12-2012

Acute Exercise and its Effect on Cognitive Performance in Sleep Deprived Individuals: A Review of Literature.

Jennifer Nicole Miller
East Tennessee State University

Acute Exercise and its Effect on Cognitive Performance in Sleep Deprived Individuals: A Review of Literature

Thesis submitted in partial fulfillment of Honors

By

Jennifer Nicole Miller
The Honors College
Midway Honors Program
East Tennessee State University

December 13, 2012

____
Dr. Michael Ramsey, Faculty Mentor

____
Dr. Beatrice Owens, Faculty Reader

____
Dr. Brandi Eveland-Sayers, Faculty Reader

CONTENTS

ABSTRACT

This literature review observes seven different studies that researched the effects of exercise on some measure of cognitive or psychological performance when sleep deprived. The purpose of this review is to consolidate the results of various exercise protocols on the effects of sleep deprivation to make a general conclusion regarding the effect on cognition. This will give insight into the future of research regarding how exercise may combat performance decrements seen when sleep deprived. There are several inconsistencies among current research concerning exercise and sleep deprivation; a standard needs to be created so the results of these studies can be extended to a larger population.

AKNOWLEDGEMENTS

I would like to extend recognition and gratitude to those who helped make this literature review possible:

My parents, Bill and Chris Miller, for supporting me throughout my education and making it possible for me to overcome all of the challenges I have been faced with.

My sister, Ashley, for managing to live with me through the stress of applying to physical therapy school, completing my thesis, and making me laugh along the way.

East Tennessee State University Honors College for the opportunity to further my knowledge with an undergraduate thesis, financial assistance, and mentorship through the Midway Honors Program.

Dr. Joy Wachs for constant availability and advice when completing my thesis seemed impossible.

Dr. Rebecca Pyles for teaching me how to be a professional and pushing me to work at a level I didn't think was possible.

Dr. Michael Ramsey for being willing to take on the position as my thesis mentor with short notice.

Dr. Brandi Eveland-Sayers for your excellence as a professor and interest your students' success.

Dr. Bea Owens for being flexible during your ever changing roles in my thesis project.

My best friend, Lindsey Cox for keeping me sane with constant prayers and support through this process.

CHAPTER 1

BACKGROUND

Sleep deprivation is an epidemic that many individuals experience. At any given point, life can become overwhelming, allowing the necessity of regular slumber to suffer. According to the National Sleep Foundation, an average of eight hours of sleep per night is recommended (Malik & Kaplan, 2005). Many would scoff at this number, claiming it to be unreasonable with the demands presented on an average day. Any less than the recommended eight hours per night would be considered sleep deprivation, bringing with it significant consequences. There are two different avenues through which sleep deprivation can be experienced, quantitative and qualitative. Quantitative sleep deprivation is the complete loss of sleep for one night or more, while qualitative sleep deprivation results from frequent waking causing a poor sleep quality (Malik & Kaplan, 2005). Both types are equally concerning in the realm of sleep deprivation and result in similar detrimental effects, however qualitative sleep deprivation often goes unnoticed due to gradual onset. Chronic sleep deprivation is common in the industrialized world and does have measurable consequences regarding behavior and physiology (Malik & Kaplan, 2005).

Cognitive Changes

Dysfunctions due to sleep loss are seen because of physiologic changes taking place in the brain. Research has been done suggesting this is the result of decreases in brain activity and function (Thomas et al., 2000). The brain prefers to use glucose as a main fuel source. Thomas and colleagues performed a study observing the changes in glucose concentrations in the brain when subjects are sleep deprived (Thomas et al., 2000). Deterioration in glucose concentration in certain areas of the brain is associated with different declines in performance. For example, cognitive function and alertness are associated with the thalamus and parietal cortices, meaning glucose concentration in those areas decline as cognitive function and alertness diminish (Thomas et al., 2000). Just as other body systems compensate for changes, the brain demonstrates similar techniques. The changes that take place “indicate that the brain may be able to compensate for the effects of [sleep deprivation] while maintaining at least partially intact performance” (Drummond et al., 2000). This compensation mechanism is crucial because it allows an individual to maintain a certain level of performance when sleep is not an option. It is important to note that these changes are due to “the failure of normal neural systems during the execution of specific tasks” (Drummond et al., 2000). While the brain is able to compensate for sleep deprivation using alternative pathways, it is evident that these changes cannot allow a sleep deprived brain to function at a level equal to a rested brain.

