INCLUSION OF FATIGUE EFFECTS IN HUMAN RELIABILITY ANALYSIS

By

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To George, my favorite feline helper

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ABBREVIATIONS

ATHEANA	A Technique for Human Event Analysis
BAC%	Blood Alcohol Content (percentage)
EFC	Error-Forcing Context
FSS	Fatigue Severity Scale
HEP	Human Error Probability
HERA	Human Event Response Analysis
HRA	Human Reliability Analysis
INL	Idaho National Laboratory
NASA	National Aeronautical and Space Administration
NRC	Nuclear Regulatory Commission
PRA	Probabilistic Risk Assessment
PSF	Performance Shaping Factor
PVT	Psychomotor Vigilance Task
SPAR-H	Standardized Plant Analysis Risk – Human Reliability Analysis
THERP	Technique for Human Error Rate Prediction
VAS	Visual Analog Scale

CHAPTER I

INTRODUCTION

Many industries experience significant losses due to human error. Despite years of research, difficulties still exist in quantifying the direct contribution of human error to incidents that result in disaster and/or losses. Human reliability analysis (HRA) attempts to quantify human error probability under various situations. This information is useful in probabilistic risk analysis (PRA) of large complex systems, such as nuclear power plants. To date, HRA has mostly used expert opinion to quantify error probabilities resulting in discrepancy of risk assessments from one analyst to another (Boring, 2007). One way to improve the technical basis of HRA methods is to quantify the effects of various performance shaping factors using empirical data. This dissertation investigates methods to develop such an objective technical basis and focuses on fatigue resulting from sleep deprivation. Information and data on sleep deprivation's effect on performance are not explicitly included in current HRA methods. This dissertation develops a methodology for including sleep deprivation effects in human reliability analysis (HRA).

Background

The degree to which fatigue impacts human performance ranges from slight to catastrophic. In the case of large complex systems, it is possible for the fatigue-related error of a single person working under sleep-deprived conditions to cause an industrial accident that can kill thousands of people, cause major environmental damage and/or cost billions of dollars (Dinges, 1995). Human error accounts for 30% to 90% of all industrial accidents (Reason, 1990). The percentage of incidents resulting from human error contributions for several industries is provided in Table 1. The US National Safety Council (1999) reported that human error was a root cause in 80% of all industrial accidents and responsible for $98.5 billion in accident-related costs. In the United States alone, human error is a contributing factor in over 90% of auto accidents (Treat et al., 1977) which cost approximately $160 billion dollars per year (Clifford, 2008).

Table 1: Estimation of Human Error Contributions as % of All Failures

Aviation	70-80%	Weigmann & Shappell (1999)
Maritime Vessels	80-85%	Baker & McCafferty (2005)
Chemical Industry	63%	Peters & Peters (2006)
Nuclear Power (US)	50-70%	Trager (1985)
Automobile	65%	Dhillon (2007)
Heavy Truck	80%	Dhillon (2007)

Human errors occur in various industries and at great cost; therefore, there is a need to assess the role of the human in these errors. Human reliability analysis (HRA) is the attempt to predict the effect of human-system interactions on system reliability (Chandler et al., 2006). HRA grew out of the need to understand the human role in the operation of complex systems, like those listed in Table 1. These complex systems tend to have a low probability of a negative incident, but with high consequence (e.g., nuclear power plants). When an incident occurs at a high-profile, largely complex system, it attracts substantial attention from both industry and the general public. For example, increased interest in occupational safety and human health resulted from the Three Mile Island nuclear power plant disaster in 1979, the Chernobyl nuclear power plant explosion in 1986, and the *Challenger* accident in 1986. These incidents have been the catalysts in driving the development of HRA methods (Reason, 1990).

One option for obtaining quantitative data for use in HRA is to collect the number of occurrences of events related to human performance (i.e., frequency data). However, since adverse events in nuclear power plants and other industries are atypical, there are not enough incidents to accurately use frequency data for HRA quantification while producing statistically significant results. HRA practitioners currently use whatever data exist (mostly expert opinion), updating when new information is obtained. The infrequency of adverse events in nuclear power plants motivates the investigation into other industries, such as aviation, medical, and the military, to gather field data.

To improve HRA, this research will explore and collate quantitative data on the effect of fatigue on performance. Cognitive fatigue, as caused by hours of wakefulness and measured through reaction time, accuracy, and the number of lapses, is evaluated in this research. Physiological measures of fatigue (e.g., critical flicker frequency, blood pressure, heart rate, etc.) are not investigated. Even though this research investigates reaction time, which does have a physical component, in simple reaction time experiments, the fatigue effect on performance has more to do with the draw on attentional capacity rather than on muscle fatigue. Reaction time is often used as a measure of cognitive performance throughout the psychological literature (Chee and Choo, 2004; Choo et al., 2005; Kobbeltvedt et al., 2005; Nilsson et al., 2005; Thomas et al., 2000; Williamson and Feyer, 2000). For the purposes of this research, fatigue will be confined to that caused by sleep deprivation (i.e., hours of wakefulness) or acute fatigue. Chronic fatigue, though an important cause of worker fatigue (Weinger and Ancoli-Israel, 2002), will not be examined in this research. The fatigue model used in this research is diagramed in Figure 1.

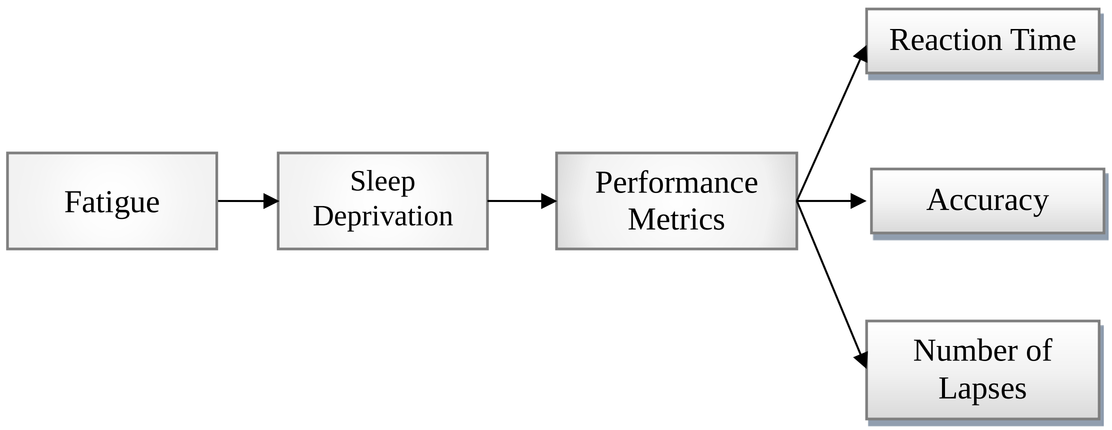

Figure 1: Fatigue Model

The length of sleep deprivation can be objectively measured by recording the hours of wakefulness. Also, sleep deprivation effects can be mitigated through risk analysis and regulation. Since fatigue cannot be directly measured, the typical performance metrics used to measure fatigue effects are: *reaction time (RT)*, *accuracy*, and *number of lapses*.

The metrics of reaction time, accuracy, and number of lapses were selected as performance measures in this research because they are the most commonly reported metrics in the sleep deprivation literature and are output variables of working memory tasks. Performance on working memory tasks is predictive of performance on a range of other cognitive tasks (Kushida et al., 2005). Working memory is considered to be fundamental to performance on virtually any neurocognitive task. The criteria for a cognitive performance task to assess neurobehavioral performance capability should have the following features: 1) uses basic expressions of performance (e.g., reaction time)**,** 2) is sensitive to homeostasis and circadian rhythms, 3) is easy to learn or perform, 4) has sufficient task load (i.e., stimulus rate) to prevent boredom, 5) has sufficient re-test reliability, and 6) reflects an aspect of real-world performance (Kushida et al., 2005). Performance tasks, such as PVT (Dinges and Powell, 1985) and SRT have the above features, and are useful in the tracking ability to access to the working memory of the prefrontal cortex of the brain.

The metrics of reaction time, accuracy, and number of lapses are typically the reported results of such working memory tasks. Reaction time, accuracy, and number of lapses provide an index of the degree of functional impairment from sleep deprivation that is meaningful and easily measurable outcome variables. Physical variables may also be measured, such as temperature and cortisol levels; but these variables do not measure performance decrements; which were the focus of this research.

These three metrics are measured through a variety of tasks in the literature, such as: vigilance tasks, timed tasks, dual or multiple tasks, mental arithmetic tasks, memory tasks, and others (Williamson and Feyer, 2000; Nilsson et al., 2005). New models are needed to transform reaction time, accuracy and number of lapses into human error probabilities (HEPs).

Research Objectives

The overall goal of this research is to improve the technical basis for including sleep deprivation effects in human reliability analysis (HRA) methods used in probabilistic risk assessment (PRA). Quantitative information to characterize the effect of sleep deprivation on performance was considered. Data were collected from existing psychological, medical, military, and transportation literature and in a structure that is compatible with meta-analysis technique and the Human Event Response Analysis (HERA) database being developed for the Nuclear Regulatory Commission (NRC), and the NASA HRA database; both of which are being developed at Idaho National Laboratory (INL).

The overall goal of this research can be divided into five sub-objectives:

1. Analyze existing HRA models and their treatment of cognitive fatigue;
2. Collect and analyze data with respect to the effect of sleep deprivation on performance through the meta-analysis research synthesis procedure;
3. Evaluate the quantitative effect of sleep deprivation on performance;
4. Derive performance shaping factor coefficients based on quantitative data to improve HRA models (e.g., SPAR-H); and
5. Conduct uncertainty analysis of the derived performance shaping factor coefficients.

The first objective includes evaluation and analysis of existing HRA methods and models, with a focus on how cognitive fatigue is covered, or not covered, in the existing models. The models investigated are: THERP (Swain and Guttman, 1983), SPAR-H (Gertman et al., 2005), and ATHEANA (USNRC, 2000). Fatigue was observed not to have been explicitly covered in THERP (Swain and Guttman, 1983), SPAR-H (Gertman et al., 2005), and ATHEANA (USNRC, 2000) HRA methods.

The second objective is to interpret and synthesize the fatigue data from research literature, nuclear power plant-specific sources, and other industries with similar demands on operating personnel. The meta-analysis technique of research synthesis is used for this purpose.

In the third objective, the quantitative effect of sleep deprivation on performance is evaluated. This is done by analyzing the data collected from objective two. For example, the change in performance after sleep deprivation is evaluated using effect size, percentage change, and failure probabilities. The results are segregated by reaction time, accuracy and number of lapses.

The fourth objective derives performance shaping factor coefficient values based on quantitative data gathered in objective two, based on the analysis in objective three. This is done through ratios of the probability of failure between the test and control conditions of performance.

The fifth objective is to conduct uncertainty analysis on the derived performance shaping factor coefficient values. The calculated performance shaping factor coefficient values show significant variability due to sparse data. Data were subdivided into twenty hour intervals (i.e., < 20, 20-40, 40-60, 60-80, and > 80), and the mean and standard deviation was used to find a confidence interval over the twenty hour time blocks. Also, the uncertainty associated with the coding process of the quantitative data is evaluated by calculating the inter-rater reliability.

Organization of the Dissertation

This dissertation is organized into six chapters. Chapter two includes a review of HRA methods, the difficulties in defining fatigue, sleep deprivation literature, and the shortcomings of current HRA methods with respect to the treatment of fatigue and sleep deprivation. The third chapter discusses the meta-analysis technique of data collection and the coding procedure. Chapter four develops the methodology used to evaluate the quantitative effect of sleep deprivation on performance and to derive performance shaping factor multipliers for modifying the base error probability. The fifth chapter provides the results of the application of methodology and uncertainty analysis. Chapter six discusses the conclusions drawn and future research needs.

CHAPTER II

FATIGUE RESEARCH AND HRA METHODS

This chapter provides a review of fatigue and sleep deprivation studies and probabilistic risk assessment (PRA) and HRA methods. The difficulties in defining sleep deprivation and the problems associated with sleep deprivation research studies are discussed. Three HRA methods are explored in detail with respect to the inclusion of fatigue effects. Incidents attributed to fatigue in the nuclear industry and other industries are discussed. Also explored in this chapter are the effects of fatigue and sleep deprivation in quantitative HRA.

Fatigue

Unlike chemical impairment due to alcohol or drugs, which can be detected by biochemical tests, fatigue is more difficult to measure and discern as the cause of reduced performance. Typically, fatigue must be inferred from the context of the situation. For example, in the case of a single car accident, fatigue or even having fallen asleep, may not be listed as the cause of the accident; instead only the end result, such as driving into a ditch, might be listed, even when it is reasonable to assume fatigue as a root cause. Despite this limitation, fatigue has increasingly been claimed as the primary cause of numerous accidents (Mitler et al., 1988).

The effects of fatigue on performance have been documented as a root cause of many of the major industrial accidents of the last thirty years (Mitler et al., 1988). Examples of some accidents with global impact that are believed to have human fatigue as a root cause are listed in Table 2. Although fatigue is not the sole cause of the accidents listed in Table 2, it is considered a contributing factor.

Table 2: Incidents That List Human Fatigue as a Root Cause[1]

Accident	Date	Country	Time of Event	Death Toll	Reference
Three Mile Island	28-Mar-79	USA	4:00	None	Mitler et al. 1988
Davis-Besse	9-Jun-85	USA	1:30	None	Mitler et al. 1988
Challenger	28-Jan-86	USA	11:39	7	Mitler et al. 1988
Hinton train disaster	8-Feb-86	Canada	8:41	23	Halliday, 1997
Chernobyl	26-Apr-86	USSR	1:23	50	Mitler et al. 1988
Exxon Valdez	24-Mar-89	USA	0:04	None	Dement, 1992
Peacock	18-Jul-96	Australia	1:55	None	Folkard, 2000
Am. Airlines Flight 1420	1-Jun-99	USA	23:50	11 deaths, 110 injured	Hirshkowitz & Smith, 2004
Staten Island Ferry	15-Oct-03	USA	15:21	11 died, 71 injured	Hirshkowitz & Smith, 2004

On January 28, 1986, National Aeronautics and Space Administration (NASA) managers, after working over 20 hour shifts, made the critical decision on whether to launch with their knowledge of O-ring failures at low temperatures; this resulted in the catastrophic failure of the shuttle orbiter *Challenger* (Mitler et al., 1988; Morgan 1996; Eller and Minkley 1998; Rogers Commission Report 1986; Reason, 1990).

On February 8, 1986, in Canada, a VIA Rail (passenger train) collided with a Canadian National Railway (freight train) near Hinton, Alberta, west of Edmonton. The

[1] Additional information on the incidents is available in Appendix B.

accident was the result of the crew of the freight train having become incapacitated by fatigue (Halliday, 1997).

On March 24, 1989, the *Exxon Valdez* oil tanker struck a reef in Prince William Sound, Alaska, and spilled 11 to 32 million gallons of crude oil. The accident was caused by the third mate improperly maneuvering the vessel. He had had only 6 hours of sleep in the previous 48 hours, while the first mate had been working for 30 hours continuously. The estimated cleanup cost was $2 billion dollars, including $41 million to clean and rehabilitate approximately 800 birds and a few hundred sea otters (NSTB, 1989; NSTB, 1990; Dement, 1992; Hassen, 2008; Eller and Minkley, 1998; *Exxon Valdez* Oil Spill Trustee Council, 2008).

At 01:55 a.m. on July 18, 1996, the *Peacock*, a cargo vessel carrying 605 tons of heavy fuel oil, ran aground on the Great Barrier Reef at full speed. The inquiry to the accident suggested that the pilot had fallen asleep fifteen minutes before the grounding. Minor damage occurred to the reef and pollution was negligible (Folkard, 2000; Parker et al., 1998). On October 15, 2003, the Staten Island Ferry, vessel *Andrew J. Barberi*, piloted by the assistant captain, ran the ferry into the dock at full speed. The pilot made no attempt to slow down because he had fallen asleep at the controls. Eleven were killed and seventy-one injured (Hirshkowitz and Smith, 2004).

On June 1, 1999, an American Airlines Flight 1420 from Dallas, Texas, to Little Rock, Arkansas, overran the runway upon landing and crashed; eleven were killed and 110 injured. Pilot fatigue and the resulting diminished judgment were listed as partial causes for the crash. The crew had been on duty for about 13½ hours at the time of the incident (Malnic, 2001; Hirshkowitz and Smith, 2004; National Transportation Safety Board, 2001).

A sampling of human error with potentially severe detrimental impacts caused by fatigue can be found when looking at the history of nuclear reactors. The Three Mile Island incident occurred on March 28, 1979; nuclear reactor coolant escaped after the pilot-operated relief valve failed to close properly. The mechanical failures were compounded by the failure of operators to recognize that the plant was experiencing a loss of coolant. When the situation was realized, the crew was not able to solve the problem until the relief crew came on and took over for the fatigued crew. The incident occurred in the morning between 04:00 and 06:00 a.m. (Reason, 1990; Harrison and Horne, 2000; Monk, 2007; Mitler et al. 1988; USNRC, 1979). Another incident occurred on June 9, 1985, at 01:30 a.m., when the Davis-Besse (Oak Harbor, Ohio) nuclear power plant went into automatic shutdown after a loss of cooling water and then had a total loss of the main feed-water. The incident was compounded when the operator pushed the incorrect button and turned off the auxiliary feed-water system. The operator's error was discovered by workers coming on the next shift (Coren, 1996; Mitler et al. 1988; USNRC, 1985).

On April 26, 1985, at approximately 01:30 a.m. at the Chernobyl nuclear power facility in the Ukraine, workers turned off critical automatic safety systems causing the reactor to begin to overheat. The sleep-deprived shift workers had turned off the cooling system instead of turning on the automated safety systems. This caused the reactor to overheat and led to the explosion that released 13 million curies of radioactive gases and less than 20 curies of iodine-131 (Coren, 1996; Mitler et al., 1988; USNRC, 1987b;

Reason, 1990). These are only a few major incidents known to have been at least in part caused by fatigue.

An example of an event resulting from fatigue that did not result in a major accident, but posed a severe threat to public safety, occurred at the Peach Bottom Atomic Energy Plant (USNRC, 1987a). In 1987, during a routine, but unannounced, inspection of the Peach Bottom plant, U.S. Nuclear Regulatory Commission (NRC) inspectors found control room operators asleep in their chairs. According to the USNRC report, the management at Peach Bottom had a plan of willful circumvention of USNRC guidelines by inventing its own mechanism to handle worker fatigue associated with the night shift work: allowing control room operators to sleep during the night shift. Consequently, the NRC ordered the power station shut down; this was a first in American nuclear power history. Despite being a state-of-the-art and high-efficiency plant, management had overlooked the effects of human limitations in 24 hour operations. Even though no nuclear accident had occurred, the plant closure, which resulted from human inattention, resulted in enormous costs.

Although the incident at Peach Bottom occurred in 1987, and guidelines were in place at the time for limiting work shift hours (10-CFR26.20), similar events still occur at nuclear power plants. Again, in 2007, at the Peach Bottom Plant, a video of sleeping security guards was taken by a fellow guard and released to the media (Mufson, 2008). Table 3 provides a list of events at nuclear power plants that involve similar situations of sleeping or inattentive workers. Incidents, such as those in Table 3, occur because the NRC procedures include only prescriptive and general guidelines on working hours and shifts, aimed at limiting worker fatigue. The USNRC recognized that fatigue is an important component to safe operations and that the fitness-for-duty guidelines (10-CFR26.20) need to be more inclusive of fatigue effects and not just chemical impairment (Persensky et al., 2002). The fitness-for-duty guidelines were changed in 2008, increasing the minimum break between shifts, limiting the reasons for waivers for overtime limits, and establishing training for fatigue management (Lenton, 2007). This move addressed the fundamental issue of fatigue and its effects on overall human error probability (HEP).

In several incidents, security officers have been found sleeping or inattentive (Seabrook, 2002; Oyster Creek, 2003; Beaver Valley, (2004 and 2005); Three Mile Island, 2007; Peach Bottom, 2007). In two incidents, security officers had fallen asleep while driving (Millstone, 2002; Braidwood, 2004). In two others, control room operators were found asleep at their stations (Massachusetts Institute of Technology, 2003; Pilgrim, 2004). Table 3 also includes incidents of work hour violations, (Susquehanna, 2002; St. Lucie, 2003), along with a court case brought by an engineer who had been fired after complaining about hours beyond the work limitations (D.C. Cook, 2004). Three reports included security officers being threatened with disciplinary actions or being sent to a psychiatrist when they complained of working their 6th day of 12 hour shifts (Indian Point, 2003; Prairie Island, 2003; Wakenhut Security, 2003).

Table 3: Recent Nuclear Power Plant Fatigue Related Incidents

Date	Plant	Report/Reference	Incident Description
Jul. 2002	Seabrook	IR ML022000576	Security officer inattentive to duty
Nov. 2002	Millstone	POGO (2002)	Security guard falls asleep and drives into concrete barrier
Nov. 2002	Susquehanna	IR 50-387/02-05 IR 50-388/02-05 IR 72-28/02-01	NCV for failure to maintain adequate shift coverage without routine heavy use of overtime
Jan. 2003	St. Lucie	IR 50-335/02-04 IR 50-389/02-04	NCV for multiple instances of individuals exceeding overtime limits without authorization
Mar. 2003	Indian Point & Prairie Island	POGO (2002); Gordon (2003)	Guards who claimed they were too tired to work a 6th 12-hour shift were sent to psychiatrists
Apr. 2003	Oyster Creek	IR 05000219-03-003	Two guards found asleep at checkpoint
Jun. 2003	MIT	IR 50-20/2003-1	Sleeping operator in control room
Aug. 2003	Wackenhut	POGO (2002)	Inside NRC reports that guards who refuse 5th or 6th 12-hour shift could face discipline
Apr. 2004	Beaver Valley	Lenton (2007)	Security guard found sleeping
Apr. 2004	D.C. Cook	I&M v. Kenneth Tipton	$264K in damages paid to an engineer fired after complaining he was forced to work excessive hours
Jun. 2004	Pilgrim	IR 05000293-05-003	Sleeping operator in control room at nuclear power plant on video
Dec. 2004	Braidwood	POGO (2002)	Security guard falls asleep, drives patrol vehicle into fence
Feb. 2005	Beaver Valley	catonavenue	Security guard found inattentive
Apr. 2007	TMI	Lenton (2007)	Security guards found inattentive
Sep. 2007	Peach Bottom	Mufson (2008)	Video of sleeping security guards released

Note: IR is a USNRC incident report, NCV is a USNRC NonCited Violation, and POGO is the Project on Government Oversight

The incidents in Table 2 and Table 3 emphasize the need for a method to measure the impact of fatigue on human performance, specifically human error. One option would be through human error probabilities (HEP). HEPs are used in human reliability analysis (HRA), which attempts to include the role of the human in the overall system reliability.

