in Wildland Firefighters During Arduous Fire" (2005). *Graduate Student Theses, Dissertations, & Professional Papers*. 9283.
https://scholarworks.umt.edu/etd/9283

EFFECT OF SUPPLEMENTAL FEEDING ON COGNITIVE FUNCTION IN WILDLAND FIREFIGHTERS DURING ARDUOUS FIRE

by

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B.S. University of Mary, Bismarck, ND, 2002

presented in partial fulfillment of the requirements

for the degree of

Master of Science

The University of Montana

May 2005

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5-25-05

Date

Goodson, Annie J. M.S., May 2005 Health and Human Performance

Effect of Supplemental Feeding on Cognitive Function in Wildland Firefighters During Arduous Fire Suppression

Chairperson, Steven E. Gaskill, Ph.D.

Previous field research with wild land firefighters (WLFF) has shown that supplemental carbohydrate (CHO) feeding, compared to a placebo (PLA) helps to maintain blood glucose, increase total daily work, and maintain a high self selected work rate without affecting firefighter's perception of work intensity (RPE).

PURPOSE: To examine the effect of supplemental CHO on reaction time, mathematical processing, sleepiness, blood glucose, physical activity, and rate of perceived exertion in wild land firefighters during 12-hour shifts of arduous fire suppression. **METHODS:** 17 WLFF (age=26.5±7.7yr, mass=82.3±9.1 kg) from elite hot shot crews volunteered for this study during actual firefighting. Prior to data collection subjects were trained to self administer all cognitive blood glucose tests. On two separate days subjects, in a random order, received either a placebo (PL) or a 20% CHO drink. They were instructed to drink 200 ml every hour (excluding first hour post breakfast and post lunch). Accelerometers were worn and recorded average movement in three directions each minute. RPE and job task were recorded each hour. Subjects performed the cognitive and blood glucose tests and before breakfast, prior to and immediately post shift. **RESULTS:** When ingesting CHO, subjects were able to maintain blood glucose (CHO=5.2, PL=4.5 mmol· L^{-1}, $p<0.05$) and were more active (CHO=493±36, PL=427±45 counts· min^{-1}, $p<0.05$). There were no significant differences in sleepiness score, RPE, and mathematical processing. Mean reaction time on the four choice test decreased with carbohydrate (CHO=401±46, PL=432±76 msec, $p<0.05$), while the number of correct responses per minute of response time increased (CHO=148.4±16.9, PL=140.4±24.0 correct· min^{-1}, $p<0.05$).

CONCLUSION: The cognitive tests used, though valid, may not be appropriate measures of decision making ability for wildland firefighters and differences found were minor. WLFF, with or without supplemental CHO, maintain cognitive function, as measured by these tests, over the 12 hour shift.

Table of Contents

Proposal

Tables

Figures

Chapter 1: INTRODUCTION

Our laboratory has previously described the total energy and hydration demands of the wildland firefighter. Based on these findings, it is apparent that whole body carbohydrate availability may be compromised and may therefore result in a progressive depletion of muscle glycogen. Recently our laboratory has extended these findings by demonstrating that the use of hourly supplemental liquid and carbohydrate feedings can improve self-selected physical work performance during low to moderate intensity extended hiking (Cerra et al., 2003) and wild land firefighting (Ruby et al., 2003; 2004), with no change in rate of perceived exertion (RPE). Furthermore, total daily work output was significantly lower (equivalent of 1.8 hours of work/day) when subjects received a placebo as compared to when they received an hourly carbohydrate feed, with most of the work reduction during the 2 hours prior to lunch and the final 4 hours in the afternoon. The blood glucose results paralleled the findings involving work output. These studies have consistently that blood glucose can be maintained during 12 hours of arduous wildfire suppression when consuming 20-40g/hr of a liquid and/or solid carbohydrate compared to a placebo. The greatest difference in blood glucose was found to be 4 and 6 hours post lunch, late in the work shift. Interestingly, this also parallels an increase in fire activity due to warmer ambient temperatures. During this later part of the work shift it is imperative that normal cognitive function be maintained to decision-making and an overall accurate and fast reaction time to changing conditions on the fire line.

Jeukendrup has recently (2004) reviewed a number of studies that evaluate the effects of carbohydrate supplementation on exercise performance. While there is some inconsistency in the relationship between hypoglycemia and exercise performance, the majority of past research has concluded that regular supplemental carbohydrate improves endurance performance (greater than 2 hours) and performance during high intensity activities lasting around 1 hour.

While the effects of carbohydrate supplementation on physical performance have been extensively studied (Ivy et al., 1983; Jeukendrup, 2004; Kreider et al., 1995), the effects on mood and cognitive performance and psychomotor tasks are less clear. Lieberman et al. (2002) demonstrated that during a 10-hour trial of moderate intensity exercise, those receiving carbohydrate demonstrated increased vigilance, decreased confusion, and increased vigor compared to those receiving a placebo. However, Green et al. (1997) found that a decrease in blood glucose improved recognition memory processing times and had no effect on task performance. Finally, during a 4-day military field exercise, it was found that vigor, vigilance, and immediate memory recall decreased, and fatigue, feelings of anger, depression, and confusion increased without a concomitant drop in blood glucose (Owen et al., 2004). Some have contributed the apparent contradictory results to the idea that cognitive impairment caused by hypoglycemia differs across subjects (Cox et al., 1993; Donohoe et al., 1999).

The purpose of this study was to independently examine the effect of hourly supplemental carbohydrate feeding versus placebo on reaction time, mathematical processing, sleepiness, blood glucose, physical activity, and rate of perceived exertion in wildland firefighters during 12-hours of arduous fire suppression.

Statement of Problem

Though it is known that the physical demands of wildland firefighting are often very arduous (4000 to 6000kcal/day (Ruby et al., 2002)), the effects of this type of work on cognition and the potential for carbohydrate supplementation to alleviate any detrimental effects are unclear.

Research Hypothesis

There will be no differences in performance on a 4-choice reaction test or a mathematical processing test, as well as no difference in activity level, rate of perceived exertion, blood glucose, or feelings of sleepiness between the carbohydrate (40g/hr, 200ml of a 20% maltodextrin solution) and placebo (200ml/hr similarly flavored) during a 12-hour shift of arduous wildfire suppression.

Significance of the Study

Wildland firefighters work 12 plus hour days, expending upwards of 6000kcal/day (Ruby et al., 2002). During the workday, crews must not only be able to perform arduous physical work, but respond accordingly to a hostile environment where weather and fire behavior can suddenly change. A firefighter needs to make quick and accurate decisions in order to maintain his/her own safety and the safety of fellow crewmembers. There are many potential hazards on the fire line, including weather changes, snags and rocks, animals, smoke, night fall, cuts, burns, dozers, helicopters and other equipment, and the fire activity itself, to name a few. It becomes apparent that a comprehensive safety plan should strive to maintain both physical and cognitive function for the duration of the work shift. Little is currently known about cognitive function late in the day in wild land firefighters. This research will help to clarify some of the cognitive functioning issues that may develop late in the work day, and whether or not inexpensive approaches to the maintenance of blood glucose can improve cognitive function.

Rationale of the Study

Previous research looking at the effects of exercise on cognitive function as well as the potential for carbohydrate supplementation to alleviate detrimental effects during extended exercise is both sparse and inconclusive.

Limitations

Limitations to this study included both variables that could not be controlled and variables that could have been, but were not. The ambient temperature and fire activity could not be controlled. Types of activities performed (line digging to look-out) were also not manipulated or controlled, as these changed daily as a result of fire activity. Finally, neither hydration status nor caloric and nutritional content of breakfast and lunch were controlled or recorded.

Delimitations

This study was designed specifically to evaluate the effects of carbohydrate supplementation on cognition in elite Hot Shot wild land firefighters during a 12-hour shift of arduous fire fighting. The results cannot be applied to other groups of individuals performing other tasks, or to other wild land firefighters with different levels of experience, or under different conditions. These results may give us an idea of what to expect in reasonably similar conditions.

Definition of terms

Cognitive function- simple reaction time as well as more complex mental processing (USARIEM, Natik, MA).

Simple reaction time- evaluated by a 4-choice test in which subjects pressed a button corresponding to one of 4 squares on a palm pilot screen that lit up. Both reaction time and accuracy were recorded (USARIEM, Natik, MA).

Mental processing- evaluated by an arithmetic test that involved a set of fifty addition and subtraction problems. Each problem involved 3 digits. The answer to the problem was either greater than 5 or less than 5. Subjects pressed a button on the left side of a palm pilot if the answer was less than 5, and a button on the right if the answer was greater than five. Both reaction time and accuracy were recorded (USARIEM, Natik, MA).

Arduous work- difficult or strenuous; expending 4000-6000 kcal/day (Ruby et al., 2002)

Hot Shot wild land firefighters- the highest category land crews in the United States. These people are highly trained, skilled and experienced firefighters who have had at least one season of experience as a wild land firefighter. Hotshot crews are generally given assignments on the toughest part of a fire and use a variety of specialized hand tools, including chainsaws and fire line explosives. The crew members serve in all phases of wild land firefighting - building fire lines, burning out, setting backfires and mopping up (National Office of Fire and Aviation).

Carbohydrate (CHO) - 20% carbohydrate solution such that there is 40 grams (160 Kcal) per 200 ml serving (Ruby et al., 2004)

Placebo- low carbohydrate fluid with less than 1 gm of carbohydrate per 200 ml (Ruby et al., 2004)

Chapter 2: LITERATURE REVIEW

During wildfire suppression, the energy expenditure of a member of a Hot Shot crew is 4000 to 6000 kcal/day (Ruby et al., 2002). Though the intensity of work may vary depending on the member's assignment based on the current fire activity, the workdays are always long; waking up around 5:00am and not returning to camp until 7:00pm or 8:00pm (some days shorter, some longer). During the workday, crews must not only be able to perform arduous physical work, but also remain mentally alert. A firefighter needs to make quick and accurate decisions in order to maintain his/her own safety and the safety of his/her crewmembers. There are many potential hazards on the fire line, including weather changes, snags and rolling rocks, animals, smoke, night fall, cuts, burns, dozers, helicopters and other equipment, in addition to unpredictable fire activity. It becomes apparent then that in order to maintain safety, a firefighter must maintain both physical and cognitive functioning. Previous research has examined the effects of physical activity in general, the number of simultaneous tasks performed, temperature, and dietary strategies on various cognitive functions.