It is well established that sleep deprivation, even for one night, can reduce the normal level of performance of any given individual. Long nights awake are commonly accepted among various populations and unlikely to diminish in the future. This brings an important question to the surface; is there a type of sleep deprivation that reigns superior? Unfortunately, research has shown that the answer is no. Regardless of chronic or acute, recent experiments have found that levels of dysfunction following sleep deprivation are comparable (Goel, Rao, Durmer, & Dinges, 2009). It is not the type of sleep deprivation that heightens the deleterious effects, but the amount. While one night of total sleep deprivation would have rapid effects on the body, several days of limited sleep deprivation would have a similar outcome. Greater amounts of sleep deprivation amplify the performance deficits experienced (Thomas et al., 2000). There is also a certain amount of recovery sleep needed to restore normal functioning after being sleep deprived.

"Studies in young adults indicate that 8 to 9 hours of extended nocturnal sleep are needed to resolve sleepiness caused by decreased sleep time" (Goel et al. 2009). It is unlikely to assume that a college student would spend the night before an important exam recovering from sleep loss in order to avoid poor performance, especially if there is any level of test anxiety. Another important factor related to recovery sleep is the effect of re-exposure to sleep loss. "Evidence suggests that even after . . . recovery sleep, individuals with a history of recent exposure to chronic sleep loss may be more vulnerable to the effects of re-exposure to sleep restriction, exhibiting nearly double the deterioration" (Czeisler, 2009). The combination of insufficient recovery sleep with this acceleration in dysfunction would have lethal effects on the performance of various individuals.

Caffeine

The best cure for the performance deficits sleep deprivation exhibits is recovery sleep and prevention, but instead people are turning toward other things to combat the negative effects. There is a tremendous market for products that claim to reverse the feelings associated with sleep deprivation, most containing caffeine or a similar agent. Coffee, soda, tea and energy drinks are all packed with caffeine and attract customers with their claim to relieve feeling tired. "When cognitive performance is critical and must be maintained . . . administration of caffeine may provide a significant advantage" (Leiberman, Tharion, Shukitt-Hale, Speckman, & Tulley, 2002). While this is a short term fix, it is still effective in treating the signs of sleep deprivation. There has been research done providing an optimal dosage and time frame, however it is easy to overdo it when under pressure. Unfortunately, there are some serious problems with caffeine use, such as unpleasant side effects. It does not provide recovery from sleep loss, only a masking of the detrimental effects (Ellenbogen, 2005). Current data is available suggesting caffeine is safe, but it also encourages infrequent use to maximize the effects, not a typical practice among caffeine users (Wesensten, Killgore, & Balkin, 2005). There is a great need for a new agent to combat sleep deprivation that would not leave the user with unwanted side effects or addiction.

Exercise

Exercise is one option that may help increase alertness and cognition in sleep deprived individuals. It is universally known that exercise is good for the body, and according to recent research, it may also be good for the brain. "[A] positive relationship between physical activity and cognitive function has been found", but "little is known about its effects on alertness in sleep deprived participants" ("Exercise and Cognitive Health", 2007; LeDuc, Caldwell, & Ruyak, 2000). If exercise can alleviate some of the symptoms of sleep deprivation, it would be much better for health than the use of other stimulants. There would still be negative factors present, such as injury or health restrictions caused by illness or disease. However, if exercise could improve alertness in sleep deprived subjects, the benefits would be much greater than the risk involved. At the right intensity and duration, exercise has arousing properties that should be explored in association with sleep deprived individuals (LeDuc et al. 2000).