Difficulties in Defining Fatigue

While fatigue is a major risk factor, it is not easy to define; few words have been less adequately described or understood (Schmitt, 1976). Fatigue is used as the name of the condition and the experience of feeling tired and weary (Bartley, 1957). Unlike physical fatigue, mental fatigue can only be inferred from the context of the evidence; which leads to fatigue often being defined in terms of its consequences rather than its causes. Fatigue is a personal experience and is a function of the individual's motivation and past and present circumstances.[2]

Fatigue results not only from prolonged activity, but also from psychological, socioeconomic, and environmental factors that affect the mind and body. Figure 2 shows Grandjean's (1968) analogy of fatigue being liquid filling a bucket. Grandjean compared fatigue to the level of liquid in the container (bucket) that is being continuously filled by: monotony of task, environment, intensity and length of work, psychological and physical factors, and it can only be emptied by recovery or rest.

[2] See Appendix A for additional information on fatigue.

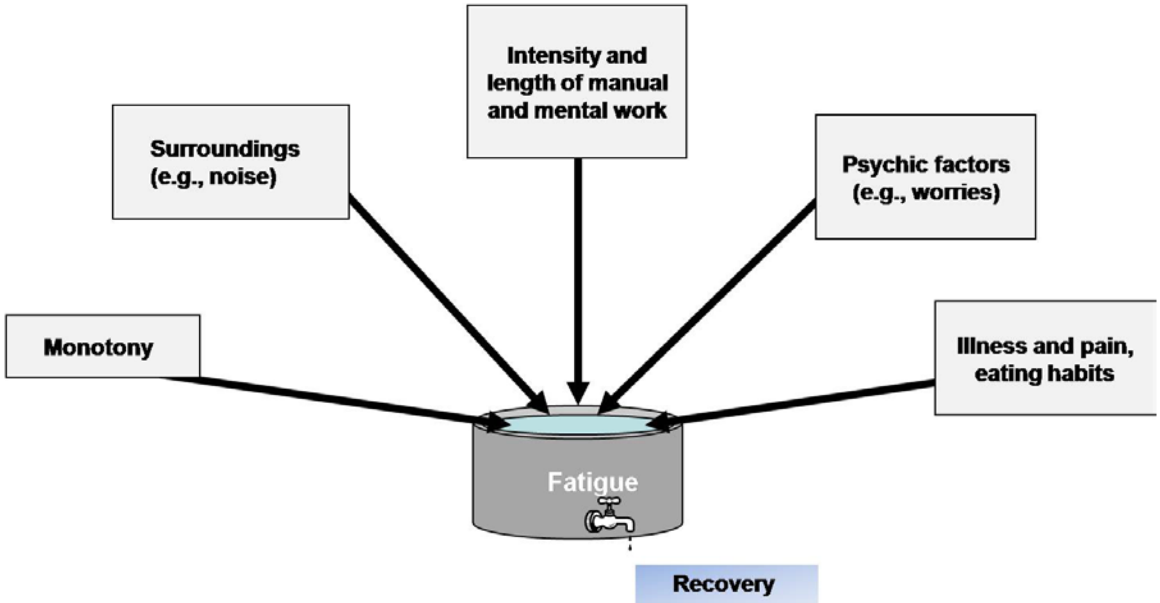

Figure 2: Fatigue as a Bucket (Grandjean, 1968)

Fatigue can lead to impaired performance, such as diminished short-term memory, reduced aversion to risk, and degraded communication skills (Dinges, 1995). Fatigued subjects tend to choose low effort/low probability of success strategies over high effort/high probability of success options. In the confines of the workplace, fatigue can occur when an individual cannot meet self-imposed or externally imposed performance goals, because of a sense of duty and/or the need to safeguard the lives of others, and is forced to continue working under adverse conditions (Brown, 1994).

Another difficulty with the study of fatigue is that it suffers from not having a formal scientific or operational definition, such as the term *work* in regards to mechanical systems, $W = F*d$ where W is work, F is force, and d is displacement. Also, the term fatigue covers mental/cognitive and physiological fatigue and acute and chronic fatigue. A further complication comes from the fact that fatigue cannot be directly measured, but instead must be inferred from changes in other conditions, such as reaction time, body temperature, sleep latency (i.e., time taken to fall asleep), etc. (Boring et al., 2007).

Measurement of Fatigue

There is no direct objective measure of fatigue. There are subjective fatigue scales that are used to indicate the level of fatigue. One of these is the fatigue severity scale (FSS) by Krupps et al. (1989) that uses nine statements on a seven-point scale of agreement; for example, one statement is how fatigue interferes with physical functioning. The fatigue severity scale measures the impact of fatigue on specific types of functioning, relating to behavioral consequences of fatigue rather than symptoms. The other commonly used fatigue scale is the visual analog scale (VAS) by Bond and Lader (1974). A 100-mm scale line, ranging from *not at all* to *extremely fatigued*, is used for the subjects to describe the level of fatigue they are experiencing. These measures are useful for the investigation of levels of fatigue, but are not appropriate for the study of effects on performance.

Work scheduling programs such as Fatigue Avoidance Scheduling Tool (FAST) (Hursh et al., 2004), Manpower and Personnel Integration (MANPRINT) (Army Regulation 602-2, 2001), and Micro Saint (USNRC, 1995) consider the effect of fatigue and sleep deprivation on performance. The software programs aid in limiting the negative effect of fatigue caused by work schedules, but rely mostly on circadian influences on performance for input. The effect of fatigue is not measured in these programs but mitigated.

Performance moderator functions (PMFs) are used in modeling and simulation of human behavior models. PMFs are similar to performance shaping factors (PSFs) used in HRA. For example, for the Endocrine response to an acute psychological stress, the PMF is continuous-time measurement of the plasma concentration level of sympathetic adrenal and pituitary hormones (Richter et al., 1996). Performance moderator functions can be used to represent the behavior or cognition that is needed in a simulation. PMFs are used in SAFTE™, from which FAST™ is derived. Both software programs are used to aid in operator scheduling, i.e., fatigue problems with sustained operation, but do not provide a quantitative value for the effect of sleep deprivation performance. The result from FAST™ is expressed in qualitative terms as a percentage of effectiveness.

The fatigue avoidance scheduling tool (FAST™) was designed by the US Air Force Research Laboratory (AFRL) in 2000 to address the problem of fatigue associated with aircrew flight scheduling (Eddy and Hursh, 2001). FAST™ is a Windows-based program that quantifies the effects of various work-rest schedules on human performance. The output from FAST™ produces a graphical display of cognitive performance effectiveness (*y*-axis), using a scale from 0 to 100% effectiveness, as a function of time (*x*-axis). The effectiveness rating represents a composite of human performance on a number of tasks, but does not provide a numerical value of the effect of sleep deprivation on performance (i.e., error probability). The goal of users is to manipulate the lengths of work and rest periods to keep performance at or above the 90% effectiveness level. Performance effectiveness is determined by: time of day, biological rhythms, time spent awake (i.e., hours of wakefulness), and amount of sleep.

Fatigue predictions in FAST™ are derived from Sleep Activity, Fatigue, and Task Effectiveness (SAFTE) (Hursh, 1998). SAFTE™ produces a three-process model of human cognitive effectiveness by integrating quantitative information about: (1) circadian rhythms in metabolic rate; (2) cognitive recovery rates related to sleep and cognitive decay rates associated with wakefulness; (3) cognitive performance effects associated with sleep inertia. The rating of cognitive effectiveness is dependent on the current balance of the sleep regulation process, the circadian process, and sleep inertia. The sleep regulation process is dependent on hours of sleep, hours of wakefulness, current sleep debt, the circadian process, and sleep fragmentation (i.e., awakening during sleep). In SAFTE™ the focus is on the circadian process, the cognitive effectiveness, and sleep regulation.

FAST™ was used to evaluate data from US freight railroads and find a correlation between effectiveness and number of human factor errors. The results found that there exists a meaningful relationship between accident risk and effectiveness (Hursh et al., 2006). Attempts to apply FAST™ to daily flying scheduling operations were unsuccessful, due to the user interface having been designed for scientists and not for operators. FAST™ has been used for operation risk management of fatigue effects, but is not designed for use in HRA.

This dissertation sought to develop a method to derive PSF coefficients that will modify the basic error probability, based on quantitative data. SAFTE™ and FAST™ are fatigue management tools trying to insure sufficient rest to maintain effective performance. While useful in designing work schedules, they are not directly applicable to HRA methods; i.e., they do not provide error probabilities or PSF coefficient values.

In further research it may be possible to extrapolate the output of FAST™ and SAFTE™ to validate the derived PSF coefficient values for sleep deprivation effects on error probabilities. The types of tasks are also not delineated in FAST™. The developed PSF coefficient derivation method can be adapted easily for specific types of tasks by using the data on similar tasks to derive the PSF coefficient values; this is not possible with FAST™.

The three main causes of cognitive fatigue are sleep deprivation, shift work, and time on task. Sleep deprivation, or hours of wakefulness, lends itself best to research studies because it is relatively simple to achieve and straightforward to measure. While fatigue and sleepiness are often used interchangeably, they are different phenomena. Sleepiness has to do with the propensity to fall asleep, while fatigue is a sense of tiredness or exhaustion associated with impaired (i.e., depletion of capacity) physical and/or cognitive functioning (Shen et al., 2006).

Fatigue effects on performance are measured indirectly through performance metrics: typically reaction time, accuracy, and number of lapses. These three metrics are measured through a variety of psycho-motor tasks in the literature, such as: vigilance tasks, timed tasks, dual or multiple tasks, mental arithmetic tasks, memory tasks, and others (Williamson and Feyer, 2000; Nilsson et al., 2005).

Measurement of Sleep Deprivation Effects on Performance

There is a wide body of research literature on the effects of fatigue on performance in many different fields. The literature predominately focuses on sleep deprivation due to its easy manipulation for study purposes as opposed to shift work and time-on-task experiments. Although it is simple to cause sleep deprivation, it does not follow that it is easy to summarize the available literature. There are no standard protocols for sleep deprivation research. There are many differences between the studies, e.g., the way sleep deprivation is induced, hours of wakefulness, what type of task is used to evaluate performance, etc., (see Table 4).

Table 4: Factors That Differ in Sleep Deprivation Studies

Definition of Sleep Deprivation	Hours of Wakefulness	
	Type of Sleep Deprivation	Acute
		Chronic
Experimental Design	Study Setting	Laboratory or Field
		Environment (e.g., Zeitgebers)
		Physical Activity Level
	Subject Differences	Age Range
		Sex
		Personal Characterisitcs
		Type of Subjects (e.g. student volunteers)
	Type of Task	Subjective, Objective, or Psychomotor
		Simulated Real World
		Real Work
	Task Details	Complexity Level (e.g., simplified task)
		Isolated Task

In order to illustrate the magnitude of fatigue effects on performance, several research studies comparing performance at various blood alcohol content (BAC %) levels and hours awake are reviewed. The purpose of these studies is to equate the performance degradation at a specific level of BAC% to that of hours of wakefulness. There exists better understanding of performance under the influence of alcohol than under sleep deprivation. These studies illustrate the lesser known, but more common, serious effects of sleep deprivation in our culture as compared to better known BAC%.

A review of six studies (Arnedt et al., 2000; Arnedt et al., 2001; Dawson and Reid, 1997; Lamond and Dawson, 1999; Marmuff et al., 2005; Williamson and Feyer, 2000) is used here for illustration of the comparison between sleep deprivation and blood alcohol concentration on performance. These studies showed that performance at 17 to 24 hours of wakefulness equated to the same level of performance at BAC% of 0.05 (the legal limit in many countries); 20 to 24 hours of wakefulness corresponded to a BAC% of 0.08 (the legal limit in the US), and 20 to 25 hours of wakefulness to a BAC% of 0.1. The results are reported in ranges of hours of wakefulness to BAC% due to the fact that different tasks were used in the studies.

The different tasks used to evaluate performance included: simulated driving task in Arnedt et al. (2000) and Arnedt et al. (2001); Mackworth clock vigilance task (Mackworth, 1950) in Williamson and Feyer (2000); simple reaction time from the CogState test battery in Marmuff et al. (2005); tracking tasks in Lamond and Dawson (1999) and Dawson and Reid (1997); grammatical reasoning and vigilance task in Lamond and Dawson (1999).

A simulated driving task measuring performance through lane position and speed deviation was used in Arnedt et al. (2000) and Arnedt et al. (2001). Performance in the simulated driving task was equivalent at 18.5 hours of wakefulness to a BAC% of 0.05 and at 20 and 21 hours of wakefulness to a BAC% of 0.08. When a tracking test was used to evaluate performance, such as in Dawson and Reid (1997) and Lamond and Dawson (1999), the results showed that 17 hours of wakefulness equated to a BAC% level of 0.05, 24 hours of wakefulness equated to a BAC% level of 0.08, and 25 hours of wakefulness equated to a BAC% level of 0.1. Two of the studies employed a vigilance task (Lamond and Dawson, 1999; Williamson and Feyer, 2000). The findings for these studies were that 17 hours of wakefulness equated to a BAC% of 0.05 and that 25 hours of wakefulness on the latency component of the vigilance task and 22.3 hours of wakefulness on the accuracy component of the vigilance task corresponded to a BAC% of 0.1. A grammatical reasoning task (Baddeley, 1968) was used in Lamond and Dawson (1999) that equated performance at the BAC% level of 0.1 to 20.3 hours.

When looking at the data from a complexity level, the more demanding the task is cognitively, the fewer hours of wakefulness are needed to produce impairment equivalent to higher BAC% levels. For example, the more complex task of grammatical reasoning performance level for 20 hours of wakefulness was the same as at the BAC% of 0.1. However, for the less cognitively demanding tracking task, performance after 25 hours of wakefulness was the same as at the BAC% level of 0.1. The damaging effects of sleep deprivation (extended hours of wakefulness) on performance is illustrated through these studies by equating common legal limits of BAC% performance to that of hours of wakefulness. Table 5 presents a summary of the hours of wakefulness that were compared with BAC% and the type of task used.

Table 5: Hours of Wakefulness Compared to BAC% Levels

Study Reference	Hrs Sleep Dep	BAC %	Task
Arnedt et al., 2001	18.5	0.05	Simulated driving task
Dawson and Reid, 1997	17	0.05	Tracking task
Marmuff et al., 2005	24	0.05	Simple reaction time
Williamson and Feyer, 2000	17	0.05	Mackworth clock
Arnedt et al., 2001	21	0.08	Simulated driving task
Dawson and Reid, 1997	24	0.08	Tracking task
Arnedt et al., 2000	20	0.08	Simulated driving task
Lamond and Dawson, 1999	20.3	0.10	Grammatical reasoning - latency
Lamond and Dawson, 1999	24.9	0.10	Vigilance - latency
Lamond and Dawson, 1999	22.3	0.10	Vigilance - accuracy
Lamond and Dawson, 1999	25.1	0.10	Tracking task

Figure 3 shows a graphical representation of BAC% compared to hours of wakefulness. Tasks are divided into three categories: complex, motor, and cognitive. Driving simulation (Arnedt et al., 2000 and Arnedt et al., 2001) was considered a complex task. Tracking tasks (Dawson and Reid, 1997 and Lamond and Dawson, 1999), vigilance tasks (Lamond and Dawson, 1999), Mackworth clock, a vigilance and tracking task, (Williamson and Feyer, 2000), and simple reaction time (Marmuff et al., 2005) were considered to be examples of motor tasks. The grammatical reasoning task used in Lamond and Dawson (1999) was considered to be a cognitive task.

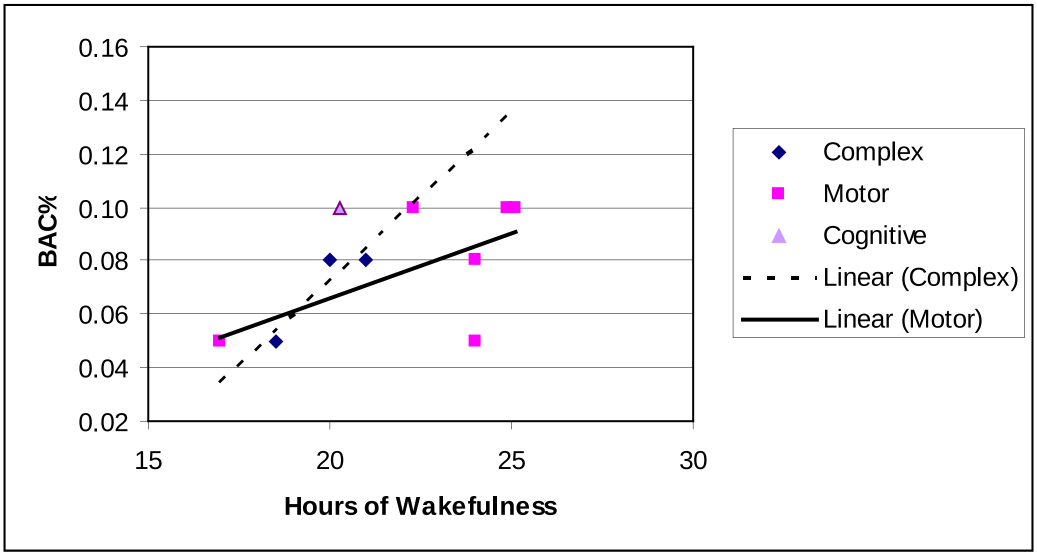

Figure 3: Hours of Wakefulness Compared to BAC%

Not many would consider driving a motor vehicle with a BAC% level above the legal limit, but few would think twice about getting behind the wheel after 20 hours of wakefulness. These findings begin to illustrate the seriousness and safety risk that the ever increasingly sleep-deprived population presents.

Sleep deprivation is important and needs to be considered in formal risk assessments. The most widely used formal risk assessment is probabilistic risk assessment (PRA) (Gertman and Blackman, 1994).

Probabilistic Risk Assessment (PRA)

Risk assessment provides a means of informing decision makers and identifying failure-prone situations. Probabilistic risk assessment (PRA) can be used to determine system reliability, improve plant layout, validate system design, and determine frequency of error incidents. Risk assessment involves identifying the potential risks (i.e., understanding of the hazards), the likelihood of occurrences (i.e., frequency), and the consequences when they do occur. Risk is the likelihood of a hazard-causing loss or damage. Often risk is defined as the probability of an incident multiplied by its consequence as in Equation 1:

$$\text{Risk} = P(\text{Event}) * \text{Consequence} \tag{1}$$

Normally, a risk analyst is concerned with what can go wrong, how likely something is to go wrong, and the consequences when something does go wrong. PRA evolved from the need to estimate the frequencies of accidents in complex systems when the data on actual incidents are very small and often zero (Bier, 1999). Typically, there are failure rates for components of the system, for example pumps and valves, but not for the overall system. These component failure rates are propagated through a fault-tree or event-tree model to estimate an overall failure probability of the system (Bier, 1999). The extreme cost of complex systems, such as nuclear power plants, made the initial development of PRA techniques cost-effective, since a power plant may cost two billion dollars while a full-scope PRA may cost only two million dollars. The resulting PRA may establish safety improvements that are in the tens of thousands of dollars in cost, while yielding large reductions in overall plant risk (Garrick, 1987).

The aim of PRA is to identify areas of significant risk and identify improvements and quantify the overall risk to the plant. PRAs analyze the risk of entire systems by decomposing the systems into their components (e.g., including hardware, software, and human operators). A PRA is begun with an initiating event and is based on the sequence of possible scenarios and possible resulting errors pursuant to that initiating event. PRA is basically a logic-tree model of the plant and its functions (e.g., fault-trees) (Reason, 1990). The general structure of PRA was established from the 1975 Rasmussen Report commonly referred to as WASH-1400 (Rasmussen, 1975).[3] The steps are:

1) identify the source of the potential hazard,
2) identify the initiating events,
3) establish possible sequences stemming from various initiating events using event-trees,
4) quantify each event sequence
    a. frequency of the initiating event
    b. probability of failure of the relevant safety system when needed, and
5) determine overall plant risk (function of all possible accident sequences and their consequences).

Even though this structure depends on conditional probabilities, which are rarely collected in practice and often independence of events is assumed, the development of a standardized PRA method was a major step forward in reliability engineering (Reason, 1990).

One difficulty in PRA is that it is limited by the lack of empirical data; this makes PRA hard to validate. This also creates a need to look for better resolution of the models. One of the least data supported components of PRA is HRA. There is a significant need to improve risk assessment in order to have a realistic risk informed approach. The Nuclear Energy Association stated, "Any improvement in the current state of knowledge … would have a positive impact on the confidence in probabilistic safety assessment results" (NEA, 1998). There is a need to improve HRA to help with the continual

[3] WASH-1400 was replaced with USNRC (1975) NUREG-75/014 and is now USNRC (1990) NUREG-1150.

improvement of PRA models, by increasing the level of detail and credibility while decreasing the amount of conservativeness.

Human Reliability Analysis (HRA)

HRA enhances probabilistic risk assessment (PRA) by including the effects of human error associated with complex systems. HRA provides a method to determine the probability that a task or job requiring human action will be performed successfully within the required time period and without extraneous human actions detrimental to system performance. The inclusion of HRA in a PRA has many advantages, including (Gertman and Blackman, 1994):

- providing quantitative estimates of human error probability,
- identifying weaknesses in operator interaction with the system (by identifying possible sources of error),
- evaluating improvements in human interfaces, and
- improving system evaluations by including human elements.

Human Reliability Analysis (HRA) grew out of the need to understand the human role in the operation of complex systems, like those listed in Table 2. These complex systems tend to have low probability of a negative incident but with high consequence. Therefore, when one of these complex systems has an incident, it attracts substantial industry wide attention. For example, an increased interest in occupational safety and health resulted from the Three Mile Island nuclear power plant in 1979, the Chernobyl nuclear power plant in 1986, and the *Challenger* accident in 1986 (Mitler et al. 1988). These incidents have been the catalysts in driving the development of HRA methods (Reason, 1990). Significant risk reductions and gains in the safety and performance of complex systems, such as nuclear power plants, are expected with the better understanding of human performance through the HRA process. (Gertman and Blackman, 1994)

The three basic steps in HRA are: 1) identification of human errors and violations, 2) modeling or representation, generally visually through event-trees, and 3) quantification of human error probability estimates (frequency and consequences of undesired outcomes). The steps of HRA are shown in Figure 4 (INL HRA Course, 2004). Sometimes the process requires several iterations to reach a final quantification.