When looking at the effects of exercise on cognition, there are many factors to consider. These include the acute duration of the work as well as the accumulated days of activity (chronic or acute), exercise intensity, and type of cognitive test (measurements of different cognitive functions). Some researchers have concluded that while long-term aerobic training improves physical performance (increases VO_2 max) (Blumenthal et al., 1991; Whitehurst, 1991), it appears that long-term exercise, or high a level of physical fitness, does little to improve baseline cognitive performance (Blumenthal et al., 1991; Brisswalter et al., 2002; Whitehurst, 1991).

The effects of fitness on cognitive function have been studied by a number of researchers. Magnié et al. (2000) looked at the electrophysiological effects of aerobic fitness and concluded that the general arousing effect induced by exercise was observed independent of aerobic fitness level. However, in a meta-analysis of 134 studies, Etnier et al. (1997) concluded that exercise and fitness have a small positive effect on baseline cognitive performance. This analysis also uncovered that are factors other than fitness level that contribute to cognitive abilities. Chronic exercisers tend to have more education and be of a higher socioeconomic class than people who are more sedentary (Etnier et al., 1997).

While the effects of fitness level on cognitive ability may be important to assess when selecting applicants to hire for wildland firefighting and to assure the ability to perform necessary tasks, once hired it is the immediate, as well as the chronic, effects of the physical work on cognitive function that need to be assessed.

Arcelin et al. (1998) demonstrated an improvement in reaction time performance with acute exercise, particularly on response speed following three 10-minute bouts of exercise at 60% VO_2 max. These finding were similar to those reported by others who have studied the effects of endurance exercise on both simple and complex cognitive tasks (Hogervorst et al., 1996; 1999). Hogervorst and colleagues (1996) studied the effects of a time trial performance (lasting about 1 hour) on cognition and reported that reaction times for both simple tasks and complex tasks requiring the inhibition of a learned response were significantly improved (without compromising accuracy) following the single bout of high intensity exercise. These data were supported by Davranche and Audiffren (2004) who concluded that moderate-intensity exercise (50%

max aerobic power) improved cognitive performance. Additional past research has determined the effects of exercise intensity on cognitive function (high versus low intensity exercise or stages of gradually increasing exercise intensity).

Féry et al. (1997) studied the reaction time of a decision making task following 3 minutes of exercise at 30%, 60%, and 90% of VO_2 max. Subjects viewed four or seven different consonants, and then when presented with different letters during the test, determined whether or not the letter was one of the original consonants presented. Reaction time for the 7-consonant set decreased during the first two stages, but increased during the final exercise stage. Similarly, when beginning at 40% VO_2 max and increasing 10% every 10 minutes until reaching 80% VO_2 max, Travlos and Marisi (1995) concluded that there appears to be an optimal exercise intensity for maximal mental performance occurring somewhere between resting level and 40% to 60% VO_2 max. These supported prior research of Reilly and Smith in 1986 who concluded that when increasing intensity from 25% VO_2 max to 85% VO_2 max , whether the task involved cognitive or psychomotor functions, performance tended to decrease once intensity reached about 40% VO_2 max . However, in contrast, Côté et al. (1992) also progressively increased physical workload until volitional exhaustion and found no attentional narrowing as intensity of exercise increased. Others have reported that consistent impairment in reaction time was apparent during high-intensity exercise, and that no facilitation was apparent during low-intensity exercise (Williams et al., 1985).

While the previously mentioned studies used a percentage of VO_2 max as a measurement of intensity, others have looked at the effects of exercise above and below the lactate threshold on cognitive function. Chmura et al. (1994) reported that deterioration of psychomotor task performance occurred at approximately 75% VO_2 max. Chmura et al. (1998) determined changes in psychomotor performance during prolonged exercise above and below the lactate threshold. One group performed 20 minutes of cycle ergometry at 110% lactate threshold, and another performed 60 minutes of cycling at 70% lactate threshold. It was reported that reaction time decreased with high intensity exercise and that after about 40 minutes of moderate intensity exercise, reaction time began to plateau.

In an attempt to clear up the inconsistencies in the results of research examining the effects of exercise on cognitive function, others have stressed not only the intensity of the exercise, but also the difference in cognitive tasks tested. When looking at the effects of endurance and interval exercise on perception and decision task, Paas and Adam (1991) reported that increases in physical workload improved decision type tasks, but impaired perception tasks, while a decrease in physical workload impaired decision tasks, and improved performance on perception tasks. Yagi et al. (1999) chose to look at auditory and visual reaction times in response to a constant moderate intensity exercise. They reported reaction times to the auditory and especially visual stimuli showed improvement with exercise. However, it was also reported that the improvements in reaction time were accompanied by decreased attention to the reaction time task and a decline in accuracy. When comparing expert and non-expert fencers, Deligniéres et al. (1994) found that non-experts experienced a deterioration of performance on reaction time tasks as exercise intensity increased while the experts improved response time (without an increase in error rate). Furthermore, when comparing the subjects' self ratings of perceived exertion, Deligniéres and colleagues (1994) found that the experts found the test to be significantly more difficult than non-experts. It was hypothesized that the reason for this may have been that the experts invested more resources in the task and thus experienced an improvement in performance. Others have suggested that subjects who are unaccustomed to exercise of high-intensity have a preconceived notion that exercise will have negative effects on cognitive function (Hogervorst et al., 1996). The results of these studies begin to address the idea of resource allocation, suggesting that when faced with both a cognitive and a physical task, one may divert attention from one task in order to perform better in the other.

Brisswalter et al. (1995) looked at the effect of varying pedal rates matched for aerobic power output on cognitive performance. It was reported that there appeared to be an optimal pedaling speed, and that the greater the amount of attention needed to control the pedaling movements, the slower the subjects responded to a simple reaction task (Brisswalter et al., 1995). While the effect of physical exercise itself appears to have an effect on cognitive function under certain conditions and for certain individuals, researchers realize that this is not the only variable that affects cognition. Perhaps there are other factors that influence cognition, such as temperature and dietary strategies.

Reviewing a number of studies in 1995, Ramsey reported that mental tasks, such as arithmetic, coding, writing, and short term memory show minimal performance losses due to heat, or enhanced levels of performance for brief exposures. However, perceptual motor tasks, such as tracking, vigilance, operating vehicles or machines, and other complex tasks, show a definite loss of performance with heat beginning at 30-33 C° (Ramsey, 1995). Likewise, Holland et al. (1985) reported that when core temperature was raised 38.8-39.05 C°, long or short-term memory and accuracy of performance of verbal logic problems, or two-digit subtractions was not affected. However, subjects also experienced a significant increase in irritability and speed of these performance tests, as well as a decrease in alertness (Holland et al., 1985). Wright et al. (2002) sought to determine whether performance was directly affected by body temperature or whether both body temperature and performance simply co vary with circadian phase. It was reported that working memory, mathematic addition, and subjective alertness were improved when body temperature was higher even after controlling for the effects of circadian phase and hours awake.

While the aforementioned studies all looked at the effects of heat on cognition, others have looked at the effects of cold on cognitive and physical performance. Hodgdon et al. (1991) studied Norwegian soldiers who were training in the artic. No changes were found in either cognitive or physical performance tasks. However, it should also be noted that while soldiers lived either in the field in tents or in barracks, all performed the cognitive and physical tests in a warm tent.

Because some studies have shown detrimental effects of physical exercise and temperature on cognitive performance, researchers have also examined what athletes, workers, or soldiers can do to alleviate these negative effects, other than work less and control the weather. The strategies most commonly examined have been dietary in nature. Comparing the effects of different degrees of dehydration on cognitive functions, it has been reported that routine mental work, running memory, psychomotor function (Sharma et al., 1986) as well as short-term memory, arithmetic efficiency, and speed of trail marking (Gopinathan et al., 1988) all progressively deteriorate as degree of dehydration increased. Impairment for mental performance becomes highly significant at 2% dehydration (Gopinathan et al., 1988; Sharma et al., 1986).

A number of researchers have examined the effects of greater than 2% dehydration on cognition. It has been demonstrated that dehydration results in an increase perceptual task reaction time (without a change in error rate), decrease tracking performance and psychomotor skills, and decrease short-term, but not long-term memory (Cian et al., 2000; 2001). The detrimental effects on short-term memory are alleviated 3.5 hours following dehydration, but subjects tend to feel increasingly tired (Cian et al., 2001). Upon rehydration (following dehydration), subjects feel less tired, and long-term memory is improved compared to those whose hydration status is held constant (euhydration), but the decision making time in perceptive discrimination tests does not improve (Cian et al., 2001). Furthermore, hyperhydration significantly improves short-term memory compared to euhydration (Cian et al., 2000).

Keeping hydration constant, other researchers have examined the potential for various dietary supplementation strategies to improve or maintain cognitive performance. When tested before exercising, caffeine has been shown to improve long-term memory performance independent of attentional and psychomotor functions (Hogervorst et al., 1999). When tested after strenuous exercise, caffeine (150mg/L) has been shown to improve attention, complex psychomotor speed, and recognition memory (Hogervorst et al., 1999). Lieberman et al. (2002) reported similar results when studying the effects of caffeine on cognitive performance during U.S. Navy SEAL training. This study was conducted during Hell Week when the trainees were exposed to sleep loss and physical and mental stressors. Lieberman and colleagues reported that sleep loss and exposure to other stressors of Hell Week resulted in a profound degradation of vigilance, mood, fine motor skills, and steadiness. However, when trainees were given 200mg of caffeine, these adverse effects were mitigated. Adding in another variable, Kruk et al. (2001) looked at the effects of caffeine, cold, and exercise on reaction time. Results similar to those reported previously, improved psychomotor performance during exercise with caffeine ingestion, were reported when subjects were tested in a thermo-neutral environment. However, this effect was blunted as ambient temperature was lowered (Kruk et al., 2001).

