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Controlled Attention and Sleep Deprivation: Adding a Self-Regulation Approach?

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Abstract

The current study examined performance on an automated task battery under short-term sleep deprivation and non-sleep deprivation conditions. Twenty-six volunteers completed the sleep deprivation study. Twenty-three volunteers completed the non-sleep deprivation study. Performance was examined across five test sessions during 25 hours of acute sleep deprivation conditions and during two days of non-sleep deprivation conditions. ANOVAs examining changes in performance from baseline levels indicated that performance under sleep deprivation conditions resulted in a decrease in performance in some tasks and an increase in estimated blood alcohol concentration. Non-sleep deprivation resulted in stable or increasing performance and a decrease in estimated blood alcohol concentration. The Controlled Attention Model suggests that the task characteristics would have helped maintain performance levels but does not explain how performance decreased on some but not all of the tasks. Extending the Controlled Attention Model to include a broader self-regulation approach suggests that on some of the tasks the participants did not adequately regulate their engagement in the task (even with rapidly changing stimuli) resulting in a decrease in performance levels. Incorporating a self-regulation approach with the Controlled Attention Model could provide a model that better explains the range of effects seen under sleep deprivation conditions.

Keywords: cognitive performance, motor performance, shift work, Controlled Attention Model, stress

1. Introduction

Although the effect of good sleep habits on health and well-being is gaining attention in many societies, chronic sleep loss continues to be a common occurrence for many people. Furthermore, modern society's reliance on 24-hour manufacturing, transportation, and service industries has created a work environment that requires shift work thus disrupting the endogenous circadian rhythms and sleep cycle in many workers. As such, the effects of sleep deprivation on the worker as well as the worker's ability to perform are important issues in many work settings.

1.1 Sleep Deprivation and Performance

The negative effects of shift work on sleep are well established (Åkerstedt, 2007; Pilcher, Lambert, & Huffcutt, 2000). There has been less effort; however, to establish and test a paradigm that can provide a theoretical basis for better understanding and predicting the effects of sleep deprivation on performance. Several reviews of the literature have concluded that sleep deprivation negatively affects performance on a wide range of tasks (Harrison & Horne, 2000; Lim & Dinges, 2010). There is a growing literature base that it is not always the simpler tasks that are more negatively affected by sleep deprivation. For example, complex language-based tasks can be more negatively affected by sleep deprivation than simpler language-based tasks (Pilcher, McClelland et al., 2007).

A recent approach to understanding the effects of sleep deprivation on performance is the Controlled Attention Model (Pilcher, Band, Odle-Dusseau, & Muth, 2007). This model suggests that tasks that are intrinsically less interesting are likely to be more negatively affected since the sleep-deprived individual would have to purposely control his or her attention in an effort to complete the task. The Controlled Attention Model can be applied to tasks that require vigilance or attention to the task, as well as tasks that require cognitive processing where the person must keep information in memory long enough to successfully complete the task. There is growing evidence that the Controlled Attention Model is useful in understanding a wide range of detrimental processes due to sleep deprivation (Lim & Dinges, 2010; Michael, Passmann, & Becker, 2012; Odle-Dusseau, Bradley, & Pilcher, 2010; Pilcher, Vander Wood, & O'Connell, 2011; Walker, Muth, Odle-Dusseau, Moore, & Pilcher, 2009).

1.2 Sleep Deprivation and Attention

The Controlled Attention Model is one approach to understanding how performance under sleep deprivation conditions is related to our attentional capacity. Human behavior can be viewed on a continuum between involuntary basic physiological mechanisms and higher level conscious cognitive processing (Pashler, Johnston, & Ruthruff, 2001). This hierarchical view of human behavior provides a means to understand complex cognitions as well as automated physiological actions and motor control and allows the connection from cognition to actual behavior (Carver & Scheier, 1998).