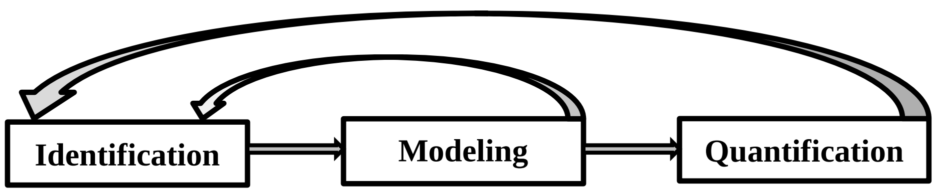

Figure 4: HRA Three-Step Process (INL HRA Course, 2004)

Identification and modeling are qualitative steps in the HRA process, while the quantification step emphasizes the calculations of error probabilities associated with specific human actions. The analyst must identify what type of human error will occur, as well as what performance factors may contribute to the error. The identification of human error and performance factors is usually done through a task analysis; this is a systematic process of specifying the functional steps, as well as an operator's skills that are needed to accomplish a task. In order to identify all potential errors and performance factors, the analyst should be familiar with the task, the environment, and the skill level that is required to perform the task.

The factors that influence human performance in complex systems are called performance shaping factors (PSF). They are environmental, personal, or task-oriented factors that influence the probability of human error. These factors are used in HRA models to modify the base or nominal human error probability (HEP). Some examples of psychological and physiological PSFs are task speed, distractions, monotonous work, emergency situations, fatigue, discomfort, and high temperature (Kirwan, 1994). Other examples of PSFs include: written procedures, training, personal skills, motivations, expectations, environment, and equipment design (Gertman and Blackman, 1994). These PSFs are an integral part of error modeling and characterization. A human error rate applicable to a particular set of circumstances is obtained by modifying the nominal human error probability, which is the base rate for an error to occur under normal operating conditions, by the PSFs. After the HRA analyst has identified the PSFs that are believed to affect performance in a particular situation, the corresponding multiplier value is used to modify the nominal HEP in order to obtain the case-specific HEP. Therefore, identifying and quantifying the effect of PSFs is a critical step in the HRA process.

There are several different HRA methods available for use in probabilistic risk assessments. Some methods are for quantification of human error rates, some are for finding error-prone situations [i.e., error-forcing context), and some methods are complete HRA models (quantification and error-forcing context) identification].

Three HRA methods are reviewed in greater detail. Those methods are Technique for Human Error Rate Prediction (THERP) by Swain and Guttman (1983), A Technique for Human Event Analysis (ATHEANA) developed in NUREG-1684

(USNRC, 2000), and Standardized Plant Analysis Risk – Human reliability analysis (SPAR-H) by Gertman et al. (2005).

THERP

THERP, i.e., Technique for Human Error Rate Prediction (Swain and Guttman, 1983), is the most widely used first generation HRA method. This is due to its ease of application and readily available numerical results for inclusion in a PRA. Other first generation HRA methods include: Success Likelihood Index Method-Multi-Attribute Utility Decomposition (SLIM-MAUD) from NUREG/CR-3518 (Embrey et al., 1983), Human Cognitive Reliability model (HCR) (Hannaman et al., 1984), human error rate assessment of intention-based errors (INTENT) (Gertman et al., 1990), and Human Error Analysis and Reduction Technique (HEART) (Williams, 1986).

For multiple tasks, THERP uses event-tree modeling where each branch represents a combination of human activities, influences upon these activities, and results of these activities. Conditional probabilities are assigned for each branch along the tree (with the possible exception of the first branch). The branches emit from binary decision points, where only correct or incorrect performances are the options. The following are the four basic steps in THERP.

1) Identify system functions that may be influenced by human error.
2) List and analyze related human operations (perform a task analysis).
3) Estimate the relevant error probabilities, using available data and expert judgment.
4) Estimate the effects of human errors on the system failure events (integrate HRA with PRA).

THERP uses tables to provide error probabilities. For example, Table 6 which is THERP *Table 20-14* is shown as an example of the available THERP tables. The table supplies HEPs for an operator failing to notice a sticking valve, when the valve has: 1) a position indicator only, 2) a position indicator and rising stem, 3) rising stem, but no position indicator, or 4) neither rising stem nor position indicator. The HEP and error factor (EF) for *THERP Table 20-14* is provided in Table 6, where EF is the square root of the upper and lower bounds of the probability. For a situation with multiple tasks or actions, multiple tables are needed to calculate the HEP; the probabilities from the tables are combined using event-trees.

Table 6: THERP Table 20-14, Estimated HEPs in Detecting Stuck Locally Operated Valves (Swain and Guttman, 1983)

Given that a locally operated valve sticks as it is being changed or restored,* the operator fails to notice the sticking valve, when it has:

Item	Potential Errors	HEP	EF
(1)	A position indicator ** only	0.001	3
(2)	A position indicator ** and a rising stem	0.002	3
(3)	A rising stem but no position indicator**	0.005	3
(4)	Neither rising stem nor position indicator**	0.01	3

* Equipment reliability specialists have estimated that the probability of a valves' sticking in this manner is approximately 0.001 per manipulation, with an error factor of 10.

** A position indicator incorporates a scale that indicates the position of the valve relative to a fully opened or fully closed position. A rising stem qualifies as a position indicator if there is a scale associated with it.

For a task involving multiple tasks, THERP does not construct an HEP from a nominal value that is modified by context-specific PSF multipliers. HEPs in THERP are calculated using event-trees of various tasks. THERP does not construct an HEP from a nominal value modified by context-specific PSF multipliers. HEPs in THERP are calculated using event-trees. Figure 5 and Figure 6 show an event-tree for two tasks (*A* and *B*) (Boring et al., 2006). Task *A* and task *B* are done in sequence. In Figure 5, success is defined when both *A* and *B* are completed successfully, and in Figure 6, success is defined when either *A* or *B* is completed successfully.

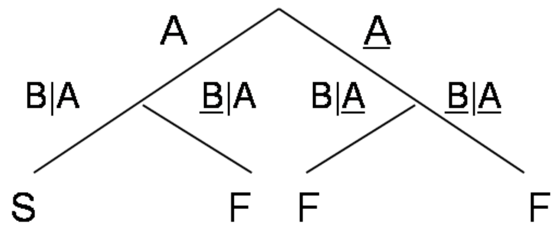

Figure 5: Event-Tree for Two Tasks (A, B): Both Completed Correctly (Boring et al., 2006)

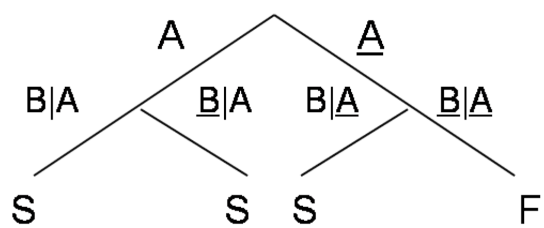

Figure 6: Event-Tree for Two Tasks (A, B): Either One Completed Correctly (Boring et al., 2006)

The notations in Figure 5 and Figure 6 are as follows:

A - Successful performance of task A
A - Unsuccessful performance of task A
B - Successful performance of task B
B - Unsuccessful performance of task B
B|A - Successful performance of task B given A
B|A - Unsuccessful performance of task B given A
B|A - Successful performance of task B given A
B|A - Unsuccessful performance of task B given A
F - Failure
S - Success.

Probabilities for Figure 5 are given by Equation 2 for success and Equation 3 for failure:

$$P(S) = P(A)P(B|A) \quad \textbf{(2)}$$

$$P(F) = 1 - P(A)P(B|A) = P(A)P(\underline{B}|\underline{A}) + P(\underline{A})P(B|\underline{A}) + P(\underline{A})P(\underline{B}|\underline{A}). \quad \textbf{(3)}$$

Probabilities for Figure 6 are given by Equation 4 for success and Equation 5 for failure:

$$P(S) = 1 - \underline{A}(\underline{B}|\underline{A}) = A(B|A) + A(\underline{B}|A) + \underline{A}(B|\underline{A}) \quad \textbf{(4)}$$

$$P(F) = \underline{A}(\underline{B}|\underline{A}). \quad \textbf{(5)}$$

The probability data used in THERP are a mixture of empirical data and expert opinion (Forester et al., 2006). THERP provides a quantitative result for a limited number of PSFs and does not provide guidance for error quantification for situations not addressed in the provided tables (Forester et al., 2006). Nor does it convincingly depict the context of the actual situation. THERP was not designed for use outside the control room, nor was it designed for modeling diagnosis errors. THERP has a limited focus on external errors (i.e., errors of omission and errors of commission), and THERP was designed to decompose already defined pre-initiator events in nuclear power plants. It has not been possible to validate the data due to the fact that much of the data used to populate the THERP data tables came from proprietary and classified sources; therefore, extrapolating them to more general cases of HRA applications is difficult.

ATHEANA

Second generation HRA methods include task context; ATHEANA (A Technique for Human Event Analysis) developed in NUREG-1624 (USNRC, 2000) is an example. Second generation HRA methods normally involve the modeling of the cognitive roots of human error, analysis of the human-machine interface, quantification of error probability, and probabilistic simulation. Examples of other second generation HRA methods are: CREAM (Hollangel, 1998), MERMOS (Bieder et al., 1998), IDAC (Chang and Mosleh, 1999), CAHR (Sträter and Bubb, 1998) and SPAR-H (Gertman et al., 2005).

ATHEANA (USNRC, 2000) focuses on identifying error-forcing contexts (i.e., why errors occur) and their influence upon the task. Error-forcing contexts are a combination of PSFs and plant conditions, regularly unexpected plant conditions, and unfavorable PSFs (USNRC, 2000). ATHEANA identifies a systematic search scheme for the identification of error-forcing contexts and is focused on events that lead directly to core damage and is not aimed at pre-initiator events. HEPs in ATHEANA are calculated by Equation 6:

$$HEP = \sum P(EFC_i)P\big(UA_{ij}|EFC_i\big)P(failure\ recovery|UA_{ij}, EFC_i) \tag{6}$$

where:

i = ith scenario,
j = jth unsafe act,
EFC = error-forcing context
$P(EFC_i)$ = the probability of error-forcing context in the particular accident scenario of analysis,
$P(UA_{ij}|\ EFC_i)$ = the conditional likelihood of the unsafe acts that can cause the human failure event,
$P(fail\ recovery\ |\ UA_{ij}, EFC_i)$ = the conditional likelihood that the unsafe action is not recovered prior to the catastrophic failure.

ATHEANA is limited by the lack of specific lists of error-forcing contexts; instead error-forcing contexts have to be developed from different scenarios. The ATHEANA methodology is developed at a conceptual level, but not in specific detail.

Also, there is no specific quantification method associated with ATHEANA; any quantitative assessment to be used in PRA has to come from expert judgment informed by the ATHEANA analysis (USNRC, 2000). Thus, a team of HRA specialists are normally required to conduct an HRA when using ATHEANA.

SPAR-H

The Standardized Plant Analysis Risk – Human reliability analysis (SPAR-H) method was developed to support plant-specific PRA and is discussed in NUREG/CR-6883 (Gertman et al., 2005). SPAR-H is a replacement and revision of the NRC's accident sequence precursor analysis. SPAR-H is primarily a quantification method for human error probability that assumes the human failure events have already been identified. A strength of SPAR-H is that it provides guidance on assigning weights to the PSFs and uses worksheets for analyst consistency and documentation. There are pre-defined PSFs for SPAR-H (e.g., Time Available, Stress, Complexity, Experience and Training, Procedures, Ergonomics, Fitness-for-Duty, and Work Process).

The SPAR-H method separates human error into two separate categories *action* (e.g., errors of commission--active errors) and *diagnosis* (e.g., errors of omission--latent errors). Separate worksheets are used for quantifying action and diagnosis errors. Different PSF weights and nominal HEP values, which are pre-defined, are associated with action and diagnosis errors in the SPAR-H method. Action errors have a nominal probability of *1.0E-3, w*hile the nominal probability for diagnosis is *1.0E-2*. Therefore, in SPAR-H under normal operating conditions, an individual has a 1 in 100 chance of committing a cognitive error and 1 in 1000 of committing an action error. Human error probabilities in SPAR-H are calculated by adjusting the nominal human error probability by a standardized weighting factor attributed to the level of action by the PSF under investigation. When the effect of PSFs is included, the overall probability is expressed as:

$$HEP = P_0 \prod_{i=1}^{8} PSF_i \quad (7)$$

where,

HEP = human error probability
P_o = nominal probability value
PSF_i = multiplier for performance shaping factor *i* in the situation investigated.

SPAR-H uses standardized worksheets and is simple to implement; these worksheets produce a mean estimate of the HEP. Although SPAR-H is relatively straightforward and follows *good practices* for HRA, one weakness is that interactions among the PSFs are not considered. SPAR-H is implicitly influenced by THERP for its base (i.e., nominal) failure rates and dependency information. The main source of uncertainty in SPAR-H comes from selecting the values for the PSFs; different users might use different PSF values with the same data.

PSFs in SPAR-H

In the SPAR-H human reliability method, the nominal human error probabilities are multiplied by PSF coefficient values. SPAR-H uses a pre-defined set of PSF multipliers, which the analyst relates according to situational context. A literature review of human behavioral sciences and HRA models was used to identify the following eight PSFs that are used in the SPAR-H method (Gertman et al., 2005):

1) Time Available
2) Stress
3) Complexity
4) Experience and Training
5) Procedures
6) Ergonomics
7) Fitness-for-Duty
8) Work Process

The last five PSFs, experience and training, procedures, ergonomics, fitness-for-duty, and work process, are event or personnel specific and are evaluated when analyzing a plant-specific model. The first three SPAR-H PSFs, time available, stress, and complexity, are evaluated immediately through HRA.

Another feature of SPAR-H is that it includes the positive influences of PSFs on human performance; these follow the inverted-U graph of the arousal curve as shown in Figure 7 and are referred to as the Yerkes-Dodson Law of arousal (Yerkes and Dodson, 1908). There is a positive influence on performance with added arousal (e.g., engaging the worker and preventing errors of omission by inattention) until the peak is reached; then there is a negative effect, as arousal/stress continues beyond the optimum point. The term *arousal* in this sense is used as a synonym of stress or complexity. Arousal plays an important role in determining what information is essential in a competitive environment to allocate scarce attention and memory resources to critical events rather than to the mundane (Christianson, 1992).

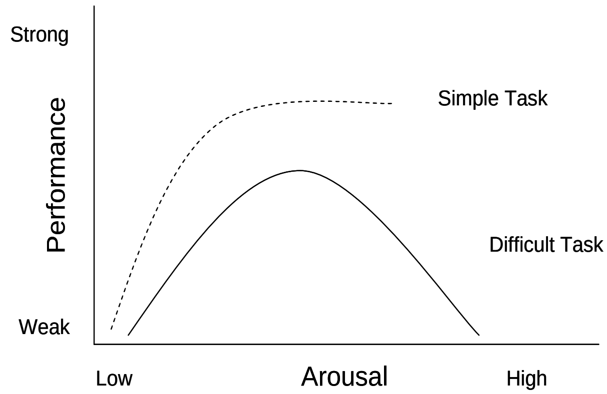

Figure 7: Yerkes-Dodson Law Inverted U-graph (Yerkes and Dodson, 1908)

Limitations in Current HRA Methods

There are four main sources of deficiencies in current HRA methods: 1) lack of empirical data for model development and validation, 2) lack of inclusion of human cognition (i.e., need for better human behavior modeling), 3) large variability in implementation, i.e., HRA parameters are different depending on the method used, (Sträter and Bubb, 1998), and 4) heavy reliance on expert judgment in selecting PSFs, and the use of them to obtain the HEP in human reliability analysis. The theoretical basis for many of the HRA methods is unclear (Blackman, 1998).

HRA methods are limited by the availability of relevant data. In order to address the first deficiency, there are currently ongoing efforts to establish HRA databases. These are available to HRA analysts and have the human error data with cited sources in order to improve the validity and reproducibility of HRA results. Examples of the databases are the Human Event Repository and Analysis (HERA) (Hallbert et al., 2006) and the Human Factors Information System (HFIS) (USNRC, 2006).

In order to model human behavior with more fidelity, the effect of human cognition and influences that significantly affect human performance, such as fatigue, needs to be considered for inclusion into HRA. The more data available on human error, especially in reference to contextual conditions, the greater the confidence in human reliability analysis (Collier, 2005). Human actions can either improve or impede in failure recovery. Researchers are beginning to include task context in HRA methods, such as ATHEANA. This is an important step forward in human error analysis.

The third deficiency in current HRA methods is variability in model implementation. There is one validation study of the THERP method that is widely cited, but there is little else in the way of validation studies that have been published. How much variance exists in HRA models that are currently being used is not clear. These factors make it difficult to assess the predictive capability of current HRA methods.

The fourth limitation of HRA is the heavy reliance on expert opinion; the fact that expert opinion is used to populate HEPs makes reproducing and validating the results difficult. The dependency on expert judgments could be reduced with an improvement in the quantitative basis for the data used to generate HEPs.

Inclusion of Fatigue in HRA Methods

Fatigue is not usually considered as a PSF in most commonly used HRA methods. Nor do current HRA methods adequately include explicit quantitative measures for the effects of fatigue. Typically, fatigue is assumed to be indirectly covered in PSFs such as fitness-for-duty in the SPAR-H method. Fatigue is a dynamic PSF that does not remain constant throughout an event, such as training would.

Fatigue is not explicitly covered in THERP. The tables of THERP deal with HEPs of actual scenarios, for example, *detecting stuck locally operated valves* from Table 20-14 of Swain and Guttman (1983). In the case of ATHEANA, fatigue comes under the error-forcing context (EFC) related to the effect of the initiator or accident sequence on the capacity of action of the control room before the incident. For retrospective analysis using ATHEANA (i.e., after the incident), fatigue effects could be considered as a sub-factor under the PSF of human performance capabilities at a low point.

In SPAR-H, fatigue could be considered a sub-factor of the fitness-for-duty PSF. However, it could be argued that fatigue would have some effect on several of the eight PSFs given their generality. For example, SPAR-H PSFs such as stress, time available, and complexity would be affected by fatigue through its competition for limited mental resource capacity. However, the main PSF that would be affected would be fitness-for-duty. The PSF fitness-for-duty is broken down into four levels in SPAR-H: *unfit* (which gives the probability of human error as 1.0), *degraded* (weight of 5), and *nominal* (weight of 1), with the additional option of selecting the category of insufficient information (weight of 1). These three levels of duty fitness were initially designed with chemically induced impairment in mind, not impairment due to fatigue (Whaley et al., 2011).

The refinement of current HRA methods can be done by focusing on specific factors that contribute to human errors, and using empirical data for quantification. This will lead to increased credibility of HRA, resulting in improved probabilistic risk assessment (PRA). An improved PRA will allow for an increased understanding of the safe operating bounds of human behavior in the twenty-four hour economy world. In general, the inclusion of the quantitative and qualitative aspects of PSFs, such as fatigue, need to be better understood and represented in the HRA methods.

Summary

Fatigue has been identified as the root cause in multiple accidents, including the *Challenger* accident in 1986, the Staten Island Ferry crash in 2003, and multiple minor incidents at nuclear power plants, for example, Peach Bottom in 1987 and 2003. Even though fatigue is linked to many major and minor accidents, it is still a condition that occurs daily. In order to illustrate the effect sleep deprivation has on simple reaction time, hours of wakefulness have been experimentally equated to BAC% levels. These experiments report that 17 hours of wakefulness (seven hours of sleep in a twenty-four hour period) have the same effect as a BAC% of 0.05, which is the legal limit in much of Europe. However, fatigue cannot be directly measured and must be measured through indirect metrics. A way to address the pervasive influence of fatigue is to format known information about fatigue into formal risk assessments. This research establishes a method to extract quantitative data about fatigue and sleep deprivation to derive human error probabilities for use in HRA.

In this chapter, HRA methods were presented along with their limitations requiring improvement. Common HRA methods, including THERP, ATHEANA, and SPAR-H, are lacking in the inclusion of fatigue and sleep deprivation effects on performance. PRA utilizes information gained from HRA to represent the human element of risk assessment.

CHAPTER III

SYNTHESIS OF SLEEP DEPRIVATION STUDIES

One way to deal with the multitude of differences in the sleep deprivation literature is to use the meta-analysis research synthesis method. This chapter gives background on meta-analysis, including the basic procedure and equations. The end result of meta-analysis is the effect size or the degree of change in the variable under study. Also, the basic differences in the sleep deprivation literature are reviewed. These differences include variability in the subjects, experimental conditions, and performance tasks. Three predefined performance tasks are discussed in greater detail, (i.e., Baddeley logical reasoning, Mackworth clock, and the PVT).

Background on Meta-Analysis

Meta-analysis is a synthesis of available research about a topic. Meta-analysis creates a structured format, through statistical procedures and a coding manual, to extract information from selected studies for the purpose of combining the findings. Meta-analysis is not a literature review, nor is it a vote counting method of available research (Hunt, 1997).

The term meta-analysis was coined by Smith and Glass (1977) with respect to studies on psychotherapy, beginning the now common practice of using quantitative synthesis techniques in social science. The idea of combining results from multiple studies was not originated by Glass, but was first introduced by Pearson in the early 1900's (Pearson, 1904).

Meta-analysis provides explanations of causal relationships; the strength of correlation suggests the causal chain of events leading to the outcome. With meta-analysis, the sub-parts (the factors that play a role in the end effect studies) of the outcome can be measured; this is a method that makes it possible to measure the indirectly-measurable fatigue effects on worker performance. The main effects can be identified and the quantitative change in effect size, due to substantive issues, can be observed. The *effect size* is the degree to which the phenomenon under investigation is present in the population. Effect size expresses the degree of difference from the null hypothesis, where the null hypothesis is that there is no effect. Meta-analysis is used to discover the underlying trends by integrating a large collection of analysis results from individual studies for the purpose of integrating the findings. This method of analysis is especially useful for studying humans, since human behavior is not easy to control for study purposes; i.e., rarely does a single study provide sufficient information on which to base policy.