Other investigators have determined the effects of amino acid supplementation on cognition during exercise. Catecholamines are involved in either the disengagement or shifting of attention (Clark et al., 1989). Stress-induced depletion of norepinephrine can be counteracted by administration of tyrosine, which in turn has been associated with an increase in memory comparison tasks as well as tracking task when compared to a group receiving placebo (Deijen et al., 1999). However, when a tracking task and a continuous memory task are administered simultaneously, tyrosine supplementation does not appear to improve performance compared to a placebo (Deijen et al., 1999). Furthermore, it has been shown that supplementation with branched chain amino acids (valine, leucine, and isoleucine) in a carbohydrate solution reduce feelings of tension, anger, and vigor as well as improve performance on a geometric shape rotation or figure identification task, following a 30-km cross-country race (Hassmén et al., 1994).

The effects of supplementation with carbohydrate, alone, on cognitive function have been evaluated under a variety of conditions. Providing a carbohydrate supplement can improve performance of one hour of high intensity exercise and increase time to exhaustion of endurance exercise lasting over two hours (Ivy et al., 1983; Jeukendrup, 2004; Kreider et al., 1995). However, the effects of carbohydrate on mood and performance of cognitive and psychomotor tasks are less clear. While some have reported no change in psychomotor skills (reaction time, coincidence anticipation timing, and eye-hand coordination) with the ingestion of carbohydrate during endurance exercise (Ivy et al., 1983), others have reported a significant improvement in choice reaction tests when subjects are supplemented with carbohydrate during exhaustive exercise (Collardeau et al., 2001), as well as improved self control when faced with a stressful task (Markus et al., 1998). Others have reported no cognitive performance enhancing effects, but an improvement in mood when subjects ingested a low-fat/ high-carbohydrate breakfast compared to a medium-fat/ medium-carbohydrate or high-fat/ low-carbohydrate breakfast (Lloyd et al., 1996). However, Kreider and colleagues (1995) reported that carbohydrate supplementation during heavy training did not affect overall psychological status, as evaluated by the Profile of Moods States questionnaire.

There has also been some concern as to whether or not carbohydrate supplementation will alter dietary intake of other macro and micronutrients. Again there is conflicting evidence. While some have reported that carbohydrate supplementation does not significantly alter normal dietary patterns of remaining macronutrients (Kreider et al., 1995), others have reported that carbohydrate supplementation significantly reduces one's intake of protein and fat, and that there is the potential for compromised vitamin and mineral status as well (Cline et al., 2000).

Other researchers have looked at the effects of carbohydrate on cognition during intermittent exercise, such as seen in many team sports such as basketball, soccer, etc.

Welsh et al. (2002) had subjects perform 60 minutes of intermittent high intensity shuttle running and vertical jumps followed by intermittent high intensity shuttle running to fatigue. Subjects were given cognitive function tests during a 20-minute half time break. It was reported that when supplemented with carbohydrate, subjects performed better on physical tasks (speed and agility of whole body motor skills, but not vertical jumping) while enhancing self-reported perceptions of fatigue. However, cognitive function evaluated by the Stroop color-word test did not change, nor did subjects' overall mood evaluated by the Profile of Mood States questionnaire.

In addition to determining the effects of carbohydrate supplementation on cognition, researchers have also examined the effects of hypoglycemia on cognitive function. By examining changes in electroencephalograms during hypoglycemia, Pramming and colleagues (1988) reported that subjects report feeling hypoglycemic even when blood glucose levels were high. However, neuropsychological performance does not deteriorate until levels of 3mmol/L and electroencephalograms show neuronal dysfunction in the cortex at blood glucose levels of 2mmol/L. King et al. (1998) lowered subjects' blood glucose levels to 2.3 to 2.7mmol/L and reported that although subjects were more fatigued, there appeared to be no adverse effects on simple or complex cognitive functions. However, Cox et al. (1993) reported that the greater the hypoglycemia, the greater the decrement in performance. Furthermore, purely cognitive skills appear to be more sensitive to hypoglycemia than do purely motor skills (Cox et al., 1993). In a study reported by Owen and colleagues (2004) looking at changes in cognition over a 4 day simulated combat mission, subjective reports of symptoms associated with hypoglycemia were increased following 24 hours, despite no change in subjects' blood glucose (5.4±0.1mmol/L). Furthermore, immediate memory recall began to decrease after 24 hours, and vigilance speed (but not accuracy) as well as delayed memory recall decreased after 48 hours. Subjects were also in negative energy balance, dehydrated (2%) and had very little sleep. In response to these findings, it should be noted that many of the studies looking at effects of hypoglycemia on cognition use Type I (Insulin Dependent Diabetes Mellitus) diabetics as subjects (Cox et al., 1993; King et al., 1998; Pramming et al., 1988). It has been reported that Type I diabetic patients experience a more pronounced neuropsychological impairment during hypoglycemia than do normal subjects, in spite of equal performances at euglycemic levels (Wirsén et al., 1992).

As stated previously, wild land firefighters are faced with arduous physical work every day, at an average workload estimated at about 45-55% VO_2max or 70-80% Ventilatory Threshold. Furthermore, they have to be mentally alert in order to make quick and accurate decisions in response to changes in fire activity, in order to maintain the safety of all crewmembers. Previous research has provided inconclusive results regarding the effects of carbohydrate supplementation on cognitive performance under these or similar conditions. Furthermore, while changes in cognition have been evaluated in endurance athletes and military personnel, the unique population of the Hot Shot wild land firefighter has never been studied directly. Thus, it was the purpose of this study was to examine cognition under normal diet or with supplemental carbohydrate feeding during 12-hour shifts of arduous fire suppression.

Chapter 3: METHODS

This study was conducted over a period of three days. The first day was used to train the subjects. After breakfast, the subjects were trained to self-administer the cognitive functioning tests using Palm ™ hand held computers and to monitor blood glucose using One Touch Ultra™ glucometers. In order to eliminate the learning effect during cognitive data collection, the subjects practiced the cognitive tests 6-8 times during breaks throughout the first day. The cognitive evaluation consisted of a sleepiness score, a 4-choice reaction test, and a mathematical processing test as described below. Days 2 and 3 were experimental days, with the subjects receiving either a placebo (PLA) drink or a 20% CHO supplement. During each day data on cognitive function, activity, perception of work exertion, blood glucose, and job task were monitored as documented below. Subjects were studied over the course of the protocol using a single-blind crossover design.

Subjects

Due to the nature of the 3-day protocol, crews working on a large fire were needed to ensure arduous fire suppression throughout the entire study. Members of three different hotshot crews working on the Fischer Fire in Leavenworth, Washington during August 2004 were recruited as subjects (n=17; 2F, 15M) for the study. Hotshot crews were approached as they arrived at the dining tent and presented with an overview of the study. Once subjects agreed to participate, consent forms were signed. Subject descriptors are shown in table 1.

Supplemental Beverage

On day two, half of the subjects were assigned to receive a placebo (<1 gm carbohydrate/200 ml) drink and half a carbohydrate drink (40 gm carbohydrate/200 ml). Subjects received the opposite on day three. The carbohydrate solution a prepackaged 20%CHO Gatorade® beverage, or a 6%CHO Gatorade® beverage with maltodextrin mixed in to make the solution 20%CHO. The placebo solution was made from a powdered Crystal Lite® drink mix. The placebo was similar in taste and sweetness to the 20% CHO solution. Subjects were blinded to the CHO content of the drink supplied to them. They were instructed to drink 200 ml every hour except for the first hour both post breakfast and post lunch. Subjects were instructed to eat ad lib for breakfast and lunch.

Activity Monitoring

During the two experimental days, subjects wore Actical™ activity monitors in their front shirt pockets during the work shifts to measure physical activity. These recorded movement left to right, front to back, and up/down. Activity was reported in counts per minute. Though this data can be converted into calories (Heil and Klippel, 2003), only relative work rates were needed for the purposes of this study.

Blood Glucose Monitoring

Subjects were trained to measure blood glucose using One Touch Ultra™ field glucometers. Subjects were provided with alcohol prep wipes and one-time-use retractable lancets. The glucometer cases contained instructions guiding the subjects through the blood glucose testing process. Subjects were instructed to cleanse the tip of one finger with the alcohol wipe, taking care to avoid calloused fingertips. The testing strip was then inserted into the glucometer. Making certain the cleansed fingertip was dry, subjects used a retractable lancet to prick the cleansed finger. After squeezing the finger using a pumping motion until a BB sized drop of blood formed, subjects placed the tip of the testing strip on the drop of blood, letting the blood move into the strip by capillary action. Subjects were instructed not to remove the glucometer from the carrying case, and thus were not able to see the glucose reading, which was automatically stored in the glucometer. The glucometer case also contained a plastic zip-lock bag for subjects to place used alcohol wipes, lancets, and glucose testing strips, to be place in a biohazard bag upon return to the lab. Subjects measured blood glucose before breakfast, immediately before leaving camp to drive to the fire, before eating lunch, and immediately before leaving the fire to return to camp.