When examining performance, it is important to consider not only what the individual chooses to attend to but also other events that could impact performance. For example, the characteristics of the task could have an effect in that tasks that present new stimuli in the visual field draw the individual's attention (Yantis & Hillstrom, 1994). The physiological state of the individual also impacts the ability of the person to attend to a task and can affect performance. Sleep deprivation and sleep restriction, for instance, affect working memory and performance (Axelsson et al., 2008; Pilcher, Band et al., 2007). Thus, attention depends not only on the individual's ability to focus but also on conditions that may be out of the immediate control of the individual.

An individual's ability to monitor how well he or she can focus attention on a task is part of the human capacity to self-regulate. Self-regulation includes the ability to monitor actions that help the individual make and fulfill plans, inhibit unwanted thoughts, and regulate social behaviors (Heatherton & Wagner, 2011). The ability to self-regulate is theorized to depend on a limited amount of internal resources within each individual that can be exhausted (Heatherton & Wagner, 2011). For example, inhibiting emotions (Vohs & Heatherton, 2000) and suppressing thoughts (Muraven, Collins, & Nienhaus, 2002) decrease self-regulatory behaviors. Although sleep restriction and sleep deprivation induce physiological fatigue, there has been little effort to date to integrate sleep deprivation results with the literature on human self-regulation.

1.3 Current Study

The current study used the Automated Performance Test Systems (APTS; RSK Assessments, Inc., Orlando, FL) to examine performance on a variety of short tasks in sleep deprived and non-sleep deprived persons. The APTS tasks used in the current study were the two-hand tapping, math processing, code substitution, grammatical reasoning, and memory search. Each task in the APTS requires different levels of cognitive or motor processing, thus, creating a testing environment where individuals had to respond to changing performance requirements in short periods of time.

The APTS was developed to detect the effects of stressors on psychomotor and cognitive performance in repeated-measures settings (Kennedy, Dunlap, Turnage, & Fowlkes, 1993). The APTS has been shown to be sensitive to the effects of real world events that could negatively affect performance such as sustained wakefulness and alcohol (Kennedy et al., 1993; Trice & Steele, 1995). The APTS has also been used to develop a model to estimate alcohol dose equivalences (Kennedy et al., 1993).

The purpose of the current study was to examine cognitive and motor processing as measured by the APTS tasks under sleep deprivation and non-sleep deprivation conditions and relate the findings to the human capacity for attention and self-regulation. As an additional means of examining performance, the APTS tasks were used to estimate blood alcohol concentration (BAC) levels. We hypothesized the following:

1) Performance on the two-hand tapping task would decrease under sleep deprivation conditions but would remain stable under non-sleep deprivation conditions. Because this task is a basic motor response, this hypothesis is based on the literature suggesting that physical performance levels decrease under sleep deprivation conditions (e.g., Pilcher & Huffcutt, 1996).

2) Performance on the short cognitive APTS tasks would remain stable or decrease slightly under sleep deprivation conditions and remain stable under non-sleep deprivation conditions. This was a more difficult hypothesis since the literature has shown mixed effects of sleep deprivation on the cognitive APTS tasks. The Controlled Attention Model suggests that the sleep-deprived participants may be able to marshal their resources and successfully complete the tasks at least in part due to the tasks being short in duration thus allowing the participants to more easily maintain their attention (Pilcher, Band et al., 2007).

3) Estimated BAC levels would decrease in the sleep deprivation study as suggested by Kennedy and colleagues (Kennedy et al., 1993).

2. Method

2.1 Sleep Deprivation Study

2.1.1 Participants

Twenty-six undergraduate students (14 males, 12 females) from Clemson University served as participants in the sleep deprivation study. Their average age was 20.4 years (SD = 2.18). The study was approved by the university's institutional ethics review board. All participants signed an informed consent before starting the study and were paid for participating.