How exercise affects the body is important in understanding its application to sleep deprivation. It has been well established that physical activity has many positive outcomes, not only improving physical well-being, but also cognition through changes to brain structure and function (Hillman, Erickson, & Kramer, 2008). There is evidence that physical activity affects cognition on several levels, from cells and molecules to behavior and systems (Hillman et al. 2008). When exercise is provided to the body as a stimulus, multiple chemical changes occur in the brain and cerebral blood flow is increased. The changes that occur in the brain during exercise would have an effect on cognition; if this effect is positive it could alleviate the symptoms of sleep deprivation. In his review, Hillman states that the effects of physical activity on brain function and cognition are positive regarding several aspects of functionality (Hillman et al. 2008). The chemical changes in the brain are in regard to production of endogenous opioids, such as endorphins, enkephalins and dynorphins (Thoren, Floras, Hoffmann, & Seals, 1990). Endorphins are known for producing the effects known as the "runner's high" because they reduce pain and create a feeling of relaxation; they have also been linked to cognitive function (Tomporowski, 2003). Reducing anxiety as a result of exercise could influence cognitive performance by allowing the subject to feel in control of their situation. Not only does exercise reduce stress and anxiety, but it also has been reported to provide clearer thinking and a better mood (Tomporowski, 2003). It has been noted that as little as ten minutes of intense exercise can allow an individual to reap the benefits of heightened endorphin levels for up to an hour (Springen, 2004).

Several facts have been presented that discourage limited sleep; however the problem still exists in multiple individuals. There are settings where sleep deprivation performance decrements are more risky than others, such as caretakers (nurses, doctors, dentists, therapists, etc.) and students who need to perform well in class and on exams to be prepared for a career. There is a need to analyze the research that has been done regarding different ways to combat sleep deprivation. One of the best options that offer no unfortunate side effects is exercise. This review will look at articles related to sleep deprivation and exercise to determine the impact on deterring the performance decrements seen with sleep deprivation.

CHAPTER 2

METHODS

A search using PubMed and CINAHL with Full Text databases through East Tennessee State University's Charles C. Sherrod Library was utilized to find the studies analyzed in this review. Search terms used for PubMed with corresponding number of articles found included: "sleep deprivation" AND "exercise (258), "sleep deprivation" AND "cognition" AND "exercise" (18), "acute exercise" AND "cognition" (35), "acute exercise" AND "cognitive performance" (14), "physical activity" OR "exercise" AND "sleep deprivation" (318). Search terms used for CINAHL with corresponding number of articles found included: "acute exercise" AND "cognition" (14), "acute exercise" AND "cognitive performance" (5), "sleep deprivation" AND "cognition" AND "exercise" (4), "sleep deprivation" AND "exercise" (43). All of the articles analyzed in this review were located on PubMed under the keywords "physical activity" OR "exercise" AND "sleep deprivation".

Seven studies were chosen based on their participant demographics, amount of sleep deprivation, and exercise intervention. They have been analyzed to determine if there is a relationship between the results of the varying research protocols. The studies included *Level of Arousal and the Ability to Maintain Wakefulness* by Bonnet and Arand; *The Acute Effects of Twenty-Four Hours of Sleep Loss on the Performance of National-Caliber Male Collegiate Weightlifters* by Blumert, Crum, Ernsting, Volek, Hallander, E. Haff, and G. Haff; *The Effects of Exercise as a Countermeasure for Fatigue in Sleep-Deprived Aviators* by LeDuc, Caldwell, and Ruyak; *Physical Activity Increases the Dissociation Between Subjective Sleepiness and Objective Performance Levels During Extended Wakefulness in Human* by Matsumoto, Mishima, Satoh, Shimizu, and Hishikawa; *Creatine Supplementation, Sleep Deprivation, Cortisol, Melatonin, and Behavior* by McMorris, Harris, Howard, Langridge, Hall, Corbett, Dicks, and Hodgson; *Effects of Sleep Deprivation on Anaerobic Exercise-Induced Changes in Auditory Brainstem Evoked Potentials* by Ozturk, Bulut, Vadar, and Uzun; and *Effects of Sleep Deprivation and Exercise on Cognitive, Motor Performance, and Mood* by Scott, McNaughton, and Polman. Table 1 summarizes the information relevant to this topic for each study and can be found in the appendix.