A high quality meta-analysis depends on four main components: success in locating studies, explicitness of criteria for selecting studies, accuracy in effect size computations, and the adherence to the assumptions of meta-analysis statistics. At its best, meta-analysis advances knowledge about a phenomenon by explicating its typical patterns and showing when effect size is larger or smaller, negative or positive, and tests theories about the phenomena (Hunt, 1997).

In meta-analysis the effect size is compared as a dependent variable across different studies, for example, how reaction time is changed by sleep deprivation. Effect size can be thought of as the degree of change in the variable under study. The empirical findings from the various studies, which can be represented by different statistics, such as ANOVA, *t*-test, and Chi-Squared, are converted to a standardized *r*-index or *d*-index. The *r*-index family includes correlation indices. The *d*-index includes the effect size represented by the standardized difference between the mean values, often referred to as Cohen's *d*. Although meta-analysis is not dependent on sample size, a weighting, based on the size of the sample, is applied to the index statistic to reduce the effect variance in the results.

Procedure for Meta-Analysis

There are five basic steps in the meta-analysis procedure: formulating the problem, collecting the data, evaluating the data, analyzing the data, and then reporting the findings. Some of the process steps are shown in Figure 8.

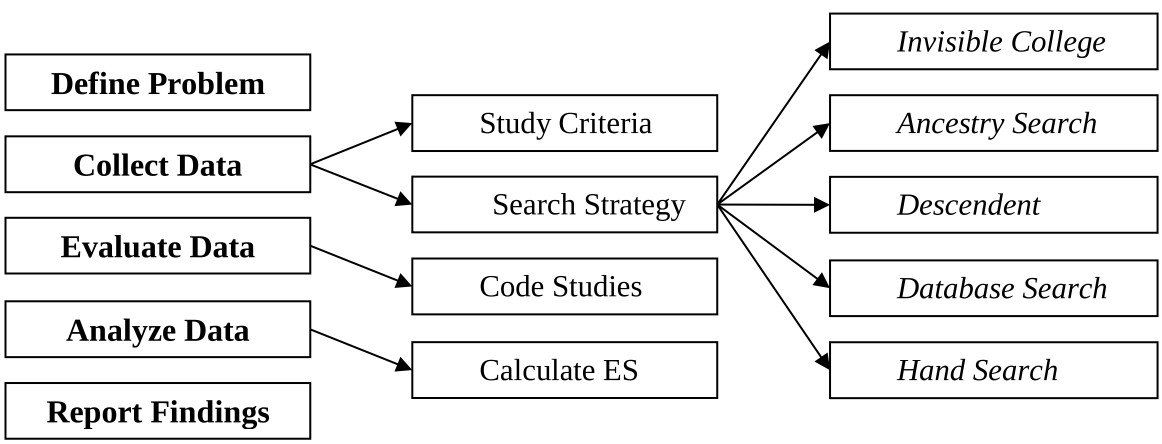

Figure 8: Meta-Analysis Procedure Diagram

The first step is to formulate the problem and define the hypothesis under investigation. This helps to define the preliminary bounds on the literature search and to identify the variables of interest. The second step, collecting the data, involves defining a search strategy and establishing study criteria. The *universe* from which the studies are drawn is refined by the search strategy and study criteria. The third step, evaluating the data, involves developing a coding manual for recording information from the studies (e.g., study descriptors, methods and procedures, and effect sizes reported in their original format). The fourth step is analyzing the data by converting effect sizes from studies that passed through the previous selection process from their original reported format to a standard statistic such as *r*-index or *d*-index; the fifth step is reporting the findings.

Equations of Meta-Analysis

Typically, effect size is calculated by using the standardized difference of the mean values between the control and test groups. Equation 8 is used to convert mean values and standard deviations into effect sizes (Lipsey and Wilson, 2001);

$$ES_{sm} = \frac{(X_1 - X_2)}{s_{pooled}} \qquad \textbf{(8)}$$

where,

ES_{sm}	=	standardized mean difference effect size
X_1	=	mean value of control
X_2	=	mean value of test
s_{pooled}	=	pooled sample deviation.

The pooled standard deviation, in Equation 8, is used because many studies lack a true control group or the control group sample size is relatively small (Coe, 2000).

$$s_{pooled} = \sqrt{\frac{(n_1 - 1)s_1^{\ 2} + (n_2 - 1)s_2^{\ 2}}{n_1 + n_2 - 1}} \qquad \textbf{(9)}$$

where,

$s_1^{\ 2}$	=	variance of sample 1
$s_2^{\ 2}$	=	variance of sample 2
n_1	=	control sample size
n_2	=	test sample size
s_{pooled}	=	pooled sample deviation.

When inferential statistics are reported in the original studies, instead of means and standard deviations, Equations 10-13 can be used to calculate the *d*-index.

$$ES_{sm} = \sqrt{\frac{F(n_1 + n_2)}{n_1 n_2}} \qquad \textbf{(10)}$$

where,

n_1	=	control sample size
n_2	=	test sample size
F	=	F-test value.

Equation 10 is the algebraic equivalent of Equation 8 and is used when data are reported as *F*-value (Lipsey and Wilson, 2001).

$$ES_{sm} = t\sqrt{\frac{(n_1 + n_2)}{n_1 n_2}} \qquad \textbf{(11)}$$

where,

n_1	=	control sample size
n_2	=	test sample size
t	=	t-test value.

Equation 11 is also the algebraic equivalent of Equation 8 and is used when statistical data are reported as t-test, note that $t^2 = F$ and that both are distributed as a chi-squared variable (χ^2) (Lipsey and Wilson, 2001).

$$ES_{sm} = 2\sqrt{\frac{\chi^2}{N - \chi^2}} \qquad \textbf{(12)}$$

where,

χ^2	=	Chi-square value
N	=	total sample size.

Equation 12 is also the algebraic equivalent of Equation 8 and can be used when statistical data are reported as chi-squared values (Lipsey and Wilson, 2001):

$$d = \frac{2r}{\sqrt{1 - r^2}} \qquad \textbf{(13)}$$

where,

d	=	Cohen's effect size
r	=	correlation.

Equation 13 is used to convert correlation (r) coefficient statistical data to Cohen's d, when correlation information is reported.

One way of interpreting effect size is to use a three point scale interpreted by Coe (2000), an effect size of 0.2 as small, 0.5 as medium, and 0.8 as large. Effect size can also be evaluated in percentiles using statistical Z-score tables. Looking at Table 7, an effect size of 0.7 would correspond, on average, to 76% of test condition individuals having performed better than the control group. Conversely, if the effect size was negative, for example -0.8, on average the control group performed 79% better than the test group.

Table 7: Interpreting Effect Size (Coe, 2000)

Effect Size	Percentage (%)	Z-Table
0.00	50%	0.5000
0.10	54%	0.5398
0.20	58%	0.5793
0.30	62%	0.6179
0.40	66%	0.6554
0.50	69%	0.6915
0.60	73%	0.7257
0.70	76%	0.7580
0.80	79%	0.7881
0.90	82%	0.8159
1.00	84%	0.8413
1.20	88%	0.8849
1.40	92%	0.9192
1.60	95%	0.9452
1.80	96%	0.9641
2.00	98%	0.9772
2.50	99%	0.9938
2.80	99.9%	0.9974

Shortcomings of Meta-Analysis

While there are many advantages to conducting a meta-analysis, there are also some shortcomings associated with the procedure. One limitation is that meta-analysis requires significant effort. Many studies can be identified using computer searches; however, the actual data need to be coded manually. Meta-analysis is a labor intensive activity that can sometimes take years depending on the topic under investigation and the amount of literature that is available.

One pitfall in meta-analysis is the inclusion of blemished studies; a good meta-analysis of bad studies will result in bad statistics. The meta-analyst is limited by the quality of research in the available studies and often there is not enough information reported in a study to determine if the statistics are correctly computed. There is need for a balance between inclusion and exclusion of studies to maintain a quality analysis. The meta-analyst is aided in limiting the inclusion of blemished studies in the synthesis by a well-defined study criterion, while also being advised to err in the direction of being broadly inclusive in research procedures in order to insure that a sufficient sample of studies is located (Reis and Judd, 2000).

Another shortcoming is that there is a large publication bias towards significant results. Non-significant findings are not often published or documented. This is often described as the *file drawer problem*; i.e., there exists a file drawer in the back of a researcher's office that is overflowing with studies on the topic in question with non-significant findings (Rosenthal, 1979). There must be a significant effort made to locate this fugitive literature in order to increase the confidence in the effect size results.

Variations among Sleep Deprivation Studies

Many differences exist between studies in the sleep deprivation literature, for example, the type of subjects used and study setting. Since the type of task used to evaluate performance is not standardized, it also can differ from study to study.

Subject Variability

Subjects differ from study to study in terms of age, sex, and physical characteristics (e.g., BMI). Older subjects have been shown to be more affected by sleep deprivation in comparison to younger subjects (Lingenfelser et al., 1994**;** Steyvers and Gaillard, 1993; Webb, 1985). Most studies seem to have more male than female participants (Thomas et al., 2000). Differences between male and female subject performances are not known. Some studies select appropriate subjects considering physical characteristics including body mass index (BMI) or the presence of preexisting sleep disorders (e.g., sleep apnea), while other studies make no mention of the personal traits of the subjects. Another difference is the origination or background of the subjects prior to the tests (i.e., education, career type, etc.). The majority of studies are conducted in the laboratory, and often, the subjects are student volunteers (Babkoff et al., 2005). However, some studies employ subjects from industry, such as medical residents (Saxena and George, 2005).

Experimental Design

The differences in experimental design complicate the study of sleep deprivation effects on performance. Differences in experimental design include study environment, control of time cues, physical activity level, and tasks performed.

The physical settings for the experiments differ in that some studies are conducted in the field, but most are conducted in laboratory settings. Field experiments have been reported in military training sessions (May and Kline, 1987; Kobbeltvedt et al., 2005) or on doctors after being on-call for long periods of time (Saxena and George, 2005). Studies conducted in the lab are easier to control by limiting the number of influences of parameters outside the study. Other study setting differences relate to the control of time cues (zeitgebers) and the physical activity level of the subjects (Aschoff, 1965).

The control of zeitgebers is also different among studies; sometimes it is not reported at all. For example, in Frey et al. (2004) subjects are removed from all time cues (e.g., light level, temperature, and constant white noise). In Wesensten et al. (2005) all time cues are kept constant. In Jones et al. (2006) and Roach et al. (2006), subjects are not allowed access to caffeine to mitigate the effects of sleep deprivation, but have free access to time cues.

Another difference in the procedure of sleep deprivation testing is the amount of activity allowed the subjects. In some of the experiments, the subjects are subjected to constant bed rest allowing for no activity while being kept awake (Caldwell et al., 2003; Frey et al., 2004). Meanwhile, in others, subjects are asked to engage in light activity such as TV, video and board games, and reading (Jones et al., 2006; Roach et al., 2006). Yet, other studies engage the subjects in heavy activity such as military training (Lieberman et al., 2005; Kobbeltvedt et al., 2005). Some studies report no information on subject activity levels at all (Thorne et al., 2005).

Not only are the settings and procedures for the experiments different, the types of tests that are used to evaluate performance may vary. There is no standard metric used to evaluate performance; studies may use single metric or multiple metrics. Typical performance evaluators could be subjective, physical, or psycho-motor. Subjective measures, such as sleepiness scales, are more appropriate for sleepiness and fatigue studies. Physical measures, such as temperature, electroencephalography (EEG), or critical flicker frequency threshold, are better measures of arousal or alertness and are very useful when investigating circadian influences (Czeisler et al. 1999). However, the focus in this research is how sleep deprivation affects performance; consequently, psychomotor tests are more appropriate. Psychomotor tests are based on mental processes (cognition) that require a motor reaction (Kushida et al., 2005).

Currently, there are no definitive psychomotor tests for evaluating sleep deprivation effects on performance. Some studies use simulated real world tasks, such as simulated combat (Lieberman et al., 2005), laparoscopic surgery (Eastridge et al., 2003), or driving simulator (Akerstedt et al., 2005; Langois et al., 1985). Other studies employ real work activities or games (Venkatraman et al., 2007; Killgore et al., 2006). However, most studies use simplified tasks that can be somewhat controlled. Three frequently employed tests are the Logical Reasoning Task (Baddeley, 1968), Mackworth Vigilance Task (Mackworth, 1950), and Psychomotor Vigilance Task - PVT (Dinges and Powell, 1985), with the PVT being the most frequently used (Gunzelmann et al., 2009). Each type of test used is briefly described in the following discussion.

Baddeley Logical Reasoning Task

The logical reasoning task (Baddeley, 1968) is a three-minute test that measures and emphasizes both speed and accuracy. The subject is presented with a series of short sentences that employ different syntax structures that claim to describe the order between two letters, such as *AB*. This test uses sentence comprehension as it is related to syntax structure. For example, sentence understanding is faster for: a positive statement than a negative one, an active faster than passive sentence, and a true sentence faster than a false sentence. The subjects read the sentences that describe the 2-letter order and are asked to identify the statements as true or false. For illustration of the task, the two letters *A* and *B* are used in *AB* order. The following four sentences are all true. The first is an example of a positive statement and an active sentence. The third sentence is an example of a negative statement and a passive sentence.

1) *A* precedes *B*.
2) *B* follows *A*.
3) *A* does not follow *B*.
4) *B* does not come before *A*.

Normally this task uses sixty-four possible combinations of six different conditions; 1) positive or negative, 2) active or passive, 3) true or false, 4) precedes or follows, 5) whether *A* or *B* is mentioned first, and 6) either the *AB* or *BA* combination. Nine studies out of the 108 utilized in the current study employ the Baddeley logical reasoning task (Rosa and Colligan, 1988; Deaconson et al., 1988; Englund et al., 1985, Haslam, 1982; Poulton et al., 1978; Rosa and Bonnet, 1993; Leonard et al., 1998; Lieberman et al., 2005; Webb, 1985).

Mackworth Clock Vigilance Task

In the Mackworth clock vigilance task (Mackworth, 1950) subjects view a circular display similar to a clock face. A pointer moves around the clock face at a steady rate. The subject is asked to react (i.e., press a button) when the pointer double jumps or skips over a point along the circle. This is a type of tracking task. The number of correct responses, false positives, and reaction time are recorded. Studies using the Mackworth clock vigilance task included Richter et al., (2005), Monk et al., (1997), and Williamson and Feyer, (2000).

Psychomotor Vigilance Task

The PVT is a standardized task that uses a computer or hand-held device (Dinges and Powell, 1985). The test is based on the Wilkinson simple visual reaction time device (Wilkinson and Houghton, 1982). The PVT was developed as a neurocognitive test for tracking to access the working memory of the prefrontal cortex of the brain; it is used to measure the magnitude of attention deficits. Performance on working memory tasks is observed to be predictive of performance on a range of other cognitive tasks (Kushida et al., 2005). Working memory is considered to be fundamental to performance on virtually any neurocognitive task. The PVT has a high level of reliability, validity, lack of dependence on aptitude, and the ability to be repeatedly administered; this makes it useful for quantifying the effects of sleep loss.

The generally ten-minute long test has been found to have no practice effect or minimal learning effects after one to three practice trials and has been validated (Kushida et al., 2005). Currently the test is often administered on a PDA device (e.g., Palm); previously, the test was administered on a personal computer. The stimulus is the onset of a four-digit millisecond clock, visually displayed in a window near a built-in response button. Pressing the button stops the tone and the clock display and provides the reaction time measurement. The subject is permitted 1.5 seconds to read the value. The inter-stimulus interval on the task typically varies randomly from 1 to 10 seconds. This provides for approximately 90 responses per trial period over ten minutes. The PVT is designed as a performance measure that generates the performance parameters of number of lapses, reaction time, and accuracy. Studies that used the PVT are listed in Table 8. The PVT provides meaningful outcome variables (reaction time, accuracy, and number of lapses) that provide an index of the degree of functional impairment from sleep deprivation.

Table 8: Studies Using the PVT

Belenky et al., 2003	Powell et al., 2001
Caldwell et al., 2003	Rajaraman et al., 2007
Doran et al., 2001	Roach et al., 2006
Drake et al., 2001	Saxena and George, 2005
Drummond et al., 2006	Swann et al., 2006
Frey et al., 2004	Thorne et al., 2005
Jewett et al., 1999	Van Dongen et al., 2003
Jones et al., 2006	Wesensten et al., 2005
Lamond et al., 2007	Wilson et al., 2007

The majority of the experiments are conducted in laboratory settings, where more control can be used in excluding confounding factors. Therefore, tests are not being conducted in realistic workplace settings and often use simplified tasks. This, in turn, makes extrapolation of the results to real-world settings difficult and potentially inaccurate. In addition, the tasks employed during laboratory tests are frequently isolated, primary tasks, instead of being representative complex tasks faced in most jobs today. The subject variability and differences in experimental design make direct comparison between studies difficult.

The study differences of the sleep deprivation literature are coded through a meta-analysis procedure. The change in performance due to sleep deprivation is the variable under investigation. The differences between the studies in the sleep deprivation literature are coded to look for causal relationships between the effect size and the study design. This information may or may not be useful in evaluating the data. The type of task used to evaluate performance can vary greatly between studies. It is important to take note of the type of task used and the performance metrics evaluated through the task. The data in this research are grouped by the performance metric reported (i.e., reaction time, accuracy, and number of lapses). The data can be further divided by variables that show some type of causal relationship, for example, task complexity level or the experimental design. The study differences coded may also be useful for use in extrapolating findings.

CHAPTER IV

RESEARCH METHODOLOGY

This chapter discusses the methodology used for data collection, data analysis, and derivation of performance shaping factor coefficients. An initial search for sleep deprivation studies evaluating performance was conducted. Data were identified through reviewing journals for sleep deprivation studies from the search strategy. The selection criteria were established and a group of 108 studies was identified. The statistical data, study descriptors, and experimental conditions were coded. The data collected from the identified studies were analyzed by looking at the difference between the mean values, percentage change, effect size, and reliability index. Performance shaping factor coefficient values were derived from the collected statistical data. The uncertainty associated with the performance shaping factor coefficients and inter-rater reliability for the coding was also calculated.

Data Collection

The data used for analysis were gathered through a meta-analysis approach. Data collection involved defining a search strategy and establishing study criteria; these criteria helped to limit or define the *universe* from which the studies were drawn. Studies that were considered included published research studies on sleep deprivation and its effect on performance, in a pretest-posttest design. A pretest and posttest experimental design compares the performance before treatment (i.e., pretest) to the performance after treatment (i.e., posttest).

The initial search strategy used computerized databases, (e.g., PubMed, Cochran, MEDLINE, PsycINFO, and PsychLit) to locate relevant publications. Search terms included fatigue, performance, sleep deprivation, shiftwork, reaction time, and accuracy. The bibliographies of these papers were then used to find more possible studies in a citation or descendent search. Authors that were found to frequently publish in the sleep deprivation field were reviewed to find more studies in an ancestry search approach. Journals, such as *Sleep* and *Journal of Sleep Research*, were searched manually for studies on the topic after locating a study from the previous search methods.

The first sampling of studies included those that evaluated the effect of sleep deprivation or fatigue on performance; these were primarily conducted in the areas of military, medical, transportation, and psychology. The first requirement was that the study was reported in English, due to the limitations of the researcher, and that all subjects be adults. Studies conducted after the 1940's were considered, since this is the time frame for modern studies conducted after WWII, when technology became a part of everyday work.

The quality of the studies was subjectively determined and relied on the peer review process of journal publications and the reputations of the journals used. One way to judge the suitability of the journals was to use the impact factor of the journal. The impact factor can be used as a metric for a journal's reputation, using the average number of citations to articles published in science and social science journals. The impact factors are calculated yearly and are part of Reuters. The top three journal impact factors are *New England Journal of Medicine* (52.6), *Lancet* (28.6), and *Journal of the American Medical Association (JAMA)* (25.6). However, the editor and chief of *JAMA*, Dr. Catherine DeAngelis, said that the impact factor is, "the easiest manipulated number in the world (Omanio, 2009). Since sleep research is a small subspace of science and social science, the journals that have impact factors will not be large and many quality journals in the field may not have an impact factor at all. Consequently, the impact factor was not considered as a definitive level of quality, but was used to aid in the subjective evaluation of journal suitability. The journals listed in Appendix C are those mentioned by the European sleep research society as pertaining to sleep research. The journals are listed in order of impact factor.

The studies selected for further review expressed the effect of sleep deprivation (i.e., the independent variable) on performance through reaction time, accuracy, and or number of lapses (i.e., the dependent variable). The studies used were collected from multiple disciplines and journals. These journals included, but were not limited to: *Journal of Sleep Research* (Nilsson et al., 2005; Thomas et al., 2000), *Sleep* (Mitler et al., 1988; Jewett et al., 1999) *Journal of Neuroscience* (Chee and Choo, 2004), *Behavior Research Methods, Instruments, & Computers* (Angus et al., 1985; Thorne et al., 2005), *Chronobiology* (Langlois et al., 1985), *Ergonomics* (Rosa and Bonnet, 1993), *Human Factors* (Wilkinson and Houghton, 1982), *Journal of the American Medical Association* (*JAMA)* (Deaconson et al., 1988), *Psychophysiology* (Drake and Roehrs, 2001), *NeuroImage* (Choo et al., 2005), *Occupational Environmental Medicine* (Williamson and Feyer, 2000), and *Organizational Behavior and Human Decision Processes* (Kobbeltvedt et al., 2005).

The data collection is limited by the quality of research reported and often there is not enough information disclosed about a study in a journal publication to determine if statistics are correctly computed. There is need for a balance between inclusion and exclusion of studies in order to maintain a quality analysis and also ensure a sufficient sample size of studies (Reis and Judd, 2000). Another limitation is the large publication bias towards significant results. Commonly non-significant findings are not published or documented (Rosenthal, 1979).

Coding Applications

The studies located from the search strategy were identified in a variety of fields. Viable studies were identified by evaluating whether or not the studies examined a change in performance due to sleep deprivation. A list of 108 studies was identified as meeting the initial criteria. Information was extracted, coded, and then grouped by experimental conditions, task characteristics, and statistical data.

Data Resources

The identification of sleep deprivation as a significant source of risk has led to sleep deprivation studies being conducted in a variety of fields and settings. The majority of data for use in this research comes from psychological experiments; many of which have been conducted under the guidance of industries such as transportation [long haul driving (Akerstedt et al., 2005), aviation (Wilson et al., 2007), railroad (Hildebrandt et al., 1974)], medical (Deaconson et al., 1988), and military (Haslam, 1982). A search of online resources and leading literature led to the discovery of studies focused on sleep deprivation and its effects on human performance. While a vast number of studies were identified, difficulties arose in utilizing much of the data presented in these studies for HRA applications due to format, content, and reporting differences.