2.1.2 Procedures

Volunteers were recruited by flyers posted on the university campus. Potential participants completed a screening questionnaire to ensure that they were in good health, did not have any diagnosed sleep disorders, reported a regular diurnal sleep/wake cycle, did not excessively drink alcohol, and did not use tobacco or drugs. The participants who met the screening criteria provided a list of dates that they could complete the study. Based on their preferred dates, research assistants assigned volunteers to groups of four to complete the study. Prior to the onset of the study, participants were given a study instruction sheet asking them to sleep approximately 8 hours a night for the three nights before the onset of the study and not to consume alcohol the night before the study. Participants were also asked not to nap or consume alcohol or caffeine on the day of the study. Participants completed daily activity logs on how long and well they slept each morning upon awakening on the three days prior to the study.

The sleep deprivation study was designed to examine the effects of sleep deprivation and working at night on performance. Participants experienced approximately 26 hours of acute sleep deprivation combined with a work period during the last 18 hours of the sleep deprivation episode. Research assistants called participants at a pre-arranged time between 8 and 10 am on the first morning of the study to ensure the participants were awake and reminded the participants not to nap during the day. Participants reported to the on-campus research laboratory at 4:30 pm on day one of the study. The work portion of the study took place from 4:30 pm until 10:00 am the next day. Training on the tasks began at 5 pm and continued until approximately 7:30 pm. The participants completed five testing sessions during the night with breaks between each session. Each testing session lasted about 2.5 hours. The testing sessions took place from approximately 8:00 to 10:30 pm, 10:45 pm to 1:15 am, 1:45 to 4:15 am, 4:30 to 7:00 am, and 7:15 to 9:45 am. The participants were provided with sandwiches, chips, fresh fruit, non-caffeinated drinks and water during the night.

2.1.3 Measures

The participants completed several vigilance and cognitive tasks during the night. All tasks were counterbalanced across participants. The APTS task was used for the current analyses. The APTS is a computerized cognitive test battery that measures cognitive and motor functioning. Five of the tasks in the APTS battery were used in the present study: two-hand tapping, math processing, code substitution, grammatical reasoning, and memory search. Participants were instructed to perform each task as quickly and accurately as possible. The participants completed each task within the APTS battery eight times during the training session on day 1 to stabilize performance levels and then completed each task once during the five testing sessions. The two-hand tapping task took 30 seconds to complete. Math processing, code substitution, grammatical reasoning, and memory search each took approximately 60 to 90 seconds to complete.

The two-hand tapping task required participants to alternately tap the K and L keys as quickly as possible for 30 seconds. In the math processing task, two single digit numbers appeared in a simple addition or subtraction function (e.g., 6-2). The participants had to decide whether the function resulted in a number greater or less than 5. Participants completed approximately 30 trials of math processing during each session. The code substitution task required participants to substitute a number for a letter according to a key displayed at the top of the screen. The code consisted of 9 letters paired with 9 numbers. Below these pairings, a stimulus letter was provided. The participants had to determine the correct number for each letter. Participants completed approximately 30 trials of code substitution during each session. The grammatical reasoning task presented a statement (e.g., A follows B) and then a pair of letters, either AB or BA. The participant had to decide whether or not the pair of letters matched the statement. Participants completed approximately 20 trials of grammatical reasoning during each session. For the memory search task, participants memorized a set of four letters and then determined if subsequent probe letters were in the initial set of letters. Participants completed approximately 50 trials of the memory search task during each session.

2.2 Non-Sleep Deprivation Study

2.2.1 Participants

Twenty-three undergraduate students (8 males, 15 females) at Clemson University participated in the study. Their average age was 20.9 years (SD = 0.97). The study was approved by the university's institutional ethics review board. All participants signed an informed consent before starting the study and were paid for their participation. Volunteers were not allowed to participate in both the sleep deprivation study and the non-sleep deprivation study.

2.2.2 Procedures

Participants were recruited and screened in the same manner as the sleep deprivation study. The volunteers who met the screening criteria were given a list of potential study dates and asked to select dates to participate in the study. Prior to the onset of the study, participants were given an instruction sheet on the guidelines for completing the study, including sleeping approximately 8 hours each night of the study and not to nap or consume alcohol during the study. To provide a measure of their sleep/wake activity, participants kept an activity log indicating how long and how well they slept. The activity logs were completed immediately upon arrival in the research laboratory on both days of the study.