Cognitive Function

Cognitive function was evaluated using three tests performed on Palm™ hand held computers. The computers were in waterproof cases that fit easily into the subjects' packs. Inside the case was a card with instructions on how to perform the tests and trouble shooting tips addressing how to stop a test, reset a test, and return to the home screen. Subjects turned the palm pilot on, selected the Ares® program, entered their subject number and pin number (both the same number), and then proceeded to perform the three tests. The subject was first asked to rank his/her sleepiness on a scale of 1 to 5. Subjects then performed a simple reaction test in which 4 squares appeared on the screen and subjects were asked to press a button corresponding to the square that lit up.

Mathematical processing was the final test. A combination of addition and subtraction of three single digit numbers appeared on the screen. Subjects were asked to press one button if the total was less than 5 and another button if the total was greater than 5. The total would never equal 5. Reaction time, number of correct responses, and thruput (number of correct responses per minute of available response time) were recorded for the 4-choice and mathematical processing tests. Subjects performed the cognitive tests after recording blood glucose before breakfast, immediately before leaving camp to head to the fire, before eating lunch, and immediately before leaving the fire to return to camp.

Rate of Perceived Exertion and Job Task

Pencils and cards with the Borg Scale of Perceived Exertion and space for recording RPE and job task were placed in the glucometer cases. Subjects were instructed to record whole body RPE and job task each hour.

Statistics

Data were analyzed by 2-way repeated measures ANOVA. Glucose was analyzed using a 2(trial) x 3(time) repeated measures ANOVA. If a significant interaction (trial x time) or significant main effect for time was found, means comparisons were performed. RPE was analyzed using a 2 (trial) x 10 (time) repeated measures ANOVA. If a significant interaction (trial x time) or significant main effect for time was found, means comparisons were performed. Activity counts were summarized hourly and analyzed by a 2 (trial) x 12 (time) repeated measures ANOVA. If a significant interaction (trial x time) or significant main effect for time was found, means comparisons were performed.

Activity counts were also averaged for the hours pre-lunch and the hours post-lunch and analyzed by a 2 (trial) x 2 (time) repeated measures ANOVA. In all statistical tests, significance was evaluated at $p < 0.1$.

Effect of Supplemental Feeding on Cognitive Function in Wildland Firefighters During Arduous Fire Suppression

A. Goodson, S.E. Gaskill, Ph.D., B.C. Ruby, Ph.D., A. McClaughry, J. Cuddy

Abstract

Previous field research with wild land firefighters (WLFF) has shown that supplemental carbohydrate (CHO) feeding, compared to a placebo (PLA) helps to maintain blood glucose, increase total daily work, and maintain a high self selected work rate without affecting firefighter's perception of work intensity (RPE).

PURPOSE: To examine the effect of supplemental CHO on reaction time, mathematical processing, sleepiness, blood glucose, physical activity, and rate of perceived exertion in wild land firefighters during 12-hour shifts of arduous fire suppression. **METHODS:** 17 WLFF (age=26.5±7.7yr, mass=82.3±9.1 kg) from elite hot shot crews volunteered for this study during actual firefighting. Prior to data collection subjects were trained to self administer all cognitive blood glucose tests. On two separate days subjects, in a random order, received either a placebo (PL) or a 20% CHO drink. They were instructed to drink 200 ml every hour (excluding first hour post breakfast and post lunch). Accelerometers were worn and recorded average movement in three directions each minute. RPE and job task were recorded each hour. Subjects performed the cognitive and blood glucose tests and before breakfast, prior to and immediately post shift. **RESULTS:** When ingesting CHO, subjects were able to maintain blood glucose (CHO=5.2, PL=4.5 $\text{mmol} \cdot \text{L}^{-1}$, $p<0.05$) and were more active (CHO=493±36, PL=427±45 $\text{counts} \cdot \text{min}^{-1}$, $p<0.05$). There were no significant differences in sleepiness score, RPE, and mathematical processing. Mean reaction time on the four choice test decreased with carbohydrate (CHO=401±46, PL=432±76 msec, $p<0.05$), while the number of correct responses per minute of response time increased (CHO=148.4±16.9, PL=140.4±24.0 correct· min^{-1}, $p<0.05$).

CONCLUSION: The cognitive tests used, though valid, may not be appropriate measures of decision making ability for wildland firefighters and differences found were minor. WLFF, with or without supplemental CHO, maintain cognitive function, as measured by these tests, over the 12 hour shift.

During wildfire suppression, the energy expenditure of a member of a Hot Shot crew is 4000 to 6000 kcal/day (Ruby et al., 2002). Though the intensity of work may vary depending on the member's assignment based on the current fire activity, the workdays are always long; waking up around 5:00am and not returning to camp until 7:00pm or 8:00pm (some days shorter, some longer). During the workday, crews must not only be able to perform arduous physical work, but also remain mentally alert. A firefighter needs to make quick and accurate decisions in order to maintain his/her own safety and the safety of his/her crewmembers. There are many potential hazards on the fire line, including weather changes, snags and rolling rocks, animals, smoke, night fall, cuts, burns, dozers, helicopters and other equipment, and the fire activity itself, to name a few. It becomes apparent then that in order to maintain safety, a firefighter must maintain both physical and cognitive functioning. In order to maintain cognitive function, one must first understand what affects cognitive function. Researchers have examined the effects of physical activity in general, the number of simultaneous tasks performed, temperature, and dietary strategies on various cognitive functions.

When looking at the effects of exercise on cognition, there are many factors to consider. These include the acute duration of the work as well as the accumulated days of activity (chronic or acute), exercise intensity, and type of cognitive test (measurements of different cognitive functions). While long-term aerobic training improves physical performance (increases VO_2 max) (Blumenthal et al., 1991; Whitehurst, 1991), it appears that long-term exercise, or high a level of physical fitness, does little to improve cognitive performance (Blumenthal et al., 1991; Brisswalter et al., 2002; Whitehurst, 1991). However, Magnié et al. (2000) concluded that the general arousing effect induced by exercise was observed independent of aerobic fitness level. In contrast, a meta-analysis by Etnier et al. (1997) concluded that exercise and fitness have a small positive effect on cognitive performance.

Furthermore, it appears that there is an optimal exercise intensity for maximal mental performance occurring somewhere between resting level and 40% to 60% VO_2 max (Travlos and Marisi, 1995). When looking at the acute effects of physical activity on cognition, researchers have reported improvements in cognition during low to moderate intensity exercise (Arcelin et al., 1998; Chmura et al., 1994; Davranche and Audiffren, 2004; Féry et al., 1997) and decrements in reaction time during high intensity exercise (Féry et al., 1997; Chmura et al., 1998; Reilly and Smith, 1986; Travlos and Marisi, 1995). However, in contrast, others have reported no attentional narrowing as intensity level increased (Côté et al., 1992) or impairment during high-intensity exercise, but no facilitation during low-intensity exercise (Williams, et al., 1985), or facilitation followed by a plateau after 40 minutes (Chmura et al., 1998).

In an attempt to clear up the inconsistencies in the results of research examining the effects of exercise on cognitive function, others have stressed not only the intensity of the exercise, but also the difference in cognitive tasks tested. Paas and Adam (1991) reported that increases in physical workload improved decision type tasks, but impaired perception tasks, while a decrease in physical workload impaired decision tasks, and improved performance on perception tasks. Yagi et al. (1999) reaction times to auditory and especially visual stimuli show improvement with exercise. However, it was also reported that the improvements in reaction time were accompanied by decreased attention to the reaction time task and a decline in accuracy. When comparing expert and non-expert fencers, Deligniéres et al. (1994) found that non-experts experienced a deterioration of performance on reaction time tasks as exercise intensity increased while the experts improved response time (without an increase in error rate). Furthermore, when comparing the subjects' self ratings of perceived exertion, Deligniéres and colleagues (1994) found that the experts found the test to be significantly more difficult than non-experts. It was hypothesized that the reason for this may have been that the experts invested more resources in the task and thus experienced an improvement in performance. Others have suggested that subjects who are unaccustomed to exercise of high-intensity have a preconceived notion that exercise will have negative effects on cognitive function (Hogervorst et al., 1996). The results of these studies begin to address the idea of resource allocation, suggesting that when faced with both a cognitive and a physical task, one may divert attention from one task in order to perform better in the other. Brisswalter et al. (1995) looked at the effect of varying pedal rates matched for aerobic power output on cognitive performance. It was reported that there appeared to be an optimal pedaling speed, and that the greater the amount of attention needed to control the pedaling movements, the slower the subjects responded to a simple reaction task (Brisswalter et al., 1995). While the effect of physical exercise itself appears to have an effect on cognitive function under certain conditions and for certain individuals, researchers realize that this is not the only variable that affects cognition. Perhaps there are other factors that influence cognition, such as temperature and dietary strategies.

Reviewing a number of studies in 1995, Ramsey reported that mental tasks, such as arithmetic, coding, writing, and short term memory show minimal performance losses due to heat, or enhanced levels of performance for brief exposures (Holland et al., 1985; Ramsey, 1995). However, perceptual motor tasks, such as tracking, vigilance, operating vehicles or machines, and other complex tasks, show a definite loss of performance with heat beginning at 30-33 degrees Celsius (Ramsey, 1995). Furthermore, irritability increases and alertness decreases as temperature increases (Holland et al., 1985).

Because some studies have shown detrimental effects of physical exercise and temperature on cognitive performance, researchers have also examined what athletes, workers, or soldiers can do to alleviate these negative effects. The strategies most commonly examined have been dietary in nature. Comparing the effects of different degrees of dehydration on cognitive functions, it has been reported that routine mental work, running memory, psychomotor function (Sharma et al., 1986) as well as short-term memory, arithmetic efficiency, and speed of trail marking (Gopinathan et al., 1988) all progressively deteriorate as degree of dehydration increases. Impairment for mental performance becomes highly significant at 2% dehydration (Gopinathan et al., 1988; Sharma et al., 1986). Dehydration of 2% or greater results in an increase perceptual task reaction time (without a change in error rate), decrease tracking performance and psychomotor skills, and decrease short-term, but not long-term memory (Cian et al., 2000; 2001). The detrimental effects on short-term memory are alleviated 3.5 hours following dehydration, but subjects tend to feel increasingly tired (Cian et al., 2001). Upon rehydration (following dehydration), subjects feel less tired, and long-term memory is improved compared to those whose hydration status is held constant (euhydration), but the decision making time in perceptive discrimination tests does not improve (Cian et al., 2001). Furthermore, hyperhydration significantly improves short-term memory compared to euhydration (Cian et al., 2000).