CHAPTER 3

ANALYSIS

Subjects

While many of the studies performed similar exercise protocols and cognitive tests, there is not a standard measurement technique among sleep deprivation research regarding exercise. By observing several aspects of each study, a conclusion about the future of research concerning sleep deprivation and exercise can be made. Each study utilized subjects between the ages of 20-30 years, with most falling under 25 years. Only two studies (Bonnet & Arand and LeDuc et al.) included male and female participants, it should also be noted that LeDuc et al. only included one female. Most studies (all but Bonnet & Arand and McMorris) approached data collection as a cross-over study that included two separate data collection dates, allowing the subjects to act as their own controls. The two studies that did not utilize cross-over were required to separate their already small sample size into two groups. As a whole, the number of subjects participating in each study was too small to make far reaching conclusions based on the results. This fact likely had an impact on the results of the studies.

Amount of Sleep Deprivation

While most of the studies had clearly defined hours of sleep deprivation, others gave basic information that was not quantitative in nature. Matsumoto et al. used "total sleep deprivation" to define the amount, and Ozturk et al. titled their amount as "one night of sleep deprivation". Without an exact defined number of hours the subjects underwent sleep deprivation, it is difficult to relate test results. Each sleep deprivation study needs to include the exact number of hours sleep deprived, wake times, and an hourly event schedule that includes testing, exercise, and observation conditions.

Exercise Protocol

Each study had a different exercise protocol that was clearly and specifically defined. Bonnet and Arand observed different levels of arousal by conducting tests that included being spoken to, sitting up in bed and lying back down, standing up beside the bed and lying back down, standing up beside the bed and doing three quick knee bends before lying back down, and doing three knee raises while lying in bed. Each segment was associated with a different level of arousal established by observing the wave latencies from EEG data. Blumert et al. observed three weight lifting techniques (snatch, clean and jerk, and front squat) as their acute exercise protocol. Testing was done immediately before and after the lifting session. LeDuc et al. used an intermittent exercise protocol in which the subjects ran on a treadmill at 70% of their VO_{2max} for 10 minutes every 2 hours. Combined with the 40 hours of sleep deprivation, that equated to a total of 3 hours and 20 minutes of exercise during the testing period. Matsumoto et al. used a similar approach with treadmill walking for 15 minutes of every hour at a rate of 0.3 kcal/kg/hour. Although the study did not directly state the number of hours sleep deprived, there was a specific 14 hour period during which testing and exercise was conducted. The intermittent exercise resulted in 3 ½ hours of walking during the testing period. Again, this is an extreme amount of exercise during the given time frame. McMorris et al. also utilized intermittent exercise for 15 minutes of every hour. The exercise was varied between walking, step ups, and stair climbing at 65% of maximum heart rate. This protocol resulted in the largest volume, 7 ½ hours of exercise over the course of 30 exercise sessions. Ozturk et al. utilized a single Wingate cycle ergometer test that was performed in the afternoon following one night of total sleep deprivation. Blumert et al. and Ozturk et al. were the only two studies to perform one single bout of exercise and anaerobic exercise. Scott et al. established a protocol involving 20 minutes of exercise on a cycle ergometer at 50% of VO_{2max} every 2 hours. This protocol resulted in 5 total hours of exercise. All but two studies (Blumert et al. and Ozturk et al.) utilized intermittent exercise as a combatant against the performance decrements seen with sleep deprivation. For each study in which intermittent exercise was performed, an extreme amount of time spent exercising potentially could have added to the already present neural fatigue.