A method for collection and synthesis of the data reported in these studies is needed. The data within the studies were reported in different ways and were found in graphs, tables, and/or within the text. Each study identified was reviewed and available data for synthesis and analysis were extracted. For example, if a study reported a change in a performance variable on a task over an increase in the hours of wakefulness of the subject, the mean values and variance of the initial and ending performance and the hours of wakefulness could be extracted.

Study Selection

Originally, 600 studies (Appendix G) were considered to be viable options that focused on sleep deprivation and its effect on performance (i.e., preliminary selection criteria). The list was reduced by excluding studies that did not report continuous hours of wakefulness (acute sleep deprivation) as the independent variable and one or more of the dependent variables (reaction time, accuracy, and number of lapses) or the data were not reported in a usable format (i.e., secondary selection criteria). For example, subjective ratings on sleepiness or fatigue were reported by Minors and Waterhouse (1987) and only time of day was reported by Mitler et al. (1988). Therefore, these studies were excluded from the original sample. The resulting 108 studies are listed in Table 9.

The studies are listed by study identification number and primary author_year of publication.

Table 9: List of 108 Studies

Study Id #	Reference	Study Id #	Reference	Study Id #	Reference
1	Nilsson_2005	37	Lenne_1997	73	Nag_1998
2	Thomas_2000	38	Sallinen_2004	74	MacDonald_1997
3	Choo_2005	39	Akerstedt_2005	75	Tilley_1982
4	Chee_2004	40	Boksem_2006	76	Rosa_1993
5	Williamson_2000	41	Monk_1997	77	Langois_1985
6	Kobbeltvedt_2005	42	Jones_2006	78	Akerstedt_1977
7	Robbins_1990	43	Hull_2003	79	Richter_2005
8	Angus_1985	44	Wright_2006	80	Hildebrandt_1974
9	Babkoff_2005	45	Halbach_2003	81	Donchin_1995
10	Swann_2006	46	Bliese_2006	82	Oginski_2000
11	Koslowsky_1992	47	Lamond_2007	83	Taffinder_1998
12	Pilcher_1996	48	Drummond_2006	84	Smith_1994
13	Belenky_2003	49	Eastridge_2003	85	Froberg_1977
14	Buck_1972	50	Engle-Friedman_2003	86	Philip_2004
15	Killgore_2006	51	Caldwell_2003	87	Powell_2001
16	Marmuff_2005	52	Rosa_1983	88	Fiorica_1968
17	Yoo_2007	53	Frey_2004	89	Cutler_1979
18	Babkoff_1985	54	Glenville_1979	90	Sharp_1988
19	Williams_1967	55	Webb_1982	91	Steyvers_1993
20	Williams_1959	56	Poulton_1978	92	Elkin_1974
21	Wilson_2007	57	Englund_1985	93	Webb_1986
22	Gundel_2007	58	Saxena_2005	94	Haslam_1983
23	Webb_1985	59	Richardson_1996	95	Sagaspe_2006
24	Dinges_1997	60	Christensen_1977	96	Scott_2006
25	Sanders_1982	61	Rosa_1988	97	Venkatraman_2007
26	Collins_1977	62	Hart_1987	98	Dinges_1988
27	Porcu_1998	63	Horne_1983	99	May_1987
28	Wojtczak_1978	64	Hoddes_1973	100	Lieberman_2005
29	Dorrian_2007	65	Webb_1984	101	Lamond_1999
30	Maury_1993	66	Haslam_1982	102	Thorne_2005
31	Borland_1986	67	Binks_1999	103	Doran_2001
32	Dawson_1997	68	Deaconson_1988	104	Wesenten_2005
33	Roach_2006	69	Leonard_1998	105	Jewett_1999
34	Reznick_1987	70	Storer_1989	106	Drake_2001
35	Daniel_1989	71	Lichtor_1989	107	Van Dongen_2003
36	Buck_1975	72	Linde_1999	108	Rajaraman_2007

A number of the viable studies among the 108 studies (Table 9) were not used in the final analysis due to one or more of the reasons below:

1) Reported chronic sleep deprivation, not acute (e.g., Study Id # = 7, 13, 46, 58, 68, 75, 76, 79, 90)
2) Did not report hours of wakefulness (e.g., Study Id # = 83)
3) Did not report control and test conditions (e.g., Study Id # = 41, 44, 78)
4) Reported incidents related to time of day and not hours of wakefulness (e.g., Study Id # = 73, 74, 77, 80, 81, 82, 84, 86).

Some studies were used only in a limited basis when they did not report standard deviation information (or standard error), but reported hours of wakefulness and test and control conditions. When no baseline (control condition) was given, but test conditions were reported for incremental times, the value at approximately 8 hours was used as the control condition. The studies were further segregated based upon the variables reported (reaction time, accuracy, and number of lapses). Some studies reported multiple variables and others only reported single variables.

Coding of Study Information

The information coded for each study was broken up into four main sections: 1) study descriptors, 2) sample descriptors, 3) experimental conditions and task information, and 4) effect size information. If a qualifier of the study could not be determined, it was coded as *not available* or *NA*.

Study Descriptors

The first step was to establish a method to identify each study. Each was assigned an identification number in numeric succession as the study was identified along with the last name of the principal author and the year of publication, in the format of *last name of first author_year*. Next, the information of the study context was coded; this information covered the type of publication (i.e., book, journal article, thesis or dissertation, technical report, conference paper, other, and indiscernible), the discipline that conducted the study (i.e., academic, medical, military, transportation, psychology, other, or indiscernible), whether the study was conducted in the field or a laboratory setting, and the country in which the study was conducted. This information is represented in Table 10.

Sample Descriptors

The next component coded from each study pertained to the description of the subjects. Origin of the subjects (i.e., student volunteer, shift workers, medical residents, nurses, and infantry soldiers) was recorded. Next recorded was the sex of the group (as percentage male) [i.e., all males (>95%), mostly males (>60%), 50% to 60% male, some males (<50%), and no males (0%)]. The age of the subjects was noted; this information was usually given as a mean or a range. Additional information on the subjects was necessary to identify whether subjects had special motivation or incentives; for example, if the subject was paid for the number correct in performing a task. This would have put a bias toward accuracy over reaction time. This information is represented in Table 10.

Table 10: Study and Sample Descriptors

Study Identifiers	Study Id #	
	1st Author_Publication Year	
Study Descriptors	Type of Publication	Journal
		Book
		Book section
		Thesis or dissertation
		Technical report
		Conference proceeding
		Government document
		Other
		Not available
	Industry or Discipline	Medical
		Military
		Transportation
		Academic
		Other
	Environment	Lab
		Field
	Country	
Sample Descriptors	From Where Subjects Pulled	Student volunteers
		Shift workers
		Medical residents
		Soldiers
		Not available
		Other
	Sex of Group	All males (>95%),
		Mostly males (>60%)
		50 to 60% males
		Some males (<50%),
		No males (<5%),
		Not available
	Mean Age of Subjects	
	Notes of Interest on Organization	

Experimental Conditions

Information collected pertaining to the experimental conditions was identified and coded. The experimental condition information included the type of comparison method used for the pretest-posttest design, either repeated measures (denoted as RM) or two group comparison (denoted as 2GC). The next category was the type of experiment blinding (i.e., single blind subject is not informed of experiment goals or double-blind the data collector and subject are not informed of experiment goals). Often this information was not available. Experimental blinding helps to prevent unconscious or conscious bias by the participants.

Next, the assignment of the subjects to the test and control condition was identified, including whether the experiment was counterbalanced, randomized, or if it could not be determined from the study (not available). Counterbalancing is when the subjects are divided and part of the subjects were exposed to the control condition, then the test condition, while the rest of the subjects were subjected to the test condition, then the control condition. Counterbalancing was done to eliminate the experimental confound of presentation order and biased results that might have occurred if information gained from the first condition improved the performance in the second condition. This is more commonly associated with a two-group comparison than with a repeated measures comparison method. If the order in which subjects were assigned to either the test or control condition was done by chance, it was considered randomized (for two group comparisons). The information collected under *experimental condition* is summarized in Table 11.

Table 11: Experimental Conditions

Experimental Condition	Comparison Method	Repeated measures (RM)
		Two group comparison (2GC)
	Experiment Blinding	Subjects blind to goals
		Subjects told of goals/practice session
		Data collector blind to goal
		Not available
	Assignment of Subjects	Counterbalanced
		Random assignment of participants to groups
		Repeated measures (RM)
		Not available

Task Characteristics

Another group of study descriptors recorded were the characteristics of the task. These included a description of the task, whether the task was self-paced or if the pace was externally set (work pace). Additionally, whether the task was the only task (primary) or if two tasks were performed at the same time (secondary) was recorded whenever the data were available. The complexity level of the task was noted whenever possible (e.g., simple or complex). Whether or not multiple performance metrics were measured at the same time was also noted (i.e., if reaction time and accuracy were recorded at the same time). The novelty of the task that subjects were asked to perform was also indicated; either one designed specifically for the experiment or a predefined task (e.g., PVT) was used. The name of the pre-defined task was used as the task description. The length of the task was recorded when the information was available (e.g., 10 minute PVT). Information on how the task was administered (e.g., use of pen and paper or computer) and the number of times the task was administered (e.g., 20 times over the test session) were recorded when available. This information is represented in Table 12.

Table 12: Characteristics of the Task

<table>
<tr><td rowspan="22">Characteristics of Task</td><td colspan="2">Description of Task</td></tr>
<tr><td rowspan="3">Pace (Work or Self)</td><td>Work paced</td></tr>
<tr><td>Self paced</td></tr>
<tr><td>Not available</td></tr>
<tr><td rowspan="3">Primary or Secondary Task</td><td>Primary</td></tr>
<tr><td>Secondary</td></tr>
<tr><td>Not available</td></tr>
<tr><td rowspan="3">Complexity of Task</td><td>Complex</td></tr>
<tr><td>Simple</td></tr>
<tr><td>Not available</td></tr>
<tr><td rowspan="4">Multiple Measures</td><td>Speed and accuracy</td></tr>
<tr><td>Speed and lapses</td></tr>
<tr><td>Accuracy and lapses</td></tr>
<tr><td>Speed, accuracy, lapses</td></tr>
<tr><td rowspan="2">Predefined Task</td><td>Predefined task</td></tr>
<tr><td>Novel task</td></tr>
<tr><td colspan="2">Type of Task</td></tr>
<tr><td colspan="2">Length of Test</td></tr>
<tr><td rowspan="5">Task Administration</td><td>Pen and paper</td></tr>
<tr><td>Computer</td></tr>
<tr><td>Handheld</td></tr>
<tr><td>Other</td></tr>
<tr><td></td><td>Not available</td></tr>
<tr><td></td><td colspan="2"># of times the test was administered</td></tr>
</table>

Statistical Data

The same study identification was assigned for use with the statistical data collection. The page number of the publication that the statistical data originated from and the type of pretest-posttest comparison, either repeated measures (denoted as RM) or two group comparisons (denoted as 2GC), were recorded. The hours of sleep deprivation, or the hours of wakefulness, incurred at the data collection point, were recorded. And whenever possible, the time of day correlating to the hours of wakefulness was recorded. One of the three performance variables (reaction time, accuracy, and number of lapses) to which data collected pertained was selected and coded. If reaction time was the metric reported, the units in which the data were reported were noted (e.g., seconds, milliseconds, or reciprocal of reaction time). How the data were presented in the original study, either in the text, a table, or graphically was also noted. There will be greater reliability in the data when presented in text or tables rather than when interpretation of a graph is required to gather the data.

The statistical data needed to calculate the effect size (ES) were coded. The sample size of pretest (control) and posttest (test) group and whether or not the number initially assigned was the same number observed were recorded. If some subjects were excluded or did not complete the experiment, the number of subjects completing the study decreased. In repeated measure (RM) studies, the sample size was the same for the control and test groups, since the same subjects were used as both the control and the test. The mean value of the variable at the control and test condition (e.g., reaction time at baseline and reaction time after sleep deprivation) and the standard deviation or standard error were recorded. If the mean information was not reported, effect sizes can also be computed through other descriptive statistics, such as proportions and frequencies (e.g., number of outcomes). An effect size was computed from significant test statistics if adequate descriptive statistics were not available; in these cases the Independent-*t*, dependent-*t*, *F*-value from one-way ANOVA, or χ^2 (Chi-squared) was recorded. This information is represented in Table 13.

Table 13: Statistical Data

Sample Size (N)	Control Condition	Assigned N
		Observed N
	Test Condition	Assigned N
		Observed N
Type of Statistical Information	Mean Value	Control
		Test
	Standard Deviation	Control
		Test
	Standard Error	Control
		Test
	Proportion Successful	Control
		Test
	# Successful Outcomes	Control
		Test
	Independent *t* -value	
	Dependent *t* -value	
	F -value (df=1)	
	χ2 (df=1)	
	Other	

Data Collected

A sample of the actual coding for the first ten studies is given in the following Tables (14-16). An example of study identifiers and study context is given in Table 14, sample descriptors and experimental conditions are given in Table 15, and characteristics of the task are given in Table 16.

Table 14: Coding Example of Study Identifiers and Study Context Data

Study Identifiers			Study Context			
Study Id #	1st Author_year	Publication year	Type of publication	Industry	Environment	Country
1	Nilsson_2005	2005	Journal	Academic	Lab	Sweden
2	Thomas_2000	2000	Journal	Academic/Medical	Lab	US
3	Choo_2005	2005	Journal	Academic/Medical	Lab	Japan
4	Chee_2004	2004	Journal	Academic/Medical	Lab	Japan
5	Williamson_2000	2000	Journal	Transportation	Lab	Australia
6	Kobbeltvedt_2005	2005	Journal	Military	Field	Norway
7	Robbins_1990	1990	Journal	Medical	Field	US
8	Angus_1985	1985	Journal	Academic	Lab	Canada
9	Babkoff_2005	2005	Journal	Academic	Lab	Israel
10	Swann_2006	2006	Journal	Academic	Lab	Australia

An example of the coding for study context for the first ten studies is given in Table 14; they were all taken from journals and were published between 1985 and 2006. The studies were conducted by various industries and in academia [(Academia #1-Nilsson_2005, #8-Angus_1985, #9-Babkoff_2005, and #10-Swann_2006), medical (#2-Thomas_2000, #3-Choo_2005, #4-Chee_2004, and #7-Robbins_1990) military (#6-Kobbeltvedt_2005), and transportation (#5-Williamson_2000)]. The majority of the studies were conducted in a laboratory setting; however, #6-Kobbelvedt_2005 and #7-Robbins_1990 were conducted in the field. The studies were conducted in various countries: Australia, Canada, Japan, Norway, Sweden, and the United States.

Table 15: Sample Descriptors and Experimental Condition Coding Example

Sample Descriptors			Experimental Condition		
Study Id #	Sex of Group	Mean Age	Comparison Method	Experiment Blinding	Assignment of Subjects
1	NA	27.6	2GC	practice session	random & matched on sex & age
2	>95% male	24.7	RM	not available	not available
3	50-95% male	21.8	RM	not available	counterbalanced
4	50-95% male	23	RM	practice session	counterbalanced
5	>95% male	35.6	RM	practice session	counterbalanced
6	>95% male	23	2GC	not available	random
7	NA	NA	RM	not available	not available
8	<5% male	21.5	RM	subjects told of goals	not available
9	< 50% male	23.8	RM	practice session	counterbalanced
10	50-95% male	24.5	RM	subjects told of goals	counterbalanced

Table 15 is an example of the actual coding of the sample descriptors and experimental conditions for the first ten studies. The sex of the subjects (% male) could not be found for two studies #1-Nilsson_2005 and #7-Robbins_1990. The subjects were all female in #8-Angus_1985, and the only other study with less than 50% male was #9-Babkoff_2005. The mean age of the subjects was not given in #7-Robbins_1990; the mean age for the other studies ranged from 21.5 to 35.6 years. The majority of the studies were repeated measures (RM) designs; #1-Nilsson_2005 and #6-Kobbeltvedt_2005 were two group comparisons designs. One study assigned subjects randomly matched by sex and age (#1-Nilsson_2005).

Table 16: Task Characteristics Coding Example

Characteristics of Task								
Study Id #	Description of task	Pace (work or self)	Primary or secondary	Complexity of task	Multiple measures	Predefined or novel	Task duration	Length of test
1	SRT & working mem	work	primary	varied	not available	predefined	36-40 min	not available
2	SRT	work	primary	simple	yes RT & A	predefined	not available	not available
3	Letter matching	work	primary	complex	not available	novel	not available	not available
4	Working memory	work	primary	complex	not available	novel	not available	not available
5	Mackworth, SRT	work	both	simple	not available	predefined	not available	not available
6	Military tatical task	work	primary	complex	not available	novel	not available	not available
7	4 different tasks	work	primary	varied	yes RT & A	predefined	30-40min	not available
8	Logical reasoning	self	primary	complex	not available	predefined	not available	6 hours
9	Temporal order judgment	not available	primary	complex	yes RT & A	predefined	25-30 min	70 min
10	PVT	work	primary	simple	yes RT & A	predefined	10min	not available

The coding of the characteristics of the task used in the first ten studies is shown in Table 16. Simple reaction time tasks were used in #1-Nilsson_2005; #2-Thomas_2000; and #5-Williamson_2000. The PVT was used in #10-Swann_2006 and the Mackworth Clock was used in #5-Williamson_2000. The task tested working memory in #1-Nilsson_2005; #3-Choo_2005; and #4-Chee_2004. A novel military task was used in #6-Kobbeltvedt_2005. A logical reasoning task was used in #8-Angus_1985 and a temporal order judgment task was used in #9-Babkoff_2005. The tasks were self-paced in #8-Angus_1985, and the pace of the task was not given in #9-Babkoff_2005; the other studies were all work paced. Only studies #2-Thomas_2000 and #5-Williamson_2000 had the subject engaged in multiple tasks at the same time; all others were the primary task. Complex tasks were used in: #3-Choo_2005; #4-Chee_2004; #6-Kobbeltvedt_2005; #8-Angus_1985; #9-Babkoff_2005. Simple tasks were used in: #2-Thomas_2000; #5-Williamson_2000; #10-Swann_2006. A combination of simple and complex tasks was used in #1-Nilsson_2005 and #7-Robbins_1990. The default *not available* (NA) was used several times due to lack of information given in the original study. Four studies recorded reaction time and accuracy simultaneously (#2-Thomas_2000; #7-Robbins_1990; #9-Babkoff_2005; and #10-Swann_2006); the other studies did not provide this information (*not available*). The length of task and testing duration was also not often reported.

The statistical data for the first four studies are given as an example in Table 17 and Table 18. The collected statistical data for all the studies are listed in Appendix E. The first study (#1-Nilsson_2005) uses a two-group comparison (2GC) study design, while the other three use a repeated measures (RM) design. The effect size number is assigned for multiple data points from the same study; for example, in #3-Choo_2005, eight different data points were collected over two different dependent variables (reaction time and accuracy). The data collected for the first study occurred after the subjects were awake for thirty-one and a half hours. The other three studies reported changes in performance at approximately twenty-four hours of wakefulness. In Table 18 the mean values for the control (pretest) and test (posttest) condition for the first four studies are shown. The standard error information was given in the first four studies since the standard deviation information was available.

Table 17: Statistical Data

Study Id #	1st Author_year	Effect Size #	Page #	Type of Comparison	Hours of Sleep Deprivation	Time of Measure	Performance Variable
1	Nilsson_2005	1.1	2	2GC	31.5	NA	Reaction Time
2	Thomas_2000	2.1	346	RM	24	NA	Reaction Time
2	Thomas_2000	2.2	346	RM	24	NA	Accuracy
3	Choo_2005	3.1	581	RM	24.4	NA	Reaction Time
3	Choo_2005	3.2	581	RM	24.4	NA	Reaction Time
3	Choo_2005	3.3	581	RM	24.4	NA	Reaction Time
3	Choo_2005	3.4	581	RM	24.4	NA	Reaction Time
3	Choo_2005	3.5	581	RM	24.4	NA	Accuracy
3	Choo_2005	3.6	581	RM	24.4	NA	Accuracy
3	Choo_2005	3.7	581	RM	24.4	NA	Accuracy
3	Choo_2005	3.8	581	RM	24.4	NA	Accuracy
4	Chee_2004	4.1	4561	RM	24	NA	Reaction Time
4	Chee_2004	4.2	4561	RM	24	NA	Reaction Time
4	Chee_2004	4.3	4561	RM	24	NA	Reaction Time
4	Chee_2004	4.4	4561	RM	24	NA	Accuracy
4	Chee_2004	4.5	4561	RM	24	NA	Accuracy

Table 18: Statistical Data Continued from Table 17

Study Id #	Primary author_year	Effect Size Id #	N				Statistical Data					
			Control		Test		Mean		Standard Dev.		Standard Error	
			Assigned	Observed	Assigned	Observed	Control	Test	Control	Test	Control	Test
1	Nilsson_2005	1.1	NA	11	NA	11	225	265	43.44	62.35	-	-
2	Thomas_2000	2.1	NA	17	NA	17	71	61.4	27.2	24.6	-	-
2	Thomas_2000	2.2	NA	17	NA	17	95.5	92.3	5.2	6.4	-	-
3	Choo_2005	3.1	14	12	NA	12	552	668	149	182	-	-
3	Choo_2005	3.2	14	12	NA	12	588	746	162	271	-	-
3	Choo_2005	3.3	14	12	NA	12	617	718	233	245	-	-
3	Choo_2005	3.4	14	12	NA	12	585.67	710.7	181.33	232.7	-	-
3	Choo_2005	3.5	14	12	NA	12	0.988	0.941	0.013	0.05	-	-
3	Choo_2005	3.6	14	12	NA	12	0.968	0.927	0.05	0.074	-	-
3	Choo_2005	3.7	14	12	NA	12	0.943	0.911	0.052	0.086	-	-
3	Choo_2005	3.8	14	12	NA	12	0.966	0.926	0.038	0.07	-	-
4	Chee_2004	4.1	NA	13	NA	13	825	883	80	110	-	-
4	Chee_2004	4.2	NA	13	NA	13	786	860	119	144	-	-
4	Chee_2004	4.3	NA	13	NA	13	378	394	58	82	-	-
4	Chee_2004	4.4	NA	13	NA	13	0.959	0.902	0.049	0.097	-	-
4	Chee_2004	4.5	NA	13	NA	13	0.957	0.926	0.055	0.086	-	-

The information collected from the studies was divided into two main groups, the study descriptors (i.e., study setup) and empirical results. Table 19 provides a listing of desired data for collection. Not all considered studies met these requirements. The data collected from the various studies used in the current research were derived from tables and graphs within each study. The hours of wakefulness, performance variable, and the difference between the test and control conditions were considered necessary for analysis. In some studies, the variation information was reported as standard error (SE) and had to be converted to standard deviation (σ) using the sample size (N) for the study (Equation 14);

$$\boldsymbol{\sigma = SE * \sqrt{N}} \ . \qquad \textbf{(14)}$$

Table 19: Desired Data for Collection

Definition of Sleep Deprivation	Type of Sleep Deprivation	Acute
		Chronic
Experimental Design	Study Setting	Lab/Field
		Environment (e.g. Zeitgebers)
		Physical Activity Level
	Subject Differences	Age Range
		Sex
		Personal Characteristics
		Type of Subjects (e.g. student volunteers)
	Type of Task	Subjective, Objective, or Psychomotor
		Simulated Real-world
		Real-work
	Task Details	Complexity Level (e.g. simplified task)
Empirical Data Collection	Hours of Wakefulness	
	Performance Variable	Reaction Time
		Accuracy
		Lapse
	Mean of Test and Control Condition	
	Standard Deviation	

Data Analysis

The previous section detailed the information that was collected. The current section details the analysis method used to examine what information or trends can be found from the collected data. This section includes a description of what data were analyzed and by what means. The difference between the means, percentage change, and effect size were calculated as a method to analyze the data. Also, a method to derive PSF coefficient values from the data was developed.