Keeping hydration constant, other researchers have examined the potential for various dietary supplementation strategies to improve or maintain cognitive performance. When tested before exercising, caffeine has been shown to improve long-term memory performance independent of attentional and psychomotor functions (Hogervorst et al., 1999). When tested after strenuous exercise, caffeine (150mg/L) has been shown to improve attention, complex psychomotor speed, and recognition memory (Hogervorst et al., 1999). Lieberman et al. (2002) reported that sleep loss and exposure to other physical stressors result in a profound degradation of vigilance, mood, fine motor skills, and steadiness, which do not occur when subjects are given 200mg of caffeine. Furthermore, improved psychomotor performance during exercise is blunted as ambient temperature is lowered (Kruk et al., 2001).

Other investigators have looked at the effects of amino acid supplementation on cognition during exercise. Stress-induced depletion of norepinephrine can be counteracted by administration of tyrosine, which in turn has been associated with an increase in memory comparison tasks as well as tracking task when compared to a group receiving placebo (Deijen et al., 1999). However, when a tracking task and a continuous memory task are administered simultaneously, tyrosine supplementation does not appear to improve performance compared to a placebo (Deijen et al., 1999). Furthermore, it has been shown that supplementation with branched chain amino acids (valine, leucine, and isoleucine) in a carbohydrate solution reduce feelings of tension, anger, and vigor as well as improve performance on a geometric shape rotation or figure identification task, following a 30-km cross-country race (Hassmén et al., 1994).

The effects of supplementation with carbohydrate, alone, on cognitive function have been evaluated under a variety of conditions. Providing a carbohydrate supplement can improve performance of one hour of high intensity exercise and increase time to exhaustion of endurance exercise lasting over two hours (Ivy et al., 1983; Jeukendrup, 2004; Kreider et al., 1995). However, the effects of carbohydrate on mood and performance of cognitive and psychomotor tasks are less clear. While some have reported no change in psychomotor skills (reaction time, coincidence anticipation timing, and eye-hand coordination) with the ingestion of carbohydrate during endurance exercise (Ivy et al., 1983), others have reported a significant improvement in choice reaction tests when subjects are supplemented with carbohydrate during exhaustive exercise (Collardeau et al., 2001), as well as improved self control when faced with a stressful task (Markus et al., 1998). Others have reported no cognitive performance enhancing effects, but an improvement in mood when subjects ingested a low-fat/ high-carbohydrate breakfast compared to a medium-fat/ medium-carbohydrate or high-fat/ low-carbohydrate breakfast (Lloyd et al., 1996). However, Kreider and colleagues (1995) reported that carbohydrate supplementation during heavy training did not affect overall psychological status, as evaluated by the Profile of Moods States questionnaire.

There has also been some concern as to whether or not carbohydrate supplementation will alter dietary intake of other macro and micronutrients. Again there is conflicting evidence. While some have reported that carbohydrate supplementation does not significantly alter normal dietary patterns of remaining macronutrients (Kreider et al., 1995), others have reported that carbohydrate supplementation significantly reduces one's intake of protein and fat, and that there is the potential for compromised vitamin and mineral status as well (Cline et al., 2000).

Other researchers have looked at the effects of carbohydrate on cognition during intermittent exercise, such as seen in many team sports such as basketball, soccer, etc. Welsh et al. (2002) reported that when supplemented with carbohydrate, subjects performed better on physical tasks (speed and agility of whole body motor skills, but not vertical jumping) while enhancing self-reported perceptions of fatigue. However, cognitive function evaluated by the Stroop color-word test did not change, nor did subjects' overall mood evaluated by the Profile of Mood States questionnaire.

In addition to looking at the effects of carbohydrate supplementation on cognition, researchers have also examined the effects of hypoglycemia on cognitive function. By examining changes in electroencephalograms during hypoglycemia, Pramming and colleagues (1988) reported that subjects report subjective feeling of hypoglycemia even while blood glucose levels were high. However, neuropsychological performance does not deteriorate until levels of 3mmol/L and electroencephalograms show neuronal dysfunction in the cortex at blood glucose levels of 2mmol/L. King et al. (1998) lowered subjects' blood glucose levels to 2.3 to 2.7mmol/L and reported that although subjects were more fatigued, there appeared to be no adverse effects on simple or complex cognitive functions. However, Cox et al. (1993) reported that the greater the hypoglycemia, the greater the decrement in performance. Furthermore, purely cognitive skills appear to be more sensitive to hypoglycemia than do purely motor skills (Cox et al., 1993). In a study reported by Owen and colleagues (2004) looking at changes in cognition over a 4 day simulated combat mission, subjective reports of symptoms associated with hypoglycemia were increased following 24 hours, despite no change in subjects' blood glucose (5.4±0.1mmol/L). Furthermore, immediate memory recall began to decrease after 24 hours, and vigilance speed (but not accuracy) as well as delayed memory recall decreased after 48 hours. Subjects were also in negative energy balance, dehydrated (2%) and had very little sleep. In response to these findings, it should be noted that many of the studies looking at effects of hypoglycemia on cognition use Type I (Insulin Dependent Diabetes Mellitus) diabetics as subjects (Cox et al., 1993; King et al., 1998; Pramming et al., 1988). It has been reported that Type I diabetic patients experience a more pronounced neuropsychological impairment during hypoglycemia than do normal subjects, in spite of equal performances at euglycemic levels (Wirsén et al., 1992).

As stated previously, wild land firefighters are faced with arduous physical work every day, at an average workload estimated at about 45-55% VO_2max or 70-80% Ventilatory Threshold. Furthermore, they have to be mentally alert in order to make quick and accurate decisions in response to changes in fire activity, in order to maintain the safety of all crewmembers. Previous research has provided inconclusive results regarding the effects of carbohydrate supplementation on cognitive performance under these or similar conditions. Furthermore, while changes in cognition have been evaluated in endurance athletes and military personnel, the unique population of the Hot Shot wild land firefighter has not been previously studied. Thus, it was the purpose of this study was to examine cognition under normal diet or with supplemental carbohydrate feeding during 12-hour shifts of arduous fire suppression.

METHODS

This study was conducted over a period of three days. The first day was used to train the subjects. After breakfast, the subjects were trained to self-administer the cognitive functioning tests using Palm ™ hand held computers and to monitor blood glucose using One Touch Ultra™ glucometers. In order to eliminate the learning effect during cognitive data collection, the subjects practiced the cognitive tests 6-8 times during breaks throughout the first day. The cognitive evaluation consisted of sleepiness score, a 4-choice reaction test, and a mathematical processing test as described below. Days 2 and 3 were experimental days, with the subjects receiving either a placebo (PLA) drink or a 20% CHO supplement. During each day data on cognitive function, activity, perception of work exertion, blood glucose, and job task were monitored as documented below. Subjects were studied over the course of the protocol using a single-blind crossover design.

Subjects

Members of three different hotshot crews working on the Fischer Fire in Leavenworth, Washington during August 2004 were recruited as subjects (n=17; 2F, 15M) for the study. Consent forms were signed. Subject descriptors are shown in Table 1.

Supplemental Beverage

On day two, subjects were randomly assigned to receive either a placebo (<1 gm carbohydrate/200 ml/hr) or a carbohydrate drink (40 gm carbohydrate/200 ml/hr) and the opposite on day three. The carbohydrate solution was a prepackaged 20%CHO Gatorade® beverage. The placebo solution was made from a powdered Crystal Lite® drink mix. The placebo was similar in taste and sweetness to the 20% CHO solution. Subjects were blinded to the CHO content of the drink supplied to them. Subjects were instructed to drink 200 ml every hour except for the first hour both post breakfast and post lunch.

Activity Monitoring

During the two experimental days, subjects wore Actical™ activity monitors in their front shirt pockets during the work shifts to measure physical activity. Activity was reported in counts per minute. Though this data can be converted into calories (Heil and Klippel, 2003), only relative work rates were needed for the purposes of this study.

Blood Glucose Monitoring

Subjects were trained to measure blood glucose using One Touch Ultra™ field glucometers. Subjects were provided with alcohol prep wipes and one-time-use retractable lancets. The glucometer cases contained instructions guiding the subjects through the blood glucose testing process. Subjects were instructed not to remove the glucometer from the carrying case, and were blinded to the resultant glucose reading, which was stored in the glucometer. Subjects measured blood glucose before breakfast, immediately before leaving camp to drive to the fire, and immediately before leaving the fire to return to camp.

Cognitive Function

Cognitive function was evaluated using three tests performed on Palm™ hand held computers. The subject was first asked to rank his/her sleepiness on a scale of 1 to 5 (1 more awake, 5 more sleepy). Subjects then performed a simple reaction test in which 4 squares appeared on the screen and subjects were asked to press a button corresponding to the square that was lit. Mathematical processing was the final test. A combination of addition and subtraction of three single digit numbers appeared on the screen. Subjects were asked to press one button if the total was less than 5 and another button if the total was greater than 5. The total would never equal 5. Reaction time, number of correct responses, and thruput (number of correct responses per minute of available response time) were recorded for the 4-choice and mathematical processing tests. Subjects performed the cognitive tests after recording blood glucose before breakfast, immediately before leaving camp to head to the fire, before eating lunch, and immediately before leaving the fire to return to camp.

Rate of Perceived Exertion and Job Task

Pencils and cards with the Borg Scale of Perceived Exertion and space for recording RPE and job task were placed in the glucometer cases. Subjects were instructed to record whole body RPE and job task each hour.