Cognitive Testing

There was just as much variety in the type of cognitive tests performed as there was with exercise protocol. Each study related intermittent exercise with intermittent testing. Therefore, it resulted in a substantial amount of testing throughout the research period. Bonnet and Arand used a Return to Wakefulness test that interpreted EKG and EEG data. They found that their different levels of arousal were directly related to the magnitude of physiological arousal. This supports the assumption that an increase in heart rate can stimulate arousal/maintain wakefulness best when sleep deprived. While Blumert et al. did not perform specific cognitive testing, sleepiness and mood were documented between the sleep deprived and non-sleep deprived groups. The results of this study are significant for this review because disturbances in mood and increased sleepiness were exhibited in the sleep deprived group following exercise, and both factors observed may have an indirect influence on cognition. LeDuc et al. performed numerous cognitive tests, some of which were specific for aviators (the subjects in the study). The conclusion was that exercise only provides short term benefits and is not able to overcome the degree of performance decrement seen when sleep deprived. It also observed that feelings of sleepiness increased less than one hour after exercising. However, the study did not discount the use of exercise when sleep deprived and stated that exercise can increase alertness without compounding fatigue.

Matsumoto et al. observed that exercise only subjectively decreases sleepiness. This is a problem because the performance decrements still exist and exercise provides a misinterpretation of those decrements by decreasing perceived sleepiness and potentially altering judgment. McMorris et al. was testing the influence of creatine on sleep deprivation in his double blind study with an intervention and placebo group. The placebo group is of most interest in this case, because they performed exercise when sleep deprived with no supplementation. The placebo group saw no increase in complex central executive tasks with testing at 18, 24, and 36 hours of sleep deprivation. While these results may seem unfortunate regarding exercise alone, the fact that there was no decrease in performance throughout the sleep deprived time period is significant. An extensive battery of tests was performed looking at psychological, physiological, and cognitive function during sleep deprivation.

Ozturk et al. had a different approach to his research, being the only study to observe anaerobic exercise, a single bout of exercise, and Auditory Brainstem Response (ABR) as measured by electrodes. It was found that sleep deprivation slowed ABR wave transmission speed through neuronal fatigue, and that exercise lessened the latency. Anaerobic exercise may increase neurological function as seen in Ozturk et al.; however the effect on mood and sleepiness as documented in Blumert et al. should be accounted for before recommending this type of exercise. Scott et al. saw decreases in mood and reaction time in the exercise group, which was related to an increased risk of mistakes. While the sleep deprivation group that did not exercise saw expected performance decrements, the exercise group exhibited even further decrement. When analyzing the results of each study, it must be kept in account that all of the articles involved very few subjects. While the results of the studies are helpful in determining the role of exercise when sleep deprived, they cannot be used to make vast assumptions about the general population.

CHAPTER 4

CONCLUSION

Despite the difference in mode, duration, frequency, and intensity of exercise; many of the studies reached similar conclusions regarding the effect of exercise on sleep deprivation. By establishing a suggested battery of tests to be performed for every sleep deprivation study including exercise, some of the discrepancy between studies can be reduced. It is obvious that exercise increases alertness; however the impact this may have on cognition when sleep deprived needs to be studied further. The need for a healthy alternative to combat sleep loss has been well established, the next step is to determine what this alternative is and how to implement it. Intermittent exercise places a tremendous amount of stress and fatigue on the body, despite this fact it was the most popular form of exercise intervention seen throughout the literature search. The only study that saw an increase in performance (in the case of ABR wave transmission speed) was the protocol that utilized a single bout of exercise (Ozturk et al., 2007). The impact that mood has on cognitive function and performance also needs to be explored; there are various results regarding the impact exercise has on mood when sleep deprived. There needs to be more research performed observing the differences between a single bout of aerobic and anaerobic exercise on tests of cognition when sleep deprived in order to suggest a proper protocol that can be used by a multitude of individuals suffering from the performance decrements related to sleep deprivation.