The non-sleep deprivation study was designed to be non-stress and non-fatigue inducing and still allow us to train the participants and assess their performance on the tasks across five testing sessions. To more closely imitate the sleep deprivation study, the non-sleep deprivation study also took place on two consecutive days. The participants completed two testing sessions on day 1 and three testing sessions on day 2. All testing sessions took place between 8:00 am and 8:00 pm. Participants were requested to sleep eight hours within a window between approximately 10 pm and 8 am the night before each day of the study. The participants were required to be awake for at least one hour before completing the first testing session of each day and were called by a research assistant at a pre-arranged time each morning to ensure they were awake. The first testing session on day 1 consisted of training on the tasks for one hour and then testing on the tasks for the second hour. The remaining testing sessions (day 1 – session 2, and day 2 – sessions 3, 4, 5) were one-hour sessions. To help avoid any stress or fatigue, all testing sessions were scheduled at least two hours apart and at each participant's convenience.

2.2.3 Measures

Participants completed several vigilance and cognitive tasks that were a subset of the tasks completed in the sleep deprivation study. All tasks were counterbalanced across participants. The APTS was used for the current analyses and was administered in the same manner as the sleep deprivation study. Some of the APTS tasks in the current study were also used in the McClelland, Pilcher and Moore (2010) study. As described below the data are analyzed in a different manner for the current study.

2.3 Data Analyses

We completed the same data analyses for the sleep deprivation and the non-sleep deprivation studies. Two-hand tapping was measured as the number of completed taps. Accuracy was used as the measure of performance on math processing, code substitution, grammatical reasoning, and memory search. Change from baseline measures were used for all measures since that can help account for individual variability in responses to the effects of sleep deprivation (Van Dongen, Baynard, Maislin, & Dinges, 2004).

We calculated baseline performance levels for each measure as the average performance level for each participant across the last three of the eight training sessions. The performance data for each testing session were then converted to measures of change from baseline. We then calculated the average change for each task for the first two testing sessions and the last three testing sessions. In the sleep deprivation study, this allowed us to compare the performance from the beginning of the night (e.g., from 8 pm to 1:15 am) when the participants could be expected to be non-sleep deprived with the performance for the remainder of the night when the participants would be sleep deprived. In the non-sleep deprivation study, this allowed us to compare the performance on day 1 to the performance on day 2.

We also calculated an estimated BAC based on the two-hand tapping, math processing, code substitution, and grammatical reasoning data from the APTS following the methodology developed by Kennedy and colleagues (1993). We used the calculated baseline performance for each measure and calculated the percent decrement in performance from baseline for each testing session during the sleep deprivation and non-sleep deprivation studies using equation one.

Percent Decrement = 100 * (baseline performance - testing session performance) / baseline performance (1)

We used the calculated percent decrement for each task to complete the Dose Equivalency Model in equation two for each testing session.

Dose Equivalency = (9 * CS + 6 * THT + 5 * MP + 2 * GR) / 1000 (2)

In this equation, CS was the percent decrement in code substitution, THT was the percent decrement in two-hand tapping, MP was the percent decrement in math processing, and GR was the percent decrement in grammatical reasoning.

The final step in estimating BAC based on APTS performance used the result from the Dose Equivalency Model in the manner described by Kennedy and colleagues (1993) in equation three for each testing session.

Estimated BAC = 0.1 * Dose Equivalency$^{0.5}$ (3)

The estimated BAC was then averaged for the first two and the last three testing sessions allowing us to compare values from the beginning to the end of each study.

SPSS 19.0 (SPSS, Inc., Chicago, IL) was used for all data analyses. We completed independent t-tests comparing the sleep reported by the sleep-deprived participants to the sleep reported by the non-sleep deprived participants. We then examined the baseline data to insure that the participants in the two studies had similar performance levels at the start of each study. We completed independent t-tests on the baseline data for each APTS task for the sleep deprivation and non-sleep deprivation groups. We completed a repeated-measures ANOVA for the sleep deprivation study data and for the non-sleep deprivation study data including all measures (two-hand tapping, math processing, code substitution, grammatical reasoning, memory search, and estimated BAC) to determine if performance differed between the beginning and end of the study (alpha = 0.05). The ANOVA results are reported as the Greenhouse-Geisser correction for sphericity.