Statistics

Data were analyzed by 2-way repeated measures ANOVA. Glucose was analyzed using a 2(trial) x 3(time) repeated measures ANOVA. If a significant interaction (trial x time) or significant main effect for time was found, means comparisons were performed. RPE was analyzed using a 2 (trial) x 10 (time) repeated measures ANOVA. If a significant interaction (trial x time) or significant main effect for time was found, means comparisons were performed. Activity counts were summarized hourly and analyzed by a 2 (trial) x 12 (time) repeated measures ANOVA. If a significant interaction (trial x time) or significant main effect for time was found, means comparisons were performed. Activity counts were also averaged for the hours pre-lunch and the hours post-lunch and analyzed by a 2 (trial) x 2 (time) repeated measures ANOVA. In all statistical tests, significance was evaluated at $p < 0.1$.

RESULTS

Blood Glucose

There was a significant difference between CHO and PLA trials across time ($p<0.1$). When subjects received 200ml of a carbohydrate rich drink (20% solution) every hour, they were able to maintain blood glucose levels throughout the 12-hour work shift. When subjects received placebo, they were not able to maintain blood glucose levels ($p<0.1$). Blood glucose in the PLA group was significantly higher pre-breakfast (5.2 ± 0.7mmol/L) than post-shift (4.5 ± 0.4mmol/L), but no difference between pre-breakfast and post-breakfast (5.6 ± 0.8mmol/L) or post-breakfast and post-shift. The blood glucose of the CHO group was significantly higher post-breakfast (5.9 ± 0.8mmol/L) than pre-breakfast (5.1 ± 0.9mmol/L), but there was no difference between pre-breakfast and post-shift (5.2 ± 1.2mmol/L) or post-breakfast and post-shift. The only significant difference between groups was at the end of the day when the CHO group had significantly higher blood glucose than the PLA group. See Figure 1.

Rate of Perceived Exertion

Rate of perceived exertion was significantly different across time regardless of which beverage subjects received ($p<0.1$). Figure 2 shows that RPE was significantly higher than hour one for each subsequent hour regardless of beverage supplement. There was not a difference in RPE when subjects received CHO compared to when they received PLA.

Activity Counts

There was a significant difference in activity counts across time regardless of which beverage was received ($p<0.1$). Figure 3 shows that regardless of which supplement received, from the fourth hour post-breakfast, until the sixth hour post-lunch, subjects were more active compared to the first hour post-breakfast ($p<0.1$).

When looking at pre-lunch and post-lunch averages, there was a significant difference between CHO and PLA trials across time. When receiving PLA, subjects were significantly more active post lunch (493.0± 236.7 counts/min) than pre-lunch (355.7 ± 165.4 counts/min). The same was true when receiving CHO (pre-lunch = 338.7 ± 110.0 counts/min; post-lunch = 658.6 ± 330.6 counts/min). Activity counts for CHO post-lunch were significantly greater than counts for PLA post-lunch ($p<0.1$). See Figure 4.

Sleepiness Score

There was a significant difference in sleepiness score across time (pre-breakfast compared to post-breakfast and post-shift) ($p<0.1$). Subjects were significantly more sleepy pre-breakfast (3.5 ± 1.7) and post-shift (3.2 ± 1.6) than post-breakfast (2.2 ± 1.1), but there was no difference between sleepiness score pre-breakfast and post-sift, regardless of which supplement was provided.

Mathematical Processing

There was no difference in the number of correct math responses either across time or between trials. See Table 2.

Analysis of mean reaction time for correct math responses revealed a significant difference across time regardless of which supplement was provided ($p<0.1$). Subjects produced correct responses faster post-shift (2095.7 + 468.5 msec) than pre-breakfast (2221.4 ± 546.6 msec). However, there was no difference in correct response reaction time between pre-breakfast and post-breakfast, or post-breakfast and post-shift. See Figure 5.

Analysis of math thruput (correct responses per minute of available response time) revealed a significant difference across time regardless of the supplement provided ($p<0.1$). The thruput pre-breakfast (25.5 ± 10.7) was significantly lower than both the thruput post-breakfast (26.8 ± 10.2) and the thruput post-shift (27.1 ± 10.3). There was no difference in the thruput post-breakfast and post-shift. See Figure 6.

Four-Choice Test

There was no difference in number of correct four-choice answers either across time or between trials. See Table 3.

Analysis of mean reaction time for correct four-choice responses revealed a significant difference between CHO and PLA trials across time ($p<0.1$). When receiving PLA, subjects were responded significantly faster post-breakfast (396.1 ± 50.5 msec) than pre-breakfast (415.8 ± 52.8 msec). There was no difference in PLA reaction time for correct responses pre-breakfast and post-shift (418.2 ± 68.3 msec). When receiving CHO, subjects responded significantly faster post-shift (393.5 ± 41.9 msec) than pre-breakfast (415.1 ± 60.5 msec). There was no significant difference in CHO reaction time for correct responses pre-breakfast and post-breakfast (401.7 ± 61.4 msec). When given

CHO, reaction time for correct responses was significantly faster post shift than when given placebo (p<0.1). See Figure 7.

Analysis of four-choice thruput (number of correct responses per minute of available response time) revealed a significant difference across time regardless of the supplement received (p<0.1). Post-breakfast thruput (151.1 ± 20.0) was significantly higher than pre-breakfast thruput (144.9 ± 19.6). There was no difference in pre-breakfast thruput and post-shift thruput (148.0 ± 19.5), or post-breakfast thruput and post-shift thruput. See Figure 8.

DISCUSSION

See Table 4 for a summary. When subjects ingested 200ml of a 20% carbohydrate liquid every hour, they were able to maintain glucose, which was consistent with what this lab has observed in the past (Ruby et al., 2003;2004). The lack of significant difference between groups in the activity counts averaged per hour was most likely due to the small sample size. When activity counts were averaged pre-lunch and post-lunch, there was a significant difference in activity level of CHO and PLA trials post-shift, which is similar to what has been seen in the past (Ruby et al., 2003; 2004). There was no significant difference in sleep score, RPE, and mathematical processing between the two trials. Subjects in both trials reported an increasing RPE throughout the day and were the most awake post-breakfast (immediately before leaving camp to drive to the fire). The mean reaction time for correct four-choice and math responses was significantly faster in the carbohydrate trial post-shift than in the placebo trial post-shift (p<0.1). There was a significant increase in number of correct four-choice responses per minute of correct response when subjects were fed CHO compared to when fed PLA , while both groups demonstrated a higher number of correct responses per minute of available response time post-breakfast compared to pre-breakfast (p<0.1). There was a significant increase in the number of correct mathematical responses per minute of available response time both post-breakfast and post-shift compared to pre-breakfast (p<0.1). The improvement seen in the carbohydrate trial, while significant, does not seem to indicate a lack of judgment during the placebo trial, rather adequate decision making on simple tasks under both conditions, but improved with supplemental carbohydrate.

The slightly improved simple decision making process and the improved reaction time, combined with maintenance of blood glucose, high work output without a perception of working harder and the anecdotal reports of the firefighters that they felt better, were more satisfied and less hungry while receiving the supplemental carbohydrates would suggest the positive value of eating at regular intervals during wildland firefighting. However, there were some possible problem areas with this study. Due to the nature of firefighting, the dangers of being on the fireline, and the training required, researchers were not permitted to travel with the subjects throughout the day. Subjects were provided with instructions and researchers had to assume that they complied. In at least one instance, this was not the case. The protocol originally called for blood glucose and cognitive tests to be taken before lunch, but after reviewing the data, it was apparent that some of the subjects had eaten lunch before taking their blood glucose, and so this data could not be used. In addition, the sample used also posed possible problems. The use of a relatively small sample size limited the statistical power of this study. The lack of sample diversity limited the results of the study. All subjects were highly trained firefighters working on a large fire. The results of this study therefore may not apply to lesser trained workers, or similarly trained workers fighting a smaller, less demanding fire. Furthermore, due to the nature of the cognitive tests used in this study, the results may only be applicable to certain types of decision-making processes posed on the fire line. The main finding with the cognitive tests was that subjects reacted faster at the end of the day when receiving CHO. However, reaction time was measured in milliseconds. Thus, this may be very important when a firefighter is trying to move out of the way of a falling snag, but not very important when he or she is trying to decide the fastest escape route.

The cognitive tasks in this research, while validated, may not be appropriate measures of decision-making ability for wildland firefighters. However, they are appropriate measure of simple reaction time and when combined with the overall series of studies done by this lab on supplemental carbohydrate feeding strongly support their benefit and strongly support that any financial cost incurred to change the shift food to incorporate frequent eating will help the firefighting effort and increase daily work production. The application of these results may be best expressed in a change of shift food. While firefighters currently receive bag lunches, it may be more appropriate to provide them with a choice of high carbohydrate foods than can be packed easily and eaten at regular intervals on the fireline. This may include things such as granola bars, raisins, and Gatorade.

The results of this study also suggest that wildland firefighters are not becoming mentally fatigued at the end of a 12-hour shift. Conversely, the data show that they are more alert at the end of the shift than earlier in the day. Though this lab has not evaluated safety issues associated with longer shift lengths, this study, when viewed in light of prior research by the military would suggest that wildland firefighters, if motivated, could maintain work output at comparable levels to 12-hour shifts for much longer. Whether they can stay mentally alert for longer has yet to be determined, but prior research would suggest somewhat longer (up to 18-24 hours) is possible.