Data Analyzed

The data were first segmented by the variable type (i.e., lapse, accuracy, and reaction time). The accuracy data were further divided by the type of accuracy reported, such as the number of false positives (false +), number correct (# correct), percentage correct (% correct), number of errors (# errors), and the percentage of errors (% errors). The data needed to calculate the difference between the mean values, effect sizes, and the reliability indexes (β) are listed in Table 20. The data required are the mean values of the test and control condition, the standard deviations or standard error of the test and control condition, and the sample size. Not all data were available in each study.

Table 20: Data Used for Analysis

Calculation	Data Required
Difference between the Means of T and C	Mean value Control
	Mean value Test
Effect Size	Mean value Control
	Mean value Test
	Standard deviation or Standard error of Control
	Standard deviation or Standard error of Test
	Sample size
Reliability Index (β)	Mean value Control
	Mean value Test
	Standard deviation or Standard error of Control
	Standard deviation or Standard error of Test

Analysis Methodology

The gathered data were then analyzed. First was to compare the pretest (control) condition and posttest (test) condition mean value difference. The next analysis of the data was to determine the percentage change between control and test condition; the effect size and reliability index were then calculated. The probability of the control and test condition being less than a threshold constant was determined and used to derive performance shaping factor coefficient values.

Difference between Mean Values

The difference between the control and test mean values (i.e., T-C) was the first comparison to be calculated; this was done to see the general trend of the data. Generally, the mean values of the test and the control condition, or the difference between the two conditions, were reported in the study; the standard deviation or standard error information was not always given. The difference between the mean values produced a larger sample of data points than other analysis methods.

Error or failure situations were defined; they were assumed to have occurred when the test condition showed a decrease in performance in comparison to the control condition. The variable *g* was used to represent the difference between the control (*C*) and test (*T*) condition. Table 21 provides the error conditions for each of the variables. The error definitions for accuracy depend on what form of accuracy was reported (i.e., the number of false positives, number or percentage of error, or the number or percentage correct).

Table 21: Error Conditions

Variable		Error Region
Lapse		$T > C$
Reaction Time		$T > C$
Accuracy	False +	$T > C$
	# of errors	$T > C$
	% of errors	$T > C$
	# correct	$C > T$
	% correct	$C > T$

Percentage Change

Due to differences between the study design and the assorted tasks employed in various studies, it is hard to draw a conclusion regarding the effect of hours of wakefulness on performance (reaction times, accuracy, and lapse) looking only at the difference between the two condition mean values. In an effort to compare the data in a more equivalent way, the percentages of increase or decrease from the control condition were calculated using Equation 15. The equation for percentage change is:

$$\% \, \boldsymbol{change} = \frac{\boldsymbol{T-C}}{\boldsymbol{C}} \tag{15}$$

where,

T = test condition value, and
C = control condition values (baseline value).

Effect Size and Reliability Index Calculations

To examine the degree of change in the dependent variables, the effect size (ES) (Equation 8) was calculated. This enabled a comparison between different studies. The effect size shows the amount of change in the dependent variable (human performance) caused by the independent variable (hours of wakefulness or sleep deprivation). The effect size, when using the standardized difference between the mean values, uses the pooled standard deviation (Equation 9).

Another dimensionless quantity, like the effect size, is the reliability index (β); it is the ratio of the mean of the function under study to the standard deviation of the function. As an example, in the case of the reaction time:

$$g = C - T \tag{16}$$

where,

T = test condition value, and
C = control condition values (baseline value).

When T is larger than C, g will be less than zero. Assuming C and T are independent normal random variables, g is also normal with a mean $\mu_g = \mu_C - \mu_T$ and variance σ_g^2 = $\sigma_C^2 + \sigma_T^2$. Failure, therefore, was defined as $C < T$; then the probability of failure was calculated as:

$$P(g<0)=\Phi\left(0-\frac{\mu_g}{\sigma_g}\right)=\Phi\left(0-\frac{\mu_C-\mu_T}{\sqrt{\sigma_C^2+\sigma_T^2}}\right) \quad \textbf{(17)}$$

where,

μ_C = baseline (control) condition value
μ_T = test condition value
$\mu_g = \mu_C - \mu_T$
σ_C = control standard deviation
σ_T = test standard deviation
$\sigma_g = \sqrt{(}\, \sigma_C^2 + \sigma_T^2.$ **(18)**

The β value was calculated using a combined standard deviation that took into account sample size from both mean values (Equation 18). The reliability index comes from the equation for error, Equation 17. The error condition was represented by the variable *g*. Using the error regions defined in Table 21 the probability that performance was reduced as hours of wakefulness increased can be calculated. The reliability index (β) is defined in Equation 19 as:

$$\beta=\left(\frac{\mu_g}{\sigma_g}\right)=\left(\frac{\mu_C-\mu_T}{\sqrt{\sigma_C^2+\sigma_T^2}}\right). \quad \textbf{(19)}$$

These quantities (effect size and β) are useful to see the sensitivity of reaction time, accuracy, and number of lapses to increasing hours of wakefulness (Griffith and Mahadevan, 2008). The usefulness of the β is its relationship to the probability of error which helps derive PSF coefficients for HRA. The above treatment results in $P\ (T > C)$. This is only useful for the number of lapses. For reaction time $P\ (T > k)\ /\ P\ (C > k)$ is more useful as explained later.

Linear Regression

A linear regression for within study characteristics was performed using the performance metric (number of lapses, reaction time, or accuracy) as the dependent variable and the hours of wakefulness as the independent variable for linear and the square of hours of wakefulness for the quadratic regression. An intercept (b_0), linear coefficient (b_1), and curvilinear coefficient (b_2) are calculated for each study. The intercept and two coefficients are used to produce an equation for performance. To correct for sample size, a weighted average also can be calculated by weighing each study by the sample size over the total sample size for all the studies.

A between-studies regression was then performed to find the relationship among between-study characteristics and the performance variable. A selection of study and task descriptors was chosen to evaluate their effect on predicted performance for a between-studies regression. Non-numeric data were coded as either yes (1) or no (0). The effect of the industry in which the study was performed was evaluated in regards to medical, military, general industry, and transportation with the default industry as academic. Two subject characteristics were evaluated, the sex of the group, i.e., percentage of male subjects, and the age of subjects. Task characteristics were the next group of study descriptors evaluated; these were: type of task (i.e., PVT, simple reaction time, grammatical reasoning or real work), task complexity (i.e., simple or complex), task pace (i.e., self or work paced), and whether the task was primary or secondary.

The variables that were identified as not having an effect on predicting performance were removed and a new between-study regression was performed. The resulting equation can be used to change the predicted performance measure to a different variable space. For example, this enables a study that was conducted in the transportation industry to be changed into the medical industry. This transformation allows for the data to be evaluated on the same study characteristics.

PSF Derivation

A quantitative measure of the effect of sleep deprivation on performance (i.e., estimation of human error probabilities) is derived in this subsection by comparing the probabilities of error in the control (pre-sleep deprivation) and test (post-sleep deprived) conditions to obtain a PSF multiplier value.

The performance measure (e.g., reaction time) under test condition and control condition can be compared to a threshold value k, in order to compute the error probability under each condition. The threshold values are selected based on the definition of a lapse for simple reaction time tasks, e.g., no response before 500 ms (Anderson et al., 2010).

In the following discussion, error is defined as the performance measure being larger than the threshold value. For example, error with respect to the control condition reaction time (C) and for the test condition reaction time (T) are mathematically defined as $C > k$ and $T > k$. The reaction times under control condition and test condition are both assumed to be normal random variables with a mean value μ_C and variance σ_C^2 for the control condition and a mean value μ_T and variance σ_T^2 for the test condition. In Figure 9 the shaded area represents either P_C or P_T, the probability of error. Since error is defined as $C > k$ or $T > k$, the probability of error is calculated as:

$$P_C = P\,(C > k) = 1 - \Phi\,((k - \mu_C) / \sigma_C) \quad \textbf{(20)}$$

$$P_T = P\,(T > k) = 1 - \Phi\,((k - \mu_T) / \sigma_T) \quad \textbf{(21)}$$

where, Φ ιs the cumulative distribution function (CDF) of a standard normal variable.

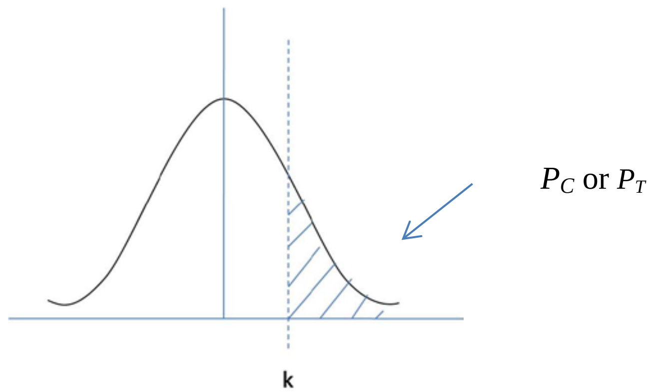

Figure 9: Normal Probability Distribution with Threshold Value (*k*)

The next step is to compare the error probabilities from Equations 20 and 21 for the control and test conditions. The probability of error in the test condition can be divided by the control condition probability of error, to show the amount of change in failure probability due to sleep deprivation, resulting in Equation 22. This may be used to inform the PSF coefficient value in Equation 7. Thus,

$$\text{PSF coefficient value} = P_T \,/\, P_C. \quad \textbf{(22)}$$

In summary, the process for the calculation of the probability ratio is as follows:

1. Calculate the probability of $C > k$,

   $P_C = P\,(C > k) = 1 - \Phi\,((k - \mu_C) / \sigma_C)$.

2. Calculate the probability of $T > k$ and

   $P_T = \mathrm{P}\,(T > k) = 1 - \Phi\,((k - \mu_T) / \sigma_T)$.

3. Calculate the ratio of probability of the test condition to the control condition, $P_T\ /\ P_C$.

The above treatment may also be used when the number of lapses is used as the performance measure, by comparing the number of lapses in each condition to a threshold value. However, there is also another way to derive PSF coefficient values for the number of lapses or the number of errors (accuracy measure), without defining a threshold value. For example, in the case of number of lapses, the probability that the number of lapses for the test condition (T_L) is greater than the number of lapses for the control condition (C_L) over the probability of T_L equal to C_L. P_L is defined in Equation 23:

$$\mathrm{P_L} = P\ (T_L > C_L)\ /\ P\ (T_L = C_L) = P\ (T_L > C_L)\ /\ 0.5 \qquad \textbf{(23)}$$

where,

C_L = control condition number of lapses
T_L = test condition number of lapses.

Outliers were removed from the analysis to reduce the PSF plots from being skewed toward one or two studies that had markedly different observations from the rest of the data (Grubbs, 1969). Outliers were also removed to prevent the ratio data (i.e., probability ratios to develop PSF coefficient values) from deviating markedly from the values for the rest of the calculated PSF coefficients. In some cases, the PSF coefficients, i.e., probability ratio ($P_T\ /\ P_C$), approach values greater than 10 when the error probability for the control condition (i.e., denominator of the ratio) is small. These cases were removed by assuming the small probabilities values to be zero and thereby removing them from the data set.

The probability ratios calculated are used to represent PSF coefficient values. The probability ratios can be used as direct measures of the PSF multiplier, as in the SPAR-H HRA method, or can be used as a means to inform in the selection of an appropriate PSF multiplier.

Uncertainty Analysis

The limited data for the PSF coefficient calculation results in significant variability. To investigate the variability of the results, the data are divided into twenty hour time blocks; the blocks were < 20, 20-40, 40-60, 60-80, and > 80 hours. A confidence interval, for each k value over each twenty hour time block, can be reported to express the variability in the derived PSF coefficient values. The 95% confidence interval using a 2-tailed t-distribution was calculated for each k value (e.g., $k = 500$) over each time block.

Another way to investigate the uncertainty of the results is to investigate the sensitivity of the results to the assumed normal distribution. The variables C and T were assumed to be normally distributed for the quantification analysis. To investigate the sensitivity of the results to this assumption, the C and T for reaction time are assumed to follow a lognormal distribution. The results are compared to the normally distributed C and T results in the quantification analysis

In many of the studies, data have to be interpreted from graphical results. Since there is some subjectivity associated with such a data collection method, the inter-rater reliability was found for a sample of studies. Inter-rater reliability is the extent to which two or more individuals (coders or raters) agree (i.e., if the coders recorded similar data).

Another source of uncertainty comes from the data being manually extracted. In order to investigate this uncertainty, the inter-rater reliability was examined. Inter-rater reliability quantifies the consistency or consensus of scores assigned by raters of the same study (Gwet, 2008). There are several operational definitions of inter-rater reliability depending on which statistics are appropriate (Saal et al., 1980). Some of the well-known methods of calculating inter-rater reliability are: joint-probability of agreement, Cohen's kappa (κ) and Fleiss' kappa (κ), correlation coefficients (e.g., Pearson's r and Spearman's ρ), intra-class correlation, and limits of agreement.

Inter-rater reliability is needed because different raters can disagree about the measurement results from the same object. The need for inter-rater reliability in this research results from differences from reading numeric data from plots (not observing data and assigning data to specific categories). This limits the type of inter-rater reliability methods that would be appropriate, since most are designed to measure the consistency of assigning data and not interpreting the results of the data.

Joint probability of agreement

Joint probability of agreement is the most simple, but least robust measure. It is simply the number of times each rating is assigned by each rater and assumes that the data are nominal. It does not take into account agreement by chance. Chance agreement will be high with a small number of categories and joint probability of agreement will be high even if there is no intrinsic agreement among raters (Cohen, 1960). Nominal data use names or labels for certain characteristics, e.g., types of rocks can be categorized as igneous, sedimentary, or metamorphic. Joint probability of agreement is used for category study observer assignments, not numerical measurements or the reading of numeric results from graphs.

Kappa statistics

Kappa statistics take into account agreement due to chance. Cohen's kappa (Cohen, 1968) is for two raters and Fleiss' kappa (Shrout, and Fleiss, 1979) is a modified version of Cohen's kappa that works for multiple rates. The data are assumed to be nominal (names or labels for certain characteristics); that is, there is no natural order to the data.

Correlation coefficients

Correlation coefficients, such as Pearson's (r) which assumes that the rating scale is continuous and Spearman's (ρ) which assumes that the scale is ordinal (i.e., measurements that describe order but not relative size), are used to measure pairwise correlation (i.e., judge which observation is preferred) among raters on an ordered scale and consider only relative position. For example, (1, 2, 1, 3) is considered perfectly correlated with (2, 3, 2, 4). Ordinal scales describe order, but not relative size.

Intra-class correlation coefficient

The interclass correlation coefficient measures a bivariate relation among variables (Kenneth et al., 1996). Intra-class correlation coefficient measures the proportion of variance of observation due to between-study variability in the actual scores (Koch, 1982). The intra-class correlation coefficient (ICC) ranges between 0.0 and 1.0; the ICC will be larger, when there is little variation between rater scores. The ICC considers the proportion of variability in a measure that is due to being part of a particular group (i.e., the extent that members of the same group act alike (Szklo and Nieto, 2004)).

Limits of agreement (Bland-Altman Plot)

Another way to express rater consensus is to calculate the mean of the differences between the two raters. Calculating a confidence limit around the mean provides insight on the level of random variation that impacts the ratings. When the raters agree, the mean will approach zero; however, if one rater is consistently higher than the other rater the mean will be larger, but the confidence interval will be smaller. When raters differ without a consistent pattern, the mean will be near zero, but the confidence interval will be large.

The difference of the means can be displayed graphically in a Bland-Altman plot (Bland and Altman, 1986). The mean difference with confidence limits (y-axis) is plotted against the average of the two ratings (x-axis). The Bland-Altman plot displays the degree of agreement between the raters, but also the level of agreement that is depending on the size (underlying value) of the data observation. For example, raters might closely agree on estimating the size of small values but disagree more with larger values.

Joint probability of agreement, Cohen's kappa, and Fleiss' kappa are used with nominal scales (category data) and are not applicable to this research data. Correlation coefficients are not applicable because they describe ordinal scales. Intra-class correlation (ICC) requires a *true value* to be known to compare to the observed data, a true value is not known in this application, so ICC rater reliability methods are not applicable. In this research, two raters were used to interpret reported results from graphical outputs, and the data were not being assigned to observational categories.

Among the aforementioned methods, the limit of agreement using a Bland-Altman plot is the most applicable for this research.

A random selection of studies is pulled from the pool of collected studies and coded by another coder, i.e., auxiliary coder. The coding by the auxiliary is compared to that of the main coder to compare for similar results. In this research, this most open for coder interpretation data were taken from a graph within the original study.

Mean values, standard deviation, minimum value, maximum values, and number of data points were calculated for the basic statistics of each overall performance metric (i.e., number of lapses, reaction time, and accuracy). The uncertainty of the derived performance shaping factor coefficients was calculated for each threshold value (i.e., k values). The uncertainty (i.e., mean value, standard deviation, minimum value, maximum values, and number of data points) was calculated for each k value derived PSF coefficient for intervals of hours of wakefulness.

Summary of Methodology

The method of data analysis was provided in this chapter. This included the method of data collection and types of information collected from the studies (e.g., study descriptors, task characteristics, and statistical data). The types of analysis that were applied to the data, along with the method of PSF coefficient derivation, were detailed. Different threshold values (k values) were selected to define the error region for the control and test condition values. The probability that the control or test condition was greater than the selected threshold values was calculated. PSF coefficients were derived by comparing the probability of failure (i.e., probability that the test metric is greater than the threshold value) for the test condition in comparison to the control condition. Results of the application of the methodology to the reported performance metrics of number of lapses, reaction time, and accuracy are reported in the following chapter.

CHAPTER V

RESULTS

This chapter discusses the results of the application of the methodology; this includes the analysis of the data including the difference between the mean values, percentage change, effect size, reliability index (β), and probability ratio. The probability ratio for different threshold values was calculated to find performance shaping factor coefficients; the results were grouped by reaction time, accuracy, and number of lapses.

Resulting Data

The number of studies that provided data for use in the quantitative analysis for each of the performance metrics (i.e., lapse, reaction time, and accuracy) is listed in Table 22. More studies reported reaction time information (65 studies) than accuracy (40 studies) and number of lapses data (18 studies). The number of studies that did not report the standard deviation information of the test conditions limited the number of studies that could be used for β, effect size, and probability calculations. These studies only looked at the difference between the mean values. Studies that did not report the number of hours of wakefulness were not usable in the analysis.

Table 22: Resulting Studies Used in Analysis

Performance Metric Variable		Number of Studies	Number of Studies Effect Sizes	Number of Studies Mean Differences	Number of Studies without Hours Reported	Studies without Standard Deviation Reported
Lapse		18	9	13	5	6
Reaction Time		65	29	29	26	17
Accuracy	False +	6	3	4	2	1
	# Error	10	5	7	2	3
	% Error	9	4	5	2	6
	# Correct	19	9	12	7	5
	% Correct	18	8	14	4	5

The studies used in the analysis are shown in Tables 23-25. The performance variables reported are denoted with the symbol *RT* for reaction time, *A* for accuracy, and *L* for number of lapses. If the difference between the mean values, effect size, and β could be calculated, it was noted in Tables 23-25. The studies that employed the PVT as their performance test were also noted with a *P*; the studies that did not report the hours of wakefulness or standard deviation information were marked with an *x* in Tables 23-25. Also, the studies that were not used in the analysis, since they only listed the number of accidents occurring at a time of day, were noted with a # symbol.

Analysis of the data was divided by the performance metric reported. The data were grouped by number of lapses, reaction time, and accuracy. The accuracy data were further divided by the type of accuracy reported (e.g., number correct, percentage correct, number of errors, percentage of error, and false positives).