3. Results

3.1 Sleep Data

Participants in the sleep deprivation study reported sleeping an average of 7 hours and 54 minutes (SD=78.21 minutes) for the three nights prior to the onset of the study and for 8 hours and 8 minutes (SD=64.5 minutes) the night immediately before the sleep deprivation period. The participants in the non-sleep deprivation study reported sleeping an average of 7 hours and 34 minutes (SD=43.14 minutes) on the night before the first day of the study and 7 hours and 28 minutes (SD=69.68 minutes) on the night before the second day of the study. There was no significant difference in sleep times prior to the onset of the study for the participants in the sleep deprivation and the participants in the non-sleep deprivation study. These results indicate that the participants followed the study instructions and were not sleep deprived prior to the sleep deprivation study or during the non-sleep deprivation study.

Table 1. Training data*

	Study				
	Sleep Deprivation		Non-Sleep Deprivation		
Measure	Mean	Standard Dev	Mean	Standard Dev	p
Two-Hand Tapping	100.95	15.22	88.34	19.97	.016
Math Processing	94.40	3.70	94.25	4.56	
Code Substitution	97.39	3.11	97.64	2.00	
Grammatical Reasoning	78.90	11.54	83.07	8.00	
Memory Search	96.27	2.34	96.13	2.10	

*Average of last three training sessions

3.2 Baseline Performance

As shown in Table 1, the participants in the sleep deprivation and non-sleep deprivation studies had similar levels of performance over the last three training sessions. The independent t-tests indicated that only the performance on the two-hand tapping task differed significantly between the two studies, $t(47) = 2.502$, p = .016, with the sleep-deprived participants performing better than the non-sleep deprived participants. As we point out in the discussion, this difference in simple motor processing is likely due to the different times of the day that training took place for the two studies.

Table 2. Sleep deprivation study results

	Time of Study				
	Beginning		End		
Measure	Raw data	Change scores*	Raw data	Change scores*	p
Two-Hand Tapping	100.79±16.22	-0.160±6.280	96.55±15.61	-4.397±6.241	.005
Math Processing	93.90±3.82	-0.490±3.710	94.03±4.43	-0.363±3.553	
Code Substitution	96.91±3.08	-0.478±3.577	94.94±5.20	-2.455±5.409	.083
Grammatical Reasoning	81.67±12.21	2.762±7.467	80.93±11.75	2.029±7.026	
Memory Search	96.26±3.84	-0.002±3.126	95.07±3.29	-1.198±2.615	.015
Estimated BAC	0.014±0.018		0.026±0.015		.011

All data are means ± standard deviation. *Change from baseline scores; Beginning: Average of testing sessions 1 and 2; End: Average of testing sessions 3, 4, and 5

Table 3. Non-sleep deprivation study results

	Time of Study				
	Beginning		End		
Measure	Raw data	Change scores*	Raw data	Change scores*	p
Two-Hand Tapping	92.70±19.80	4.355±7.085	93.25±18.66	4.906±6.626	
Math Processing	93.67±4.90	-0.575±4.198	94.78±4.42	0.535±4.54	
Code Substitution	97.81±2.56	0.173±2.471	97.48±2.80	-0.152±2.990	
Grammatical Reasoning	81.28±12.03	-1.792±11.595	89.85±8.04	6.778±9.416	<.001
Memory Search	97.25±1.44	1.121±2.554	97.33±1.91	1.200±2.282	
Estimated BAC	0.009±0.012		0.004±0.008		

All data are means ± standard deviation. *Change from baseline scores; Beginning: Average of testing sessions on day 1; End: Average of testing sessions on day 2