This study has provided support to previous research that in addition to benefits to physical activity, supplemental carbohydrate feedings positively affect cognitive function. However, this study is by no means all-inclusive. Future research may include the use of other measures of cognitive functioning, such as those that evaluate more complex decision-making skills. The effects of different independent variables on cognitive function need to be evaluated, such as number of hours of sleep, hydration status, job description, heat, stress, and diet preferences (self-selected eating habits versus regular carbohydrate feedings). Cognitive functioning is necessary to ensure safety on the fire line. The only way to learn how to maintain cognitive functioning is to learn what affects it. Perhaps by learning this, one can help to prevent unnecessary deaths associated with wildland firefighting.

Age	26.5 ± 7.7
Weight (kg)	82.32 ± 9.10
Height (cm)	177.29 ± 7.11

Table 1. Subject descriptors (mean ± standard deviation)
Members of three different hotshot crews working on the Fischer Fire in Leavenworth, Washington during August 2004 were recruited as subjects (n=17; 2F, 15M) for the study.

Drink	Pre-Breakfast	Post-Breakfast	Post-Shift
PLA	44.9 ± 5.6	46.4 ± 3.1	45.7 ± 3.0
CHO	44.7 ± 4.2	45.3 ± 5.5	45.667 ± 3.7

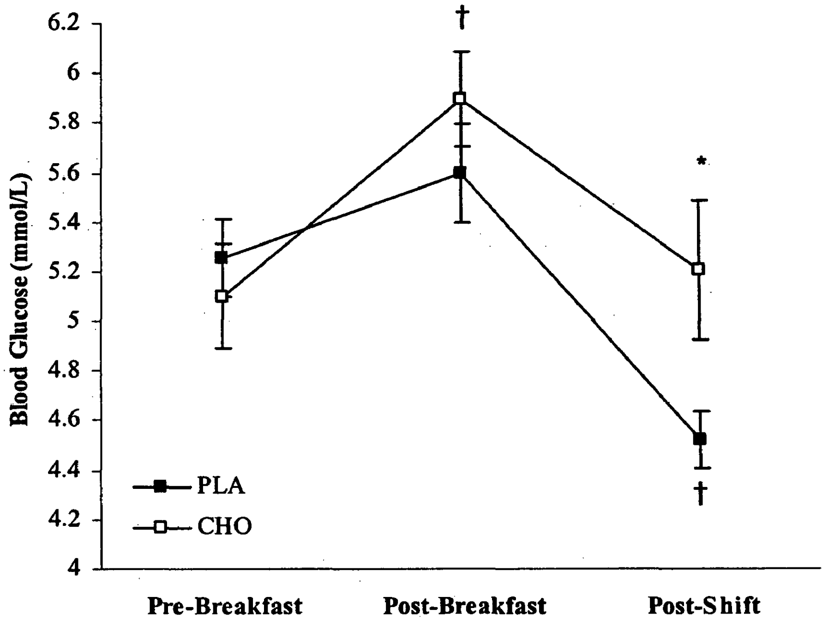
Table 2. Correct math responses (mean ± standard deviation)
There was no difference in the number of correct math responses either across time (pre-breakfast compared to post-breakfast and post-shift) or between trials CHO compared to PLA) ($p<0.1$).

Drink	Pre-Breakfast	Post-Breakfast	Post-Shift
PLA	49.3 ± 1.0	49.3 ± 1.0	49.4 ± 0.7
CHO	49.3 ± 0.6	49.5 ± 0.8	49.2 ± 0.9

Table 3. Correct four-choice responses (mean ± standard deviation)
There was no difference in number of correct four-choice answers either across time (pre-breakfast compared to post-breakfast and post-shift) or between trials CHO compared to PLA) ($p<0.1$).

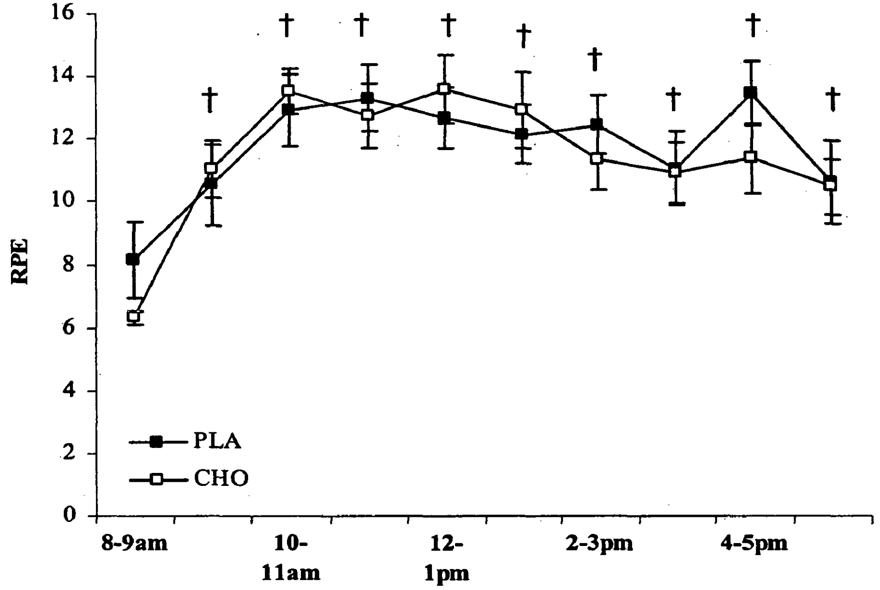
Variable	**Main Findings**
Blood Glucose	Maintain throughout work shift CHO > PLA at end of shift
Activity Counts Per Hour	No difference between CHO / PLA
Average Activity Counts Pre-Lunch	No difference between CHO / PLA
Average Activity Counts Post-Lunch	CHO > PLA
Rate of Perceived Exertion	No difference between CHO / PLA
Sleep Score	No difference between CHO / PLA Most alert post-breakfast in both trials
Correct Math Responses	No difference between CHO / PLA No difference across time
Reaction Time for Correct Math Responses	No difference between CHO / PLA Improved across time in both trials
Correct Math Responses Per Minute of Available Response Time (Thruput)	No difference between CHO / PLA Improved across time in both trials
Correct 4-Choice Responses	No difference between CHO / PLA No difference across time
Reaction Time for Correct 4-Choice Responses	CHO faster post-shift than PLA
Correct 4-Choice Responses Per Minute of Available Response Time (Thruput)	No difference between CHO / PLA Highest post-breakfast in both trials

Table 4. Summary of Results
When ingesting 200ml of a 20% CHO solution every hour (compared to PLA), subjects were able to maintain blood glucose throughout a 12-hour shift, and worked harder post-lunch. There was no difference between trials (CHO vs. PLA) in hourly activity counts, average pre-lunch activity, rate of perceived exertion throughout the day, sleepiness, correct math responses, or correct 4-choice responses. Subjects responded faster, and answered more math questions correctly per minute of available response time post-breakfast and post-shift compared to pre-breakfast regardless of which supplement was provided (CHO or PLA). Reaction time for 4-Choice responses was significantly faster post-shift when subjects received CHO compared to PLA. Whether receiving CHO or PLA, subjects' 4-Choice thruput (correct responses per minute of available response time) was greatest post-breakfast (compared to pre-breakfast and post-shift).



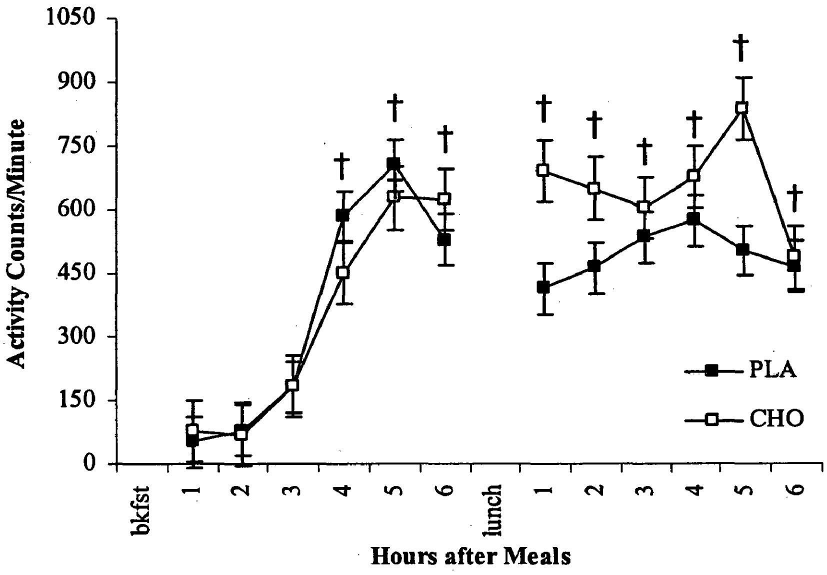
†- p< 0.1 vs. pre-breakfast
*- p< 0.1 vs. PLA

Figure 1. Blood glucose (mean ± standard error)
Blood glucose was significantly higher in the CHO trial post-breakfast than pre-breakfast and significantly lower in the PLA trial post-shift than pre-breakfast. Blood glucose was significantly higher in the CHO trial post-shift than in the PLA trial post-shift.



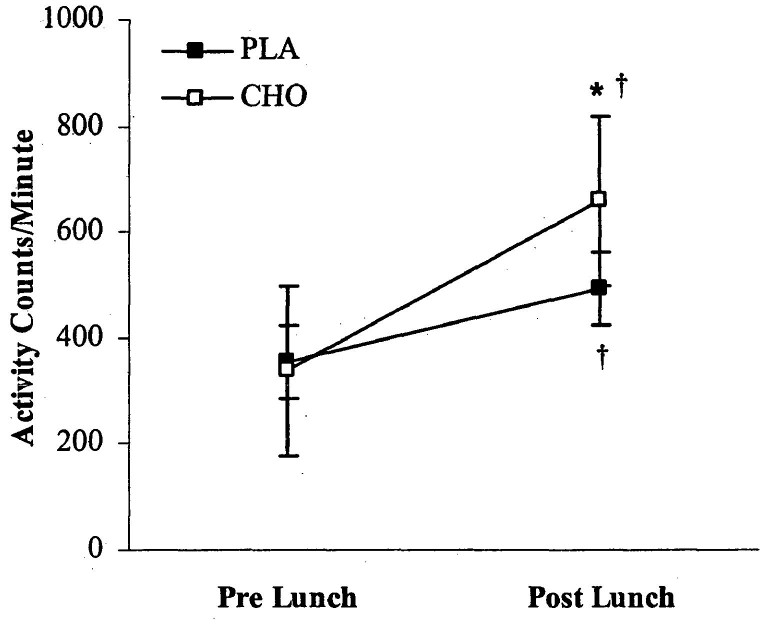
†- $p < 0.1$ vs. 8-9am regardless of trial (CHO or PLA)

Figure 2. Rate of perceived exertion (mean ± standard error)
RPE was significantly higher than hour one for each subsequent hour regardless of beverage supplement. There was no difference in RPE between trials (CHO vs. PLA).