CHAPTER 5

PRACTICAL APPLICATION

One population known for accumulating sleep loss is college students. College students in one study reported sleeping on average less than seven hours per night, staying awake all night nearly once a month and getting less sleep than needed over 10 times per month (Engle-Friedman et al., 2003). The demands of academic and social circles can easily overwhelm an ambitious young person. High achievement in academics is expected from college students and many cut back on sleep to meet these expectations. However, there is evidence that shows sleep deprivation dramatically reduces the cognitive abilities required for good academic performance. "Cognitive functions particularly affected by sleep loss include, psychomotor and cognitive speed, vigilant and executive attention, working memory, and higher cognitive abilities" (Goel et al., 2009). Each function is important to guarantee effective study techniques and class lecture recall for the student. Settling for fewer hours of sleep each night is commonly seen among students, but missing an hour of sleep here or there can quickly amount to the loss of a full night's rest. Earlier discussion outlined the threat of qualitative sleep deprivation, allowing "cognitive deficits [to] accumulate to severe levels over time without full awareness by the affected individual" (Goel et al., 2009). Few dedicated college students would ever dream of taking an important exam after chugging some beers with their friends, but pulling an all-nighter can have similar effects. Sleep deprivation can be manifested as impairments similar to a blood alcohol level at or above the legal limit, causing an unpredictable instability of cognitive function (Goel et al., 2009). Traditional students may have a heightened disadvantage because "data reveal that young adults are most severely affected by acute sleep deprivation" (Czeisler, 2009). A contributing factor in the poor performance of college students, sleep loss has a serious impact on young adults trying to meet the demands of everyday life.

There are a variety of reasons students lack sleep, but some are cutting back in order to spend more time studying. This may be counterproductive when observing how sleep loss impacts effort. Instead of challenging themselves, a sleep deprived person is more likely to study subjects requiring limited effort that provide the most reward. A recent study looked at the results of two groups, sleep deprived and non-sleep deprived, when performing the Math Effort Task. While "[t]here was no difference between the sleep groups on percent of additions correctly completed . . . the [sleep deprivation] group selected a lower level of difficulty from the very first trial . . . [and] continued to choose lower levels of difficulty throughout the assessment relative to the [non-sleep deprived] group" (Engle-Friedman et al., 2003). This lack of effort combined with the cognitive decrements of sleep deprivation creates a serious problem for students striving to do well academically. Some sleep deprivation research uses repetitive tests requiring the participants to solve math problems that can quickly become tedious. However, results show that the decrease in cognitive ability was a direct result of sleep deprivation and not of effort or motivation due to repetition or duration of tasks (Thomas et al., 2000). This proves that while sleep deprivation does impact focus, the cognitive deficits are not related to a lack of focus, but to sleep deprivation. Research has also found that when given a choice, subjects chose non-intellectual tasks that demanded little effort. As task difficulty increases during sleep deprivation, more cognitive resources must be recruited, making an easy task harder than performing a more difficult version when rested (Drummond, Brown, Salamat, & Gillin, 2004). Due to limited focus and cognition, studying would fall into the category of tasks considered significantly more difficult when sleep deprived. This is a contradictory statement because many students are losing sleep to spend more time studying or completing other academic tasks.

While students may be at the greatest risk for sleep deprivation, there certainly are other populations that would benefit from additional research in the area of exercise and sleep deprivation. Anyone working as a caretaker or in the medical field would benefit from this information, as would parents, shift workers, and the list goes on and on. There are many careers or lifestyles that demand limited sleep and high productivity. A study that encompassed many ages, male and female, multiple fitness levels, individualized exercise intensities, and sleep deprivation would produce results that could be used across many populations. Regardless of the results that one acute bout of exercise may have on sleep deprivation; they would be helpful for many individuals and close a gap in sleep deprivation research.

REFERENCES

Blumert, P. A., Crum, A. J., Ernsting, M., Volek, J. S., Hollander, D. B., Haff, E. E., & Haff, G. G. (2007). The acute effects of twenty-four hours of sleep loss on the performance of national-caliber male collegiate weightlifters. *Journal of Strength and Conditioning Research,* 21.4, 1146-1154.