3.3 APTS Performance

The means and standard deviations for the raw data and the change scores of each measure are show in Table 2 for the sleep deprivation study and in Table 3 for the non-sleep deprivation study. The number of taps decreased during the sleep deprivation study but remained stable in the non-sleep deprivation study. The ANOVA results indicated a significant decrease in two-hand tapping in the sleep deprivation study, $F(1,25) = 9.647$, $p=.005$, partial $eta^2=.278$, and no significant change in the non-sleep deprivation study. There was no significant change in math processing levels in either study. Performance on the code substitution task decreased under sleep deprivation conditions but remained stable in the non-sleep deprivation study. The ANOVA showed that the change in performance on the code substitution task in the sleep deprivation study approached significance, $F(1,25) = 3.272$, $p=.083$, partial $eta^2=.116$, and no significant change in the non-sleep deprivation study. In contrast, performance on the grammatical reasoning task remained stable in the sleep deprivation study but improved in the non-sleep deprivation study. There was a significant increase in grammatical reasoning in the non-sleep deprivation study, $F(1,22) = 844.687$, $p<.001$, partial $eta^2=.441$, and no significant change in the sleep deprivation study. Performance on the memory search task decreased in the sleep deprivation study and remained stable in the non-sleep deprivation study. The ANOVA indicated a significant decrease in performance on the memory search task in the sleep deprivation study, $F(1,25) = 6.773$, $p=.015$, partial $eta^2=.213$, and no significant change in the non-sleep deprivation study.

The means and standard deviations for the estimated BAC levels are shown in Table 2 for the sleep deprivation study and in Table 3 for the non-sleep deprivation study. The estimated BAC levels increased in the sleep deprivation study and remained stable in the non-sleep deprivation study. The ANOVA results indicated a significant increase in estimated BAC in the sleep deprivation study, $F(1,25) = 7.572$, $p=.011$, partial $eta^2=.232$, and no significant change in the non-sleep deprivation study.

4. Discussion

The current results indicate that performance on the subtasks of the APTS decreased or remained stable under sleep deprivation and either remained stable or improved under non-sleep deprivation conditions. Furthermore, the estimated BAC levels based on APTS performance increased under sleep deprivation conditions but remained stable under non-sleep deprivation conditions. These results support our hypotheses and provide additional evidence suggesting that sleep deprivation has differential effects on performance.

4.1 APTS Performance

The sleep-deprived participants showed a decrease in performance on the 2-hand tapping task. This change in performance supports previous research indicating that sleep deprivation negatively affects motor responding (Pilcher & Huffcutt, 1996), even very short durations of motor performance. As noted in our second hypothesis, the short duration of the cognitive-based APTS subtasks could have made it easier for the participants to maintain the necessary attention to perform well. This would help explain the stable performance levels on the math processing and grammatical reasoning subtasks in the sleep deprivation study. It is important to note; however, that the near significant decrease in performance on the code substitution task and the significant decrease in performance on the memory search task indicate that the participants did not perform equally well on all of the subtasks.

Performance on the APTS remained stable in the non-sleep deprivation study indicating that the participants maintained their ability to perform when being tested multiple times in a well-rested state across two days. Furthermore, the non-sleep deprived participants improved their performance on the grammatical reasoning task. This increase in performance occurred on the second day, following the sleep episode between the two days of the study. For comparison, grammatical reasoning decreased slightly between the first half and the second half of the night in the sleep deprivation study, indicating that practice alone was not enough to improve performance independent of sleep. These results suggest that the sleep episode in the non-sleep deprivation study may have contributed to an improvement in grammatical reasoning performance, supporting previous studies indicating that sleep plays an active role in improving performance and memory (Aly & Moscovitch, 2010; Lau, Tucker, & Fishbein, 2010; Rasch & Born, 2008). Future research could be designed to examine why performance on only the grammatical reasoning task improved under non-sleep deprivation conditions. It could be that the grammatical reasoning task required an additional level of cognitive processing that was not required in the math processing, code substitution, or memory search task; a level of processing that sleep could enable.