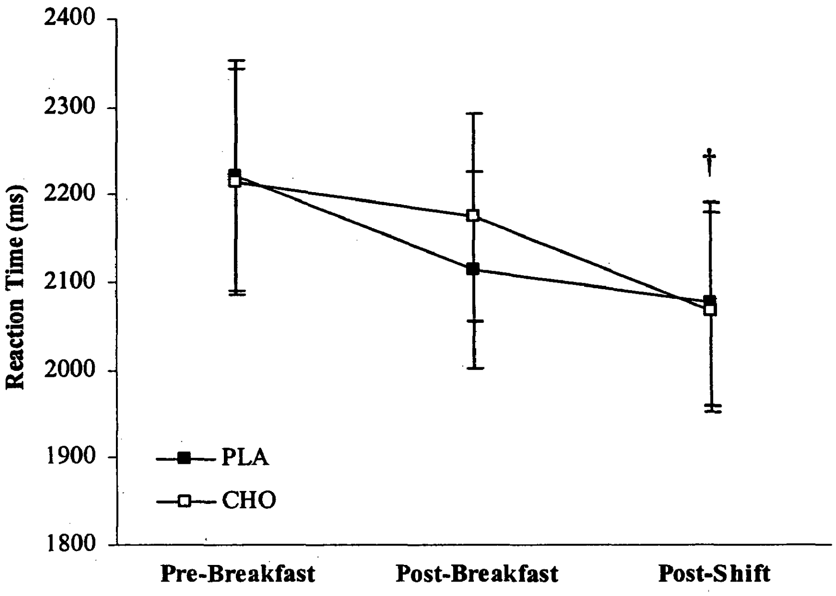
†- $p < 0.1$ vs. hour 1 post-breakfast

Figure 3. Hourly activity (mean ± standard error)
Regardless of which supplement received, from the fourth hour post-breakfast, until the sixth hour post-lunch, subjects were more active compared to the first hour post-breakfast. There was no difference in activity counts between trials (CHO vs. PLA).



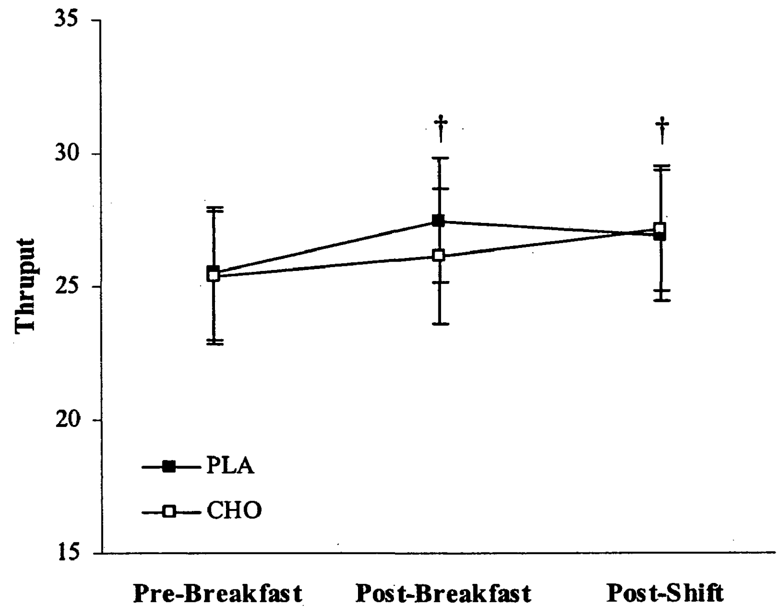
†- $p < 0.1$ vs. pre-lunch
*- $p < 0.1$ vs. PLA

Figure 4. Pre-lunch/post-lunch activity (mean ± standard error)
When pre-lunch and post-lunch activity counts were averaged, there was a significant difference between CHO and PLA trials across time. When receiving PLA or CHO, subjects were significantly more active post lunch than pre-lunch. Activity counts for CHO post-lunch were significantly greater than counts for PLA post-lunch ($p<0.1$).



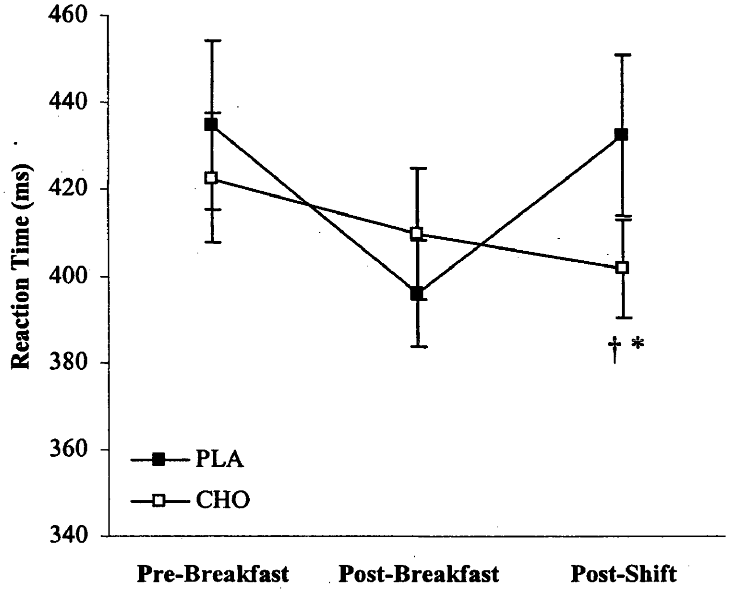
†- $p < 0.1$ vs. pre-breakfast regardless of trial (CHO or PLA)

Figure 5. Mathematical processing reaction time (mean ± standard error)
Analysis of mean reaction time for correct math responses revealed a significant difference across time regardless of which supplement was provided ($p<0.1$). Subjects produced correct responses faster post-shift than pre-breakfast. There was no difference in correct response reaction time between pre-breakfast and post-breakfast, or post-breakfast and post-shift.



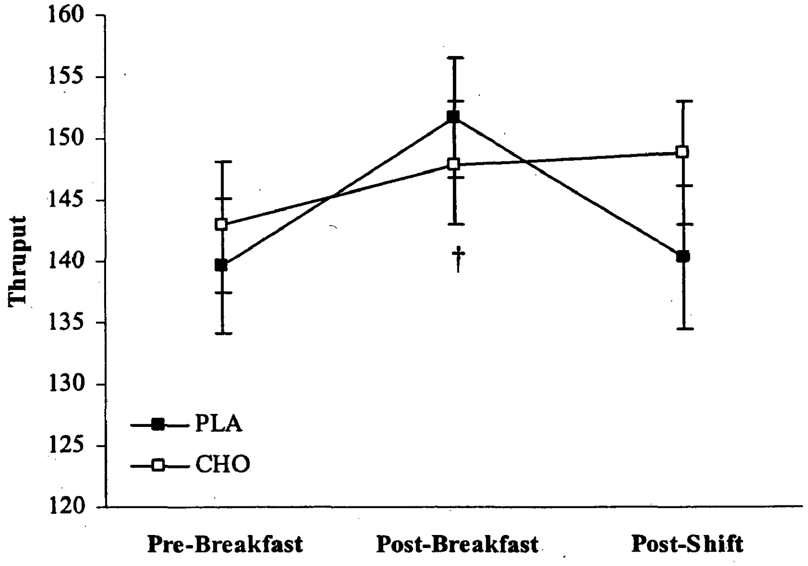
†- $p < 0.1$ vs. pre-breakfast regardless of trial (CHO or PLA)

Figure 6. Mathematical processing thruput (mean ± standard error)
Analysis of math thruput (correct responses per minute of available response time) revealed a significant difference across time regardless of the supplement provided ($p<0.1$). The thruput pre-breakfast was significantly lower than both the thruput post-breakfast and the thruput post-shift. There was no difference in the thruput post-breakfast and post-shift.



†- p < 0.1 vs. pre-breakfast
*- p < 0.1 vs. PLA

Figure 7. Four-choice reaction time (mean ± standard error)
There was a significant difference in mean reaction time for correct four-choice responses between CHO and PLA trials across time. Subjects were responded significantly faster post-breakfast than pre-breakfast in the PLA trial. There was no difference in PLA reaction time for correct responses pre-breakfast and post-shift. Subjects responded significantly faster post-shift than pre-breakfast when receiving CHO. There was no significant difference in CHO reaction time for correct responses pre-breakfast and post-breakfast. Reaction time for correct four-choice responses was significantly faster post-shift when subjects received CHO versus receiving PLA.



† - $p < 0.1$ vs. pre-breakfast regardless of trial (CHO or PLA)

Figure 8. Four-choice thruput (mean ± standard error)
Analysis of four-choice thruput (number of correct responses per minute of available response time) revealed a significant difference across time regardless of trial (CHO or PLA). Post-breakfast thruput was significantly higher than pre-breakfast thruput. There was no difference in pre-breakfast thruput and post-shift thruput, or post-breakfast thruput and post-shift thruput.

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