Bonnet, M. H. & Arand, D. L. (1999). Level of arousal and the ability to maintain wakefulness. *Journal of Sleep Research,* 8, 247-254.

Czeisler, C. A. (2009). Medical and genetic differences in the adverse impact of sleep loss on performance: ethical considerations for the medical profession. *Transactions of the American Clinical and Climatological Association*, 2009, 249-285.

Drummond, S. P., Brown, G. G., Gillin, J. C., Stricker, J. L., Wong, E. C., & Buxton, R. B. (2000). Altered brain response to verbal learning following sleep deprivation. *Nature*, 403, 655-657.

Drummond, S. P., Brown, G. G., Salamat, J. S., & Gillin, J. C. (2004). Increasing task difficulty facilitates the cerebral compensatory response to total sleep deprivation. *Sleep*, 27.3, 445-451.

Ellenbogen, J. M. (2005). Cognitive benefits of sleep and their loss due to sleep deprivation. *Neurology*, 64, 25-27.

Engle-Friedman, M., Riela, S., Golan, R., Ventuneac, A. M., Davis, C. M., Jefferson, A. D., & Major, D. (2003). The effect of sleep loss on next day effort. *Journal of Sleep Research*, 12, 113-124.

Exercise and cognitive health: the debate continues. (2007). San Francisco: *Annals of Neurology*, 13-14.

Goel, N., Rao, H., Durmer, J. S., & Dinges, D. F. (2009). Neurocognitive consequences of sleep deprivation. *Seminars in Neurology*, 29.4 , 320-338.

Hillman, C. H., Erickson, K. I., & Kramer, A. F. (2008). Be smart, exercise your heart: exercise effects on brain and cognition. *Nature Reviews*, 9, 58-65.

LeDuc, P. A., Caldwell, J. A. & Ruyak, P. S. (2000). The effects of exercise as a countermeasure for fatigue in sleep-deprived aviators. *Military Psychology*, 12.4, 249-266.

Lieberman, H. R., Tharion, W. J., Shukitt-Hale, B., Speckman, K. L., & Tulley, R. (2002). Effects of caffeine, sleep loss, and stress on cognitive performance and mood during U.S. Navy SEAL training. *Psychopharmacology,* 164, 250-261.

Malik, S. W., & Kaplan, J. (2005). Sleep deprivation. *Primary Care: Clinics in Office Practice*, 32, 475-490.

Matsumoto, Y., Mishima, K., Satoh, K., Shimizu, T., & Hishikawa, Y. (2002). Physical activity increases the dissociation between subjective sleepiness and objective performance levels during extending wakefulness in human. *Neuroscience Letters,* 326, 133-136.

McMorris, T., Harris, R. C., Howard, A. N., Langridge, G., Hall, B., Corbett, J., . . . Hodgson, C. (2007). Creatine supplementation, sleep deprivation, cortisol, melatonin and behavior. *Physiology and Behavior*, 90, 21-28.

Ozturk, L., Bulut, E., Vadar, S. A., Uzun, C. (2007). Effects of sleep deprivation on anaerobic exercise-induced changes in auditory brainstem evoked potentials. *Clinical Physiology Functional Imaging,*27, 263-267.

Scott, J. P. R., McNaughton, L. R., Polman, R. C. J. (2006). Effects of sleep deprivation and exercise on cognitive motor performance and mood. *Physiology and Behavior*, 87, 396-408.

Springen, K. (2004). The serenity workout. *Newsweek*, 144.13, 68-71.

Thomas, M., Sing, H., Belenky, G., Holcomb, H., Mayberg, H., Dannals, R., . . . Redmond, D. (2000). Neural basis of alertness and cognitive performance impairments during sleepiness: effects of 24 h of sleep deprivation on waking human regional brain activity. *Journal of Sleep Research,* 9 , 335-352.