It is interesting to note that the participants in the sleep deprivation study performed significantly better on the two-hand tapping task during training than the participants in the non-sleep deprivation study. This difference in simple motor response is likely due to the time of day when training occurred in the two studies. Training in the sleep deprivation study occurred between 5 and 7:30 pm, the period of time in the circadian rhythm when our body temperature and alertness is reaching its highest point of the day. In contrast, training in the non-sleep deprivation study occurred during the morning of day 1 of the study. Although the circadian rhythm in body temperature and alertness is increasing during the morning, it does not approach its peak until later in the day. These findings support earlier research suggesting that physical performance follows the circadian rhythm in body temperature including an improvement in performance in the late afternoon to early evening (Reilly & Edwards, 2007).

4.2 Estimated Blood Alcohol Concentration

Several studies have compared the effects of alcohol consumption and sleep deprivation on performance. One study found that 17 hours of sustained wakefulness results in an impairment in psychomotor performance on a tracking task equivalent to a BAC level of 0.05% and that 24 hours of sustained wakefulness resulted in a decline in performance to levels that resembled a BAC of 0.10% (Dawson & Reid, 1997). Other studies report similar results using psychomotor tasks (Maruff, Falleti, Collie, Darby, & McStephen, 2005; Williamson & Feyer, 2000; Williamson, Feyer, Mattick, Friswell, & Finlay-Brown, 2001) and driving skills (Arnedt, Wilde, Munt, &

MacLean, 2001; Fairclough & Graham, 1999). Unfortunately, the relative effects of sleep deprivation and BAC level using tasks that require more complex processing is less well documented. One study examined the effects of 0.05% BAC and 24 hours of sustained wakefulness on performance on a variety of tasks (Falleti, Maruff, Collie, Darby, & McStephen, 2003). Falleti and colleagues conclude that some tasks are equally affected by alcohol and fatigue but not all tasks. In general, speed of responding seems to be more affected by sleep deprivation than alcohol whereas accuracy on memory and learning seems more negatively affected by alcohol. This suggests that the type of task may also have an effect on the relationships among BAC level, sleep deprivation, and performance.

The current data suggest that examining performance under sleep deprivation conditions as estimated BAC can be useful. The estimated BAC levels found in the current study were within the range of the BAC levels reported in previous studies (Dawson & Reid, 1997; Maruff et al., 2005; Williamson & Feyer, 2000). The findings from Falleti and colleagues (2003) suggest that the slightly lower estimated alcohol levels in the current study could have been a reflection of the task characteristics of the APTS, in that the APTS used tasks that included simple motor processing as well as short duration cognitive processing to approximate the BAC.

4.3 Controlled Attention Model and Self-Regulation

The Controlled Attention Model provides a rational that can help explain the current results. As noted in our second hypothesis, the Controlled Attention Model suggests that the relative short duration of each the APTS subtasks would make the tasks easier to perform in that the participants could more easily maintain their attention for the duration of the task. The stable performance seen on the math processing and grammatical reasoning tasks in the sleep deprivation study support this premise. However, the changes in performance on the code substitution and memory search tasks, suggest that the short duration of the task is not always enough to ensure stable performance.

It is important to recognize that the Controlled Attention Model can also be interpreted in terms of the participants' ability to regulate their own attention and engagement. Attempting to describe human performance based solely on the characteristics of the task or environment is limited. Instead, one must consider the participant's choice in paying attention and remaining engaged in the task. The change in performance on the code substitution and the memory search tasks in the sleep deprivation study support this interpretation. Of the cognitive subtasks in the current study, it can be argued that the code substitution task was the simplest since the letter-number combinations were present on the computer screen and the participants simply had to match the correct combination. The decrease in performance on the code substitution task suggests that the participants did not maintain the necessary attention to pick the correct matches even when the task provided a rapid change in the stimuli that could help keep the participants engaged. Similarly, the participants did not perform well on the memory search task across the sleep deprivation period, suggesting that working memory was compromised in the sleep-deprived participants. In contrast, the participants appeared to maintain their attention and effort on the math processing and grammatical reasoning tasks and, thus, maintained their performance across the sleep deprivation period.