Table 23: Resulting Studies and Performance Variables Reported Part 1

Study Id #	1st Author_year	PVT	RT	Accuracy	Lapse data	# Accidents	Diff mean	ES	No hrs data	No stdev
1	Nilsson_2005		RT							
2	Thomas_2000		RT	A						
3	Choo_2005		RT	A						
4	Chee_2004		RT	A						
5	Williamson_2000		RT	A						x
6	Kobbeltvedt_2005		RT							x
7	Robbins_1990		RT	A						
8	Angus_1985			A						
9	Babkoff_2005			A						x
10	Swann_2006	P	RT	A	L		x	x	x	
11	Koslowsky_1992								x	x
12	Pilcher_1996		RT						x	x
13	Belenky_2003	P	RT		L				x	
14	Buck_1972		RT	A						x
15	Killgore_2006		RT							x
16	Marmuff_2005		RT							x
17	Yoo_2007		RT	A						
18	Babkoff_1985			A	L		x			x
19	Williams_1967		RT							
20	Williams_1959		RT	A	L		x			x
21	Wilson_2007	P	RT	A	L		x			x
22	Gundel_2007		RT						x	
23	Webb_1985		RT						x	
24	Dinges_1997				L				x	
25	Sanders_1982		RT							
26	Collins_1977			A						
27	Porcu_1998		RT	A					x	
28	Wojtczak_1978		RT						x	x
29	Dorrian_2007	P	RT						x	x
30	Maury_1993		RT						x	
31	Borland_1986			A						
32	Dawson_1997			A						
33	Roach_2006	P	RT							
34	Reznick_1987		RT						x	x
35	Daniel_1989		RT						x	x

Table 24: Resulting Studies and Performance Variables Reported Part 2

Study Id #	1st Author_year	PVT	RT	Accuracy	Lapse data	# Accidents	Diff mean	ES	No hrs data	No stdev
36	Buck_1975		RT						x	x
37	Lenne_1997		RT						x	
38	Sallinen_2004									
39	Akerstedt_2005									
40	Boksem_2005									
41	Monk_1997		RT	A						x
42	Jones_2006	P	RT							
43	Hull_2003			A						
44	Wright_2006									
45	Halbach_2003		RT	A					x	x
46	Bliese_2006								x	
47	Lamond_2007	P			L		x	x		
48	Drummond_2006	P	RT	A						
49	Eastridge_2003			A						
50	Engle-Friedman_2003		RT	A					x	
51	Caldwell_2003	P	RT		L		x	x		
52	Rosa_1983		RT						x	x
53	Frey_2004	P	RT	A	L		x	x		
54	Glenville_1979		RT		L				x	x
55	Webb_1982			A					x	
56	Poulton_1978			A						
57	Englund_1985			A						
58	Saxena_2005	P	RT		L				x	
59	Richardon_1996		RT						x	
60	Christensen_1977			A					x	
61	Rosa_1988		RT						x	
62	Hart_1987		RT						x	x
63	Horne_1983			A						x
64	Hoddes_1973			A						
65	Webb_1984			A						x
66	Haslam_1982			A						
67	Binks_1999			A						
68	Deaconson_1988		RT	A					x	
69	Leonard_1998			A					x	x
70	Storer_1989		RT	A						

Table 25: Resulting Studies and Performance Variables Reported Part 3

Study Id #	1st Author_year	PVT	RT	Accuracy	Lapse data	# Accidents	Diff mean	ES	No hrs data	No stdev
71	Lichtor_1989		RT							
72	Linde_1999		RT	A					x	
73	Nag_1998					#				
74	MacDonald_1997					#				
75	Tilley_1982		RT						x	x
76	Rosa_1993		RT						x	
77	Langois_1985					#				
78	Akerstedt_1977			A						x
79	Richter_2005			A					x	
80	Hildebrandt_1974					#				
81	Donchin_1995					#				
82	Oginski_2000					#				
83	Taffinder_1998		RT	A					x	
84	Smith_1994					#				
85	Froberg_1977			A			x			x
86	Philip_2004		RT		L				x	
87	Powell_2001	P	RT		L		x	ES	x	
88	Fiorica_1968			A						
89	Cutler_1979									
90	Sharp_1988		RT						x	
91	Steyvers_1993		RT		L		x	ES		x
92	Elkin_1974			A						x
93	Webb_1986			A						x
94	Haslam_1983			A						
95	Sagaspe_2006		RT							
96	Scott_2006		RT							
97	Venkatraman_2007		RT							
98	Dinges_1988		RT							
99	May_1987			A						
100	Lieberman_2005		RT	A	L		x	ES		
101	Lamond_1999		RT	A						
102	Thorne_2005	P	RT							x
103	Doran_2001	P	RT	A						
104	Wesenten_2005	P	RT							
105	Jewett_1999	P	RT		L		x	ES		
106	Drake_2001	P	RT							
107	Van Dongen_2003	P			L		x	ES		x
108	Rajaraman_2007	P			L		x	ES		

Data on Number of Lapses

The studies that reported the number of lapses as a performance metric are listed in Table 26; these studies are a subset of the 108 listed in Tables 23-25. The studies that could be used for further analysis, to calculate the difference between the means, effect size, and standard deviation, are listed in Table 26, along with studies that were not used due to missing data, i.e., studies without hours of wakefulness and studies without standard deviation information.

Table 26: Studies w.r.t. Data on Number of Lapses

Number of Lapses	
Studies reporting number of lapses	(10, 13, 18, 20, 21, 24, 47, 51, 53, 54, 58, 86, 87, 91, 100, 105, 107, 108)
Studies without hours of wakefulness	(13, 24, 54, 58, 86)
Studies without standard deviation	(18, 20, 21, 91, 107)
Difference between the means	(10, 18, 20, 21, 47, 51, 53, 87, 91, 100, 105, 107, 108)
Effect size	(10, 47, 51, 53, 87, 91, 100, 105, 108)
Studies used	(10, 18, 20, 21, 47, 51, 53, 87, 91, 100, 105, 107, 108)

Quantitative Effect of Sleep Deprivation on Number of Lapses

The first analysis was to find the difference between the control and test condition mean values of number of lapses, corresponding to different hours of wakefulness. The difference between the mean values (i.e., *T* - *C*) of the number of lapses was plotted in Figure 10. There are 68 data points from eleven studies. Multiple data points from the same study are reported as independent data points and do not distinguish between different types of tasks.

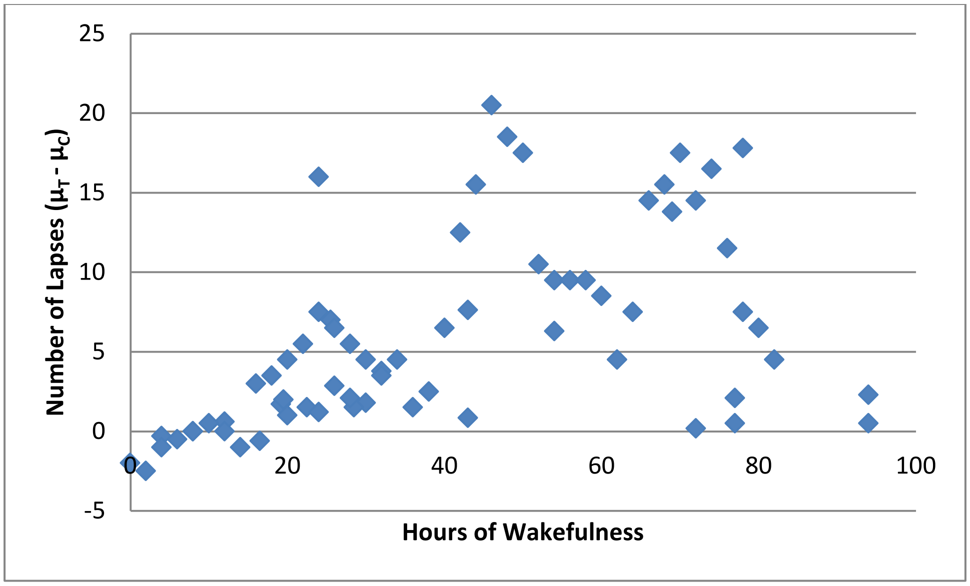

Figure 10: Differences between the Means for Number of Lapses

The difference between the number of lapses in the control and test condition increases as the hours of wakefulness increase. The hours of wakefulness varied from 0 to 94 hours. The difference between the means ranged from -2.5 at 2 hours of wakefulness to 20.5 at 48 hours of wakefulness. The scatter of the data increased after the 40 hours of wakefulness mark. The difference between the mean values before twenty hours of wakefulness was close to zero and sometimes negative; meaning that the number of lapses was larger before the subject was sleep-deprived. A possible explanation for a greater number of lapses before being sleep deprived corresponds to the Yerkes-Dodson law of arousal (Yerkes and Dodson, 1908) that performance increases up to a point of stimulation and then decreases thereafter.

The number of data points that came from each study is provided in Table 27. Five studies provided a single data point and one study provided forty-one data points.

Different data points resulted from data collected at multiple hours of wakefulness (e.g., #108-Rajaraman_2007) and multiple tasks (e.g., #53-Frey_2004).

Table 27: Number of Data Points for Differences between Means for Number of Lapses

Study Id #	# of Data Points
10	1
18	1
20	4
21	5
47	1
51	6
53	2
87	1
100	4
105	1
108	41

Additional analysis of the data focused on the percentage change in the number of lapses from the control to the test condition. The percentage increase was found using Equation 15. There were sixty-eight data points used from eleven studies, and they were plotted in Figure 11.

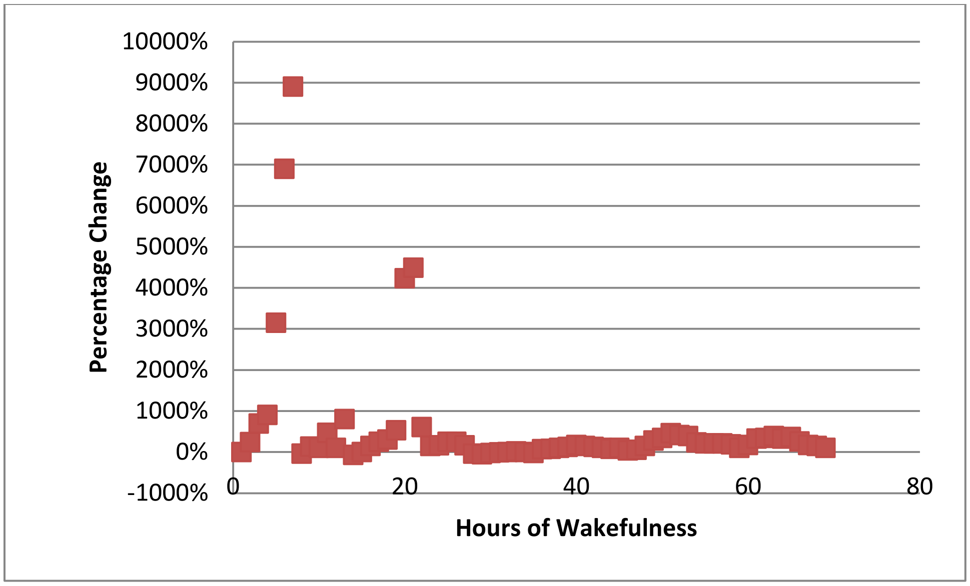

Figure 11: Percentage Change for Number of Lapses

Outliers that came from two studies (#20-Williams_1959 and #58-Saxena_2005) were removed and the data were replotted in Figure 12. The six removed data points ranged from 900% to 8900% for the percentage change. All the number of lapses data from the two studies (#20-Williams_1959 and #58-Saxena_2005) were removed for Figure 12. The high percentage increase in comparison to the rest of the data was due to a very small number of lapses in the control condition in comparison to the test condition. Study #20-Williams_1959 used a visual vigilance task, and #58-Saxena_2005 used the PVT.

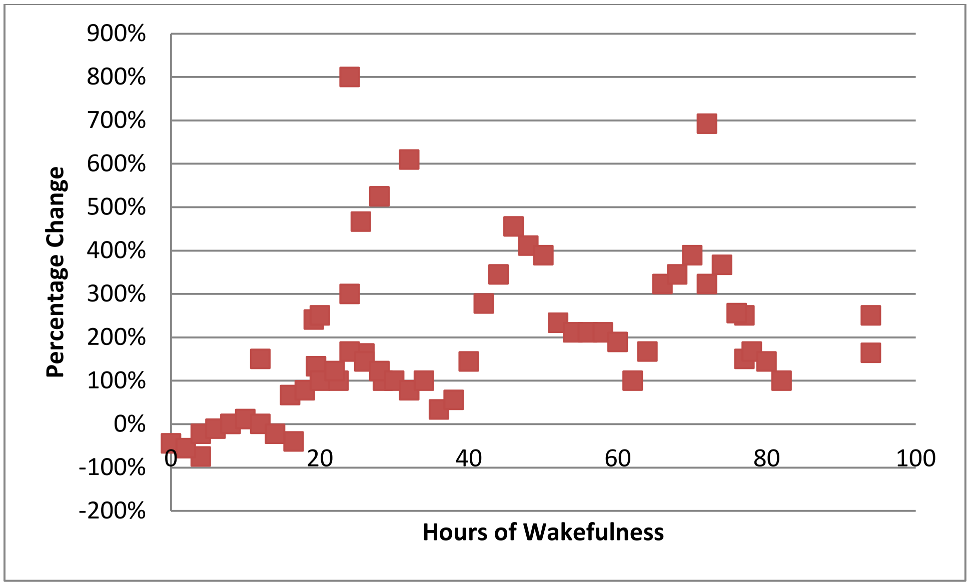

Figure 12: Percentage Change for Number of Lapses (Outliers > 900% Removed)

The variation of the data increased after the twenty hour mark. There was a general trend that the percentage of increase enlarges as hours of wakefulness increase. After sixty hours of wakefulness, all the data were above a hundred percentage increase.

The next step was to determine the effect size (Equation 8) and reliability index (β) values (Equation 19) for the number of lapses at each available data point; these are plotted in Figure 13. The ES and β values show the standardized difference between the number of lapses for the control and test conditions as caused by discrete values of hours of wakefulness. Figure 13 uses multiple data points from one study.

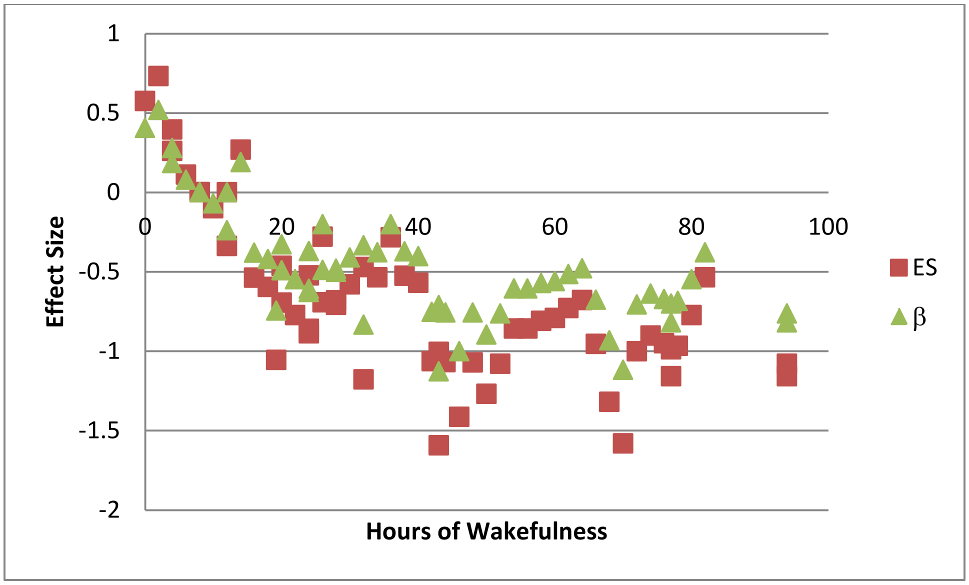

Figure 13: ES and β for Number of Lapses

The ES and β values increased in the negative direction as hours of wakefulness increased. A negative ES means the number of lapses increases as hours of wakefulness increase, i.e., performance deterioration as hours of sleep deprivation increase. The effect sizes ranged from (-0.732 to 1.594), and β values ranged from (-0.517 to 1.127). There were fifty-eight data points from eight different studies; forty-one data points came from one study (#108-Rajaraman_2007). The allocation of data points to studies is provided in Table 28. The majority of the studies used the PVT as the task (e.g., #10-Swann_2006, #47-Lamond_2007, #51-Caldwell_2003, #53-Frey_2004, #87-Powell_2001, #105-Jewett_1999, and #108-Rajaraman_2007). A novel reaction time test, in addition to the PVT, was used in #53-Frey_2004 and a four-choice reaction time task and a grammatical reasoning task were used in #100-Lieberman_2005.

Table 28: Number of Data Points for ES Calculation (Number of Lapses)

Study Id #	# of Data Points
10	1
47	1
51	6
53	2
87	1
100	4
105	1
108	41

The probability of error, defined as a greater number of lapses after sleep deprivation than the baseline condition, is calculated using the β from Equation 19. The probability of $T > C$ using Equation 17 is plotted in Figure 14. The probability that T is greater than C approaches seventy-percent after forty hours of wakefulness.

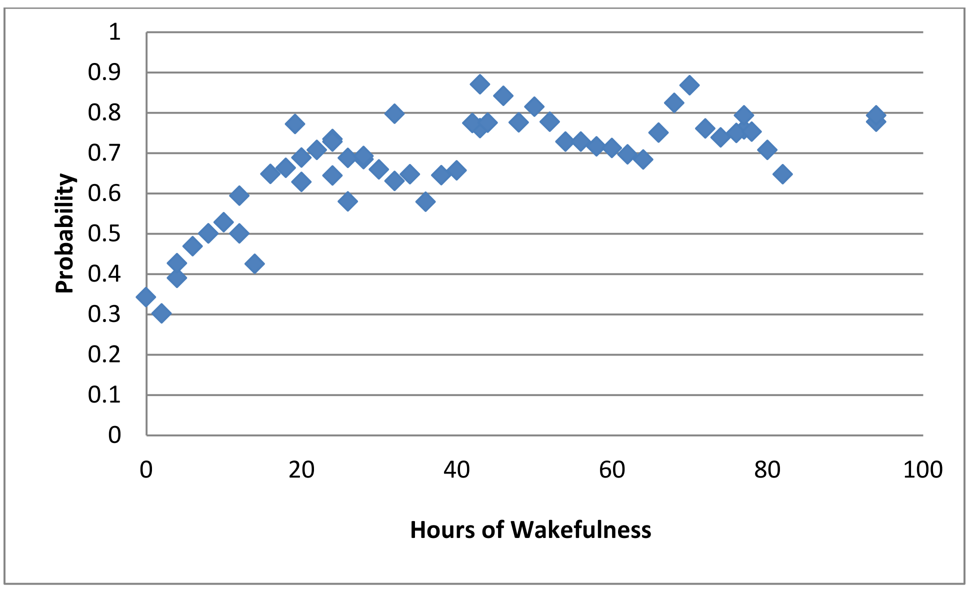

Figure 14: Probability P($T > C$) for Number of Lapses

Linear Regression for Number of Lapses

A linear regression was performed on the number of lapses data. An intercept (b_0), linear coefficient (b_1), and curvilinear coefficient (b_2) were found separately by a multi-variable regression for each study. The dependent variable was the performance metric, i.e., the number of lapses. Independent variables were the hours of wakefulness and the square of the hours of wakefulness for the performance measure. A weighted average was calculated by weighting each study by the ratio of the study sample size to the total sample size for all studies, Table 29. Studies that had only one time measure were graphed in order to find the regression coefficients (#10-Swann_2006, #18-Babkoff_1985, #47-Lamond_2007, #87-Powell_2001, and #105-Jewett_1999).

Table 29: Number of Lapses vs. Hours of Wakefulness: Within-Study Regression Coefficients

Study #	N	b_0	b_1 (H)	b_2 (H^2)	W - b_0	W - b_1 (H)	W - b_2 (H^2)
10	12	0.710	0.089	0	0.029	0.004	0
18	6	0.026	0.002	0	0.001	0	0
20	74	0.351	-0.085	0.004	0.089	-0.022	0.001
21	9	1.297	-0.042	0.007	0.040	-0.001	2.05E-04
47	30	2.000	0.666	0	0.207	0.069	0
51	15	0.274	0.007	0.002	0.014	3.37E-04	1.27E-04
53	25	0.095	0	0.002	0.008	0	1.98E-04
87	8	0.620	0.118	0	0.017	0.003	0
100	31	1.400	0.012	-3.41E-05	0.150	0.001	-3.65E-06
105	32	1.750	0.109	0	0.193	0.012	0
108	48	0.298	0.502	-0.004	0.049	0.083	-0.001
N - SUM	290.0	8.8	1.4	1.13E-02	0.8	0.1	8.83E-04
AVG	26.4	0.8	0.1	1.03E-03	0.1	1.36E-02	8.02E-05

The average of the intercept (b_0), linear coefficient (b_1), and curvilinear coefficient (b_2) for all the studies is used to derive predicted performance for the within-study regression. The derived performance equations, simple average and weighted simple average, based on the simple average of regression coefficients are listed in Table 30. These equations were then used to perform a between-study regression to find the relationship between-study characteristics and the performance variable (i.e., number of lapses).

Table 30: Overall Number of Lapses Equation Based on Within-study Regression

		b_0	b_1 (H)	b_2 (H^2)
Simple Average	y =	0.073	0.125	1.89E-03
Weighted Average	y =	0.802	0.014	1.47E-04

Several task descriptors were evaluated to find their effect on performance. These study variables were type of industry (i.e., medical, military, general industry, transportation and academia as the default), percentage of male subjects, age of subjects, type of task (i.e., PVT, simple reaction time, grammatical reasoning, or real-world task), and task characteristics (simple or complex, self or work paced, and primary or secondary). The resulting coefficients are listed in Table 31.

Table 31: Between-Studies Regression Coefficients for Number of Lapses vs. Hours of Wakefulness

	Intercept	Medical	Military	Industry	Transpor.	Sex of Group	Age
b_0	1.37	0	-0.08	0	1.03	-0.02	0.05
b_1	-0.30	0	-0.34	0	-0.43	0.00	0.00
b_2	0.01	0	0	0	0.01	0.00	-1.23E-03

	PVT	SRT	Gram Res	Real-world	Complex	Work Pace	Primary
b_0	-0.60	-0.49	0	0	0	-0.47	0
b_1	0.30	0.64	0	0	0	-0.01	0
b_2	0.01	0	0	0	0	-0.01	0

	Intercept	Medical	Military	Industry	Transpor.	Sex of Group	Age
$W - b_0$	0.185	0	0.043	0	-0.002	-0.002	0.001
$W - b_1$	-0.085	0	-0.050	0	-0.058	0.001	0.002
$W - b_2$	0.002	0	0	0	0.000	4.40E-05	-2.1E-04

	PVT	SRT	Gram Res	Real-world	Complex	Work Pace	Primary
$W - b_0$	-0.026	-0.063	0	0	0	-0.024	0
$W - b_1$	0.044	0.106	0	0	0	0.008	0
$W - b_2$	0.001	0	0	0	0	-0.001	0

The variables that were identified as not having a significant effect on predicting performance were removed, and a new between-study regression was performed. Studies conducted in the medical field or general industry and the task descriptors: grammatical reasoning task, real-world task, complex or simple, and primary or secondary task, were not identified as study characteristics that affected performance outcomes. These study variables were removed, and the between-study regression was performed again with the resulting regression coefficients presented in Table 32.