Thoren, P., Floras, J. S., Hoffmann, P., & Seals, D. R. (1990). Endorphins and exercise: physiological mechanisms and clinical implications. *Medicine and Science in Sports and Exercise,* 22.4, 417-428.

Tomporowski, P. D. (2003). Effects of acute bouts of exercise on cognition. *Acta Psychologica*, 112, 297-324.

Wesensten, N. J., Killgore, W. D. S., & Balkin, T. J. (2005). Performance and alertness effects of caffeine, dextroamphetamine, and modafinil during sleep deprivation. *Journal of Sleep Research*, 14, 255-266.

APPENDIX

Author	Year	Subjects	Mean Age	Sleep Deprivation	Exercise	Nutrition	Testing	Results	Conclusion
Bonnet and Arand	1999	14- 8 male, 6 female	26 ± 5.5 yrs	31 hours, Testing at 7, 19, 31 hours	Levels of arousal- talk, sit, stand, knee bends, knee raises	None documented	EKG, EEG	Verbal and physical activity return to wakefulness related to magnitude of physiological arousal	Alertness/sleepiness based on level of arousal may impact cognition, help maintain wakefulness
Blumert et al.	2007	9 male	20.7 ± 1.2 yrs	24 hours	Snatch, clean and jerk, front squat	No caffeine or eating	Subjective sleepiness, POMS	Significant difference in vigor, confusion, fatigue, depression, sleepiness for SD group	Complex motor skills more affected by SD than basic tasks, SD does not alter physical performance but does significantly alter psychological state

Author	Year	Subjects	Mean Age	Sleep Deprivation	Exercise	Nutrition	Testing	Results	Conclusion
LeDuc et al.	2000	12- 11 male, 1 female	29.9 yrs	40 hours	Treadmill at 70% VO_{2max} for 10 mins every 2 hours	None documented	Repeated tests of sustained wakefulness, VAS, POMS, multi-attribute task battery, synthetic work battery, flight simulation	Exercise has short term benefits but performance decrements still exist	Exercise is a countermeasure for fatigue, increases alertness without compounding fatigue
Matsumoto et al.	2002	8 male	21.1 yrs	"Total sleep deprivation"	Walking 15 mins at 0.3 kcal/kg/hr every hour	Normal meals, documented hydration, no caffeine	VAS, digit symbol substitution test, hand and eye coordination test	Exercise subjectively decreases sleepiness, but increased sleepiness results in decreased performance	A dissociation between brain function and perceived sleepiness with exercise may influence judgement

Author	Year	Subjects	Mean Age	Sleep Deprivation	Exercise	Nutrition	Testing	Results	Conclusion
McMorris et al.	2007	19 male- 10 intervention, 9 placebo	21.1 ± 1.9 yrs	36 hours Testing at 18, 24, 36 hours	Walking 15 mins, step ups, or stair climbing (both 2 x 5) at 65% HR_{max}	No meat, fish, or caffeine; meals and snacks provided	Random number generation, measure of redundancy, verbal short term memory, choice reaction time test, dynamic balance test, POMS	Intervention group took 5g of creatine 4 times per day for 7 days prior to testing, double blind, both groups exercised	Creatine saw improvement in RNG only after 36 hours SD and linear increase in complex central executive tasks while placebo saw no increase
Ozturk et al.	2007	7 male	22.4 ± 1.0 yrs	"one night deprivation"	Single Wingate cycle ergometer test	No caffeine	Auditory Brainstem Responses measured by electrodes	SD had no influence on anaerobic performance, shortened ABR wave transmission speed	Shows CNS response to SD as neuronal fatigue and slower wave transmission, exercise lessened latency
Scott et al.	2006	6 male- 3 exercise, 3 rest	22 ± 0.3 yrs	30 hours	20 mins cycle ergometer at 50% VO_{2peak} every 2 hours	Regular meals provided	Reaction time, computerized tracking, number cancellation, POMS	SD saw fatigue, depression and decrease in vigor. Exercise group poorer mood and reaction time	Decreases seen in exercise group may create increased risk of mistakes