Integrating the process of self-regulation with the Controlled Attention Model provides a broader approach to understanding the effects of sleep deprivation. Personal control of attention is one aspect of self-regulation. Self-regulation has been defined in a variety of ways including metacognitive and motivational approaches (Hong & O'Neil, 2001). The self-regulation process allows individuals to reach and maintain personal goals at work, in education, and in daily life (e.g., Carver & Scheier, 1990; Bouffard, Bouchard, Goulet, Denoncourt, & Couture, 2005). Sufficient sleep has been found to replenish the internal resources that are essential for self-regulation (Barber. Munz, Bagsby, & Powell, 2012). Since sleep deprivation affects our lives in many ways, it is important to consider how sleep deprivation may change our ability to monitor our personal engagement and attention and how that may affect our decision-making, long-term goals, and general well-being.

Although understanding how sleep-deprived persons regulate their behavior could be a useful tool, researchers have not yet considered self-regulation when interpreting the effects of sleep deprivation. Self-regulation can be used to manage internal and external resources, prioritize goals, manage time, and track goal completion in many components of life (Corno, 2001). The Controlled Attention Model suggests that the process of controlling attention, one type of self-regulated behavior, is negatively affected by sleep deprivation. It is also feasible that sleep deprivation may interact with other self-regulated behaviors and choices in ways that are not yet fully explored. Future research is needed that addresses the effects of sleep deprivation on a wider range of self-regulatory behaviors. If future research indicates that self-regulatory behaviors are affected under sleep deprivation conditions, it could be useful to expand the current Controlled Attention Model to incorporate a broader self-regulation approach.

4.4 Conclusions

There are several limitations in the current studies. One limitation is that the non-sleep deprivation study was not designed to be a complete control for the sleep deprivation study. Unfortunately, implementing a true control study that assesses performance multiple times during the night without adding the potential confounding effects of sleep deprivation is impossible. We purposely designed the non-sleep deprivation study to provide us with a means of comparing performance across five testing sessions without the added sleep deprivation element. Another limitation is that the current studies did not attempt to control for participants' natural circadian rhythms. We recognize that our endogenous circadian rhythms cannot be modified or controlled without introducing extreme measures to shift the participants' rhythms. Instead, we focused on performance during the day in the non-sleep deprivation study and at night in the sleep deprivation study. This allowed us to compare daytime performance when our endogenous circadian rhythm encourages us to be more alert to nighttime performance when our circadian rhythm encourages us to be less alert. Finally, the current studies did not use the same subjects and, thus, did not fully account for individual differences. To account for this, we compared performance on the two groups during training and we completed the data analyses using change from baseline data.

Applying the Controlled Attention Model to sleep habits and performance could be useful in many work place and other real-world settings when completing tasks under sleep deprivation conditions. Sleep deprivation is a common occurrence in modern society where many individuals are required to adjust their sleep/wake pattern when doing shiftwork while others purposely partially deprive themselves of sleep while thinking that it will have little effect on their ability to perform and make good decisions. The Controlled Attention Model and the self-regulation theory suggest that tasks that require the individual to purposely focus attention would be most negatively affected by sleep loss. This could include tasks that require constant attention to complete such as driving a truck, piloting an airplane, or monitoring the radar in air traffic control settings. It could also include tasks that require active engagement on the part of the individual to understand and correctly complete the task. Tasks that require active engagement occur in many work and educational situations where vigilance, active processing, and learning are necessary. As such, using the Controlled Attention Model and the self-regulation theory may provide a means to better cope with the effects of sleep deprivation in many settings in our modern society.

The current results support the use of the Controlled Attention Model to better understand how sleep loss negatively affects performance. Furthermore, incorporating a broader self-regulation approach may provide additional benefits when interpreting the effects of sleep deprivation in real world settings. Applying a self-regulation approach in sleep loss situations could provide a broad background from which to better understand how basic cognitive mechanisms such as attention and working memory may contribute to the performance deficits in many workplace and real world settings.

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