Table 32: Between-Studies Regression for Number of Lapses: Non-Significant Variables Removed

	Intercept	Military	Transpor.	Sex of Group	Age	PVT	SRT	Work Pace
b_0 *	1.373	-0.0815	1.029	-0.017	0.047	-0.599	-0.488	-0.469
b_1 *	-0.300	-0.3379	-0.435	0.004	0.003	0.297	0.641	-0.008
b_2 *	0.013	0	0.008	2.62E-04	-0.001	0.006	0	-0.008
	Intercept	Military	Transpor.	Sex of Group	Age	PVT	SRT	Work Pace
W - b_0 *	0.185	0.0426	-0.002	-0.002	0.001	-0.026	-0.063	-0.024
W - b_1 *	-0.085	-0.0495	-0.058	0.001	0.002	0.044	0.106	0.008
W - b_2 *	0.002	0	3.18E-04	4.40E-05	-2.15E-04	0.001	0	-0.001

As an example from Table 32 the un-weighted between-studies regression equation would be:

y = [1.373 - 0.082(military) + 1.03(transportation) - 0.017(sex) + 0.047(age) – 0.599(PVT) -0.488(SRT) – 0.469(work pace)] + [-.300 - 0.388(military) - 0.435(transportation) + 0.004(sex) + 0.003(age) + 0.297(PVT) +0.641(SRT) – 0.008(work pace)]H + [0.013 + 0.008(transportation) + 0.0003(sex) - 0.001(age) + 0.006(PVT)– 0.008(work pace)]H^2

H represents hours of wakefulness and y the predicted number of lapses. The variables (e.g., military) take values either 0 or 1, and are determined by the study characteristics associated with the desired prediction.

Non-significant variables are removed from the predictive model (Table 32). Whether the task was complex or simple or primary or secondary did not affect the performance across the studies. Specific tasks, such as grammatical reasoning tasks and real-world tasks, did not have an affect nor did certain industry groups such as medical or general industry. No further analysis was performed using the derived equations. However, the results do show that subject characteristics and type of task employed affect the performance measure.

Derivation of Probability Ratios for Number of Lapses

The probability ratios examine the enhancement of probability in the test vs. the control condition. For the number of lapse data there are two methods that can be used to derive probability ratio values. The first method uses Equation 23 ($P_L = P\ (T_L > C_L)$ / 0.5) and the second method uses Equation 22 ($P_T\ /\ P_C$). The probability ratios resulting from Equation 22 are affected by the choice of threshold value (k).

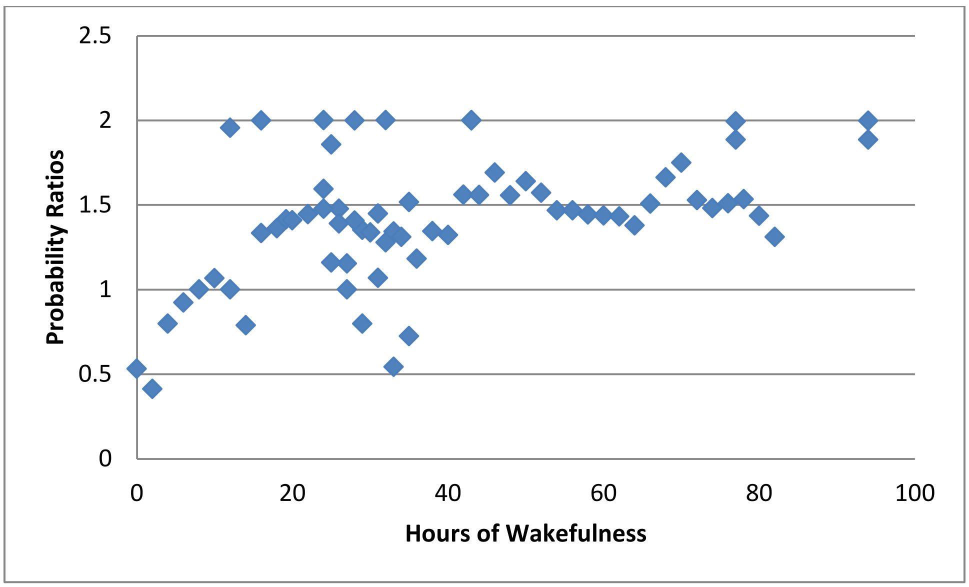

Figure 15: Probability Ratios P(*T*>*C*)/0.5 for Number of Lapses vs. Hours of Wakefulness

Using the probability ratio from Equation 23 for the number of lapses data, sixty-eight probability ratio values were calculated from thirteen studies. No outliers were removed. The probability ratios statistics over all time periods are mean 1.42, standard deviation 0.162, and 95% confidence interval for the mean is [1.25, 1.58]. The results show two dips occurring around forty hours and just after sixty hours of wakefulness, these may result from the diurnal or circadian rhythms effect on performance. The results for this method to derive PSF coefficient values are not dependent upon selection of threshold values (*k*).

The second type of analysis is to calculate the probability of failure for the control and test conditions, using Equations 21 and 22 respectively. The probability of error was calculated for all the data points with the type of task not differentiated. The average of the control condition mean values (number of lapses) was 3.06, the average test mean value was 8.9, the average *T* - *C* was 5.87, and the average of control mean value for all data plus three standard deviations was 8.709. This information was used in selecting the *k* values; six different values for *k* were selected, *k* = 1, 2, 3, 6, 9, and 10. Extremely large (e.g., *k* = 10 for #10- Swann_2006 had a ratio of 1.36 E52) and extremely small (e.g., *k* = 6 for #100- Lieberman_2005 had a ratio of 2.75 E-74) ratios were eliminated. The removed outliers occurred when one of the probabilities (i.e., $P(C > k)$ or $P(T > k)$ was close to zero. The plotted ratios were all less than ten. Two data points for *k* = 1, one for *k* = 3, and eleven for *k* = 6, 9, 10 were removed. No data were removed when a *k* = 2 was used. The result is plotted in Figure 16.

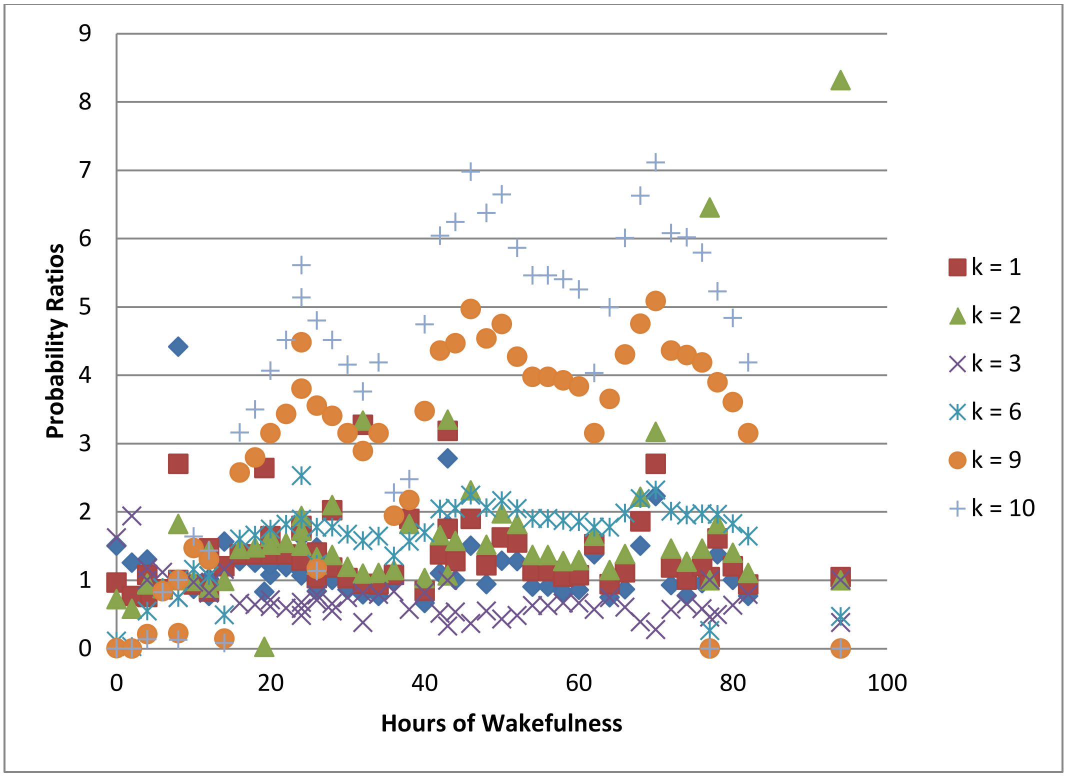

Figure 16: Probability Ratios for Number of Lapses vs. Hours of Wakefulness

Seven different data series were plotted in Figure 16. A similar pattern emerged of three *dips* that increased as hours of wakefulness increased from threshold values $k = 9$ and $k = 10$. The dips may possibly be linked to circadian rhythms. Only $k = 9$ and $k = 10$ are plotted in Figure 17. The data for these two k values came from the same studies.

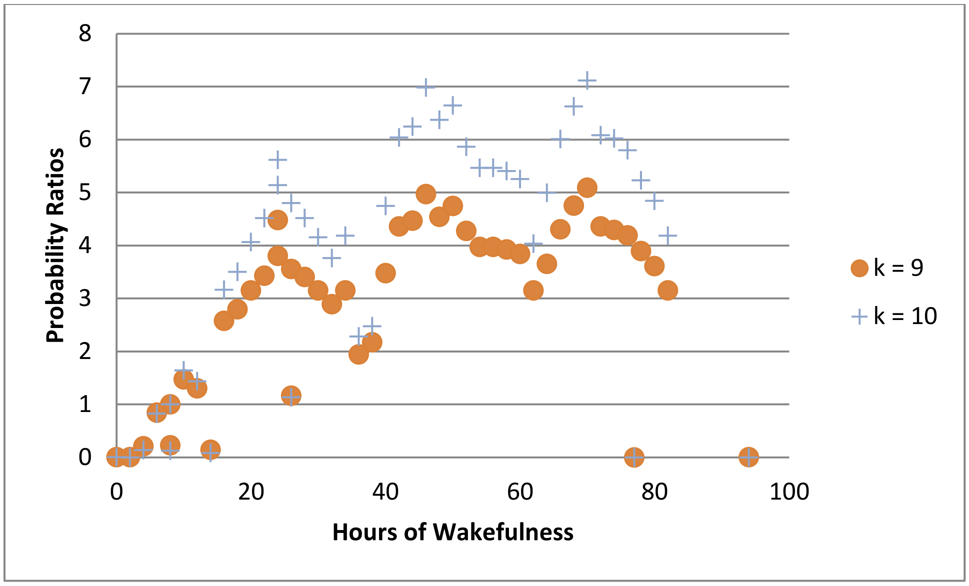

Figure 17: Probability Ratios for Number of Lapses (*k* = 9, 10)

In order to find the best-fit line to describe the probability ratio values, a different trend-line was fit to specific time intervals. The pattern of the probability ratios $k = 9$ and 10 showed three distinct dips; in order to best fit the data, the time intervals were broken down into ten hour time blocks. The intervals were: less than ten hours, ten to twenty hours, twenty to forty hours, forty to fifty hours, fifty to sixty hours, sixty to seventy hours, and greater than seventy hours. The resulting equations and R^2 values are listed in Table 33. Equations for the interval of ten to twenty hours of wakefulness had the lowest R^2 value, $k = 9$ had a R^2 of 0.76, and $k = 10$ had a R^2 of 0.796. An exponential fit for the interval of twenty to forty hours had the best fit. Polynomial equations were the best-fit for the other time intervals.

Table 33: Probability Ratios for Number of Lapses (*k* = 9, 10)

Hours	R^2	*k* = 9
< 10	0.998	y = 0.002x6 - 0.088x5 + 1.097x4 - 7.009x3 + 24.25x2 - 42.70x + 30.44
10 to 20	0.760	y = -0.013x3 + 0.649x2 - 9.793x + 48.23
20 to 40	1	y = 6.555e-0.01x
40 to 50	1	y = 0.001x5 - 0.313x4 + 28.16x3 - 1261.x2 + 28211x - 25201
50 to 60	1	y = 0.000x5 - 0.059x4 + 6.537x3 - 359.3x2 + 9862.x - 10808
60 to 70	1	y = -6E-05x5 + 0.019x4 - 2.786x3 + 194.3x2 - 6758.x + 93776
70 to 80	1	y = -0.012x6 + 5.796x5 - 1086.x4 + 10854x3 - 6E+06x2 + 2E+08x - 2E+09

Hours	R^2	*k* = 10
< 10	0.977	y = 0.002x6 - 0.060x5 + 0.683x4 - 3.917x3 + 12.26x2 - 21.50x + 20.54
10 to 20	0.796	y = -0.017x3 + 0.810x2 - 12.22x + 59.94
20 to 40	1	y = 7.219e-0.01x
40 to 50	1	y = 0.002x5 - 0.446x4 + 40.02x3 - 1792.x2 + 40093x - 35811
50 to 60	1	y = 0.000x5 - 0.065x4 + 7.181x3 - 394.1x2 + 10795x - 11805
60 to 70	1	y = -0.000x5 + 0.079x4 - 10.80x3 + 729.4x2 - 24604x + 33161
70 to 80	1	y = -0.017x6 + 7.905x5 - 1481.x4 + 14803x3 - 8E+06x2 + 2E+08x - 3E+09

The data for $k = 2$ were plotted in Figure 18; no outliers needed to be removed from the analysis for being extremely large or small. Two outliers of 6.452 at 77 hours of wakefulness and 8.317 at 94 hours of wakefulness both come from the study #100-Lieberman_2005.

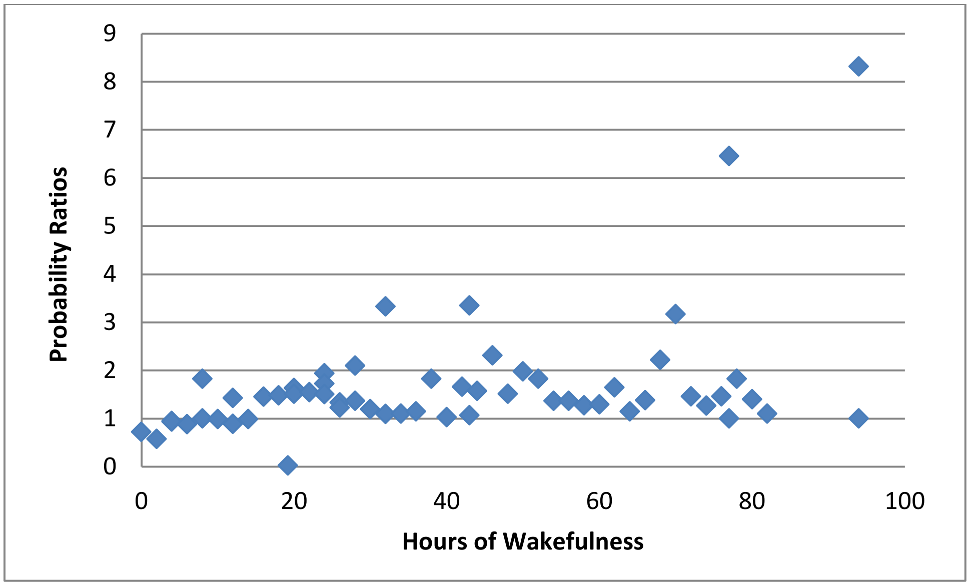

Figure 18: Probability Ratios for Number of Lapses (*k* = 2)

The equations for *k* = 2, subdivided into time intervals of less than ten hours, ten to twenty hours, twenty to forty hours, forty to fifty hours, fifty to sixty hours, sixty to seventy hours, and greater than seventy hours, are listed in Table 34. A low R^2 value for the intervals of forty to fifty hours, fifty to sixty hours, sixty to seventy hours, and seventy to eighty hours of wakefulness, 0.345 and 0.358 respectively, were associated with the best-fit to data even with a sixth degree polynomial.

Table 34: Probability Ratios for Number of Lapses (k = 2)

Hours	R^2	k = 2
< 10	0.866	$y = -0.006x^6 + 0.190x^5 - 2.142x^4 + 11.99x^3 - 34.76x^2 + 48.57x - 23.85$
10 to 20	0.925	$y = 0.001x^6 - 0.109x^5 + 4.009x^4 - 77.77x^3 + 839.0x^2 - 4772.x + 11181$
20 to 40	0.966	$y = -0.000x^3 + 0.045x^2 - 1.067x + 9.713$
40 to 50	0.345	$y = 0.002x^6 - 0.682x^5 + 76.43x^4 - 4559.x^3 + 15282x^2 - 3E+06x + 2E+07$
50 to 60	1	$y = 0.000x^5 - 0.147x^4 + 16.27x^3 - 897.7x^2 + 24733x - 27224$
60 to 70	1	$y = 0.000x^5 - 0.121x^4 + 16.17x^3 - 1073.x^2 + 35574x - 47117$
70 to 80	0.358	$y = 0.006x^6 - 2.974x^5 + 557.6x^4 - 55722x^3 + 3E+06x^2 - 9E+07x + 1E+09$

A different pattern emerged from the data when $k \leq 6$ was plotted, as in Figure 19, excluding k = 2. The probability ratios ranged from zero to less than five. From Figure 16, the probability ratio increases up to twenty hours of wakefulness. The majority of the derived probability ratios are greater than one. If the probability ratio is greater than one and is applied as a PSF coefficient, it will increase the overall error probability.

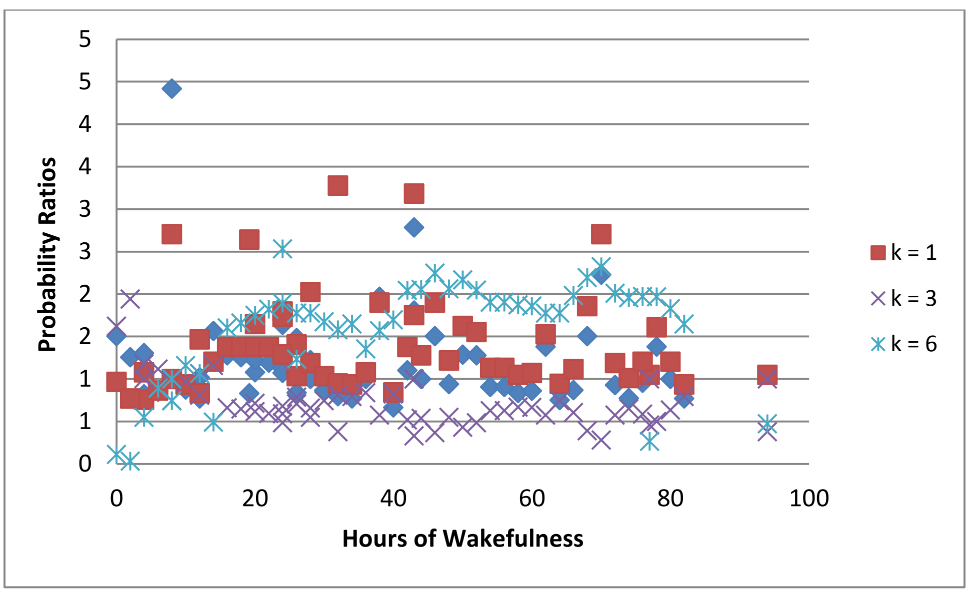

Figure 19: Probability Ratios for Number of Lapses (k = 1, 3, 6)

The equations for *k* = 1, 3, and 6, subdivided into time intervals of less than ten, ten to twenty, twenty to forty, twenty to forty, forty to sixty, sixty to seventy, and greater than seventy hours, are listed in Table 35. The lowest R^2 values for *k* = 1 occurred in the interval for forty to fifty hours (R^2 = 0.706), *k* = 3 occurred in the interval for twenty to forty hours (R^2 = 0.726) where a line was unable to be fit due to lack of data, and *k* = 6 occurred in the interval for twenty to forty hours (R^2 = 0.702). A polynomial equation was fit to each interval, except for an exponential fit for twenty to forty hours for *k* = 6.

Table 35: Probability Ratios for Number of Lapses (*k* = 1, 3, 6)

Hours	R^2	$k = 1$
< 10	0.999	$y = 0.004x^6 - 0.147x^5 + 1.787x^4 - 11.14x^3 + 37.43x^2 - 63.80x + 43.87$
10 to 20	0.891	$y = -0.001x^6 + 0.109x^5 - 4.061x^4 + 79.75x^3 - 871.1x^2 + 5018x - 11901$
20 to 40	0.997	$y = -0.000x^3 + 0.057x^2 - 1.420x + 13.03$
40 to 50	0.706	$y = 0.004x^6 - 1.127x^5 + 126.4x^4 - 7555.x^3 + 25366x^2 - 5E+06x + 3E+07$
50 to 60	1	$y = 0.000x^5 - 0.141x^4 + 15.60x^3 - 860.9x^2 + 23728x - 26130$
60 to 70	1	$y = 0.000x^5 - 0.147x^4 + 19.54x^3 - 1294.x^2 + 42811x - 56586$
> 70	0.969	$y = -0.000x^5 + 0.333x^4 - 49.93x^3 + 3742.x^2 - 14021x + 2E+06$
Hours	R^2	$k = 3$
< 10	1	$y = 0.101x^4 - 1.490x^3 + 7.959x^2 - 18.15x + 15.58$
10 to 20	0.921	$y = 0.000x^6 - 0.051x^5 + 1.949x^4 - 39.09x^3 + 436.1x^2 - 2565.x + 6211.$
20 to 40	0.726	$y = 0.000x^3 - 0.064x^2 + 1.902x - 16.69$
40 to 50	0.846	$y = 0.004x^6 - 1.188x^5 + 133.3x^4 - 7972.x^3 + 26777x^2 - 5E+06x + 4E+07$
50 to 60	1	$y = 0.000x^5 - 0.129x^4 + 14.30x^3 - 789.7x^2 + 21775x - 23988$
60 to 70	1	$y = 0.000x^5 - 0.167x^4 + 22.18x^3 - 1465.x^2 + 48400x - 63862$
> 70	1	$y = -0.000x^5 + 0.162x^4 - 24.32x^3 + 1820.x^2 - 68135x + 1E+06$
Hours	R^2	$k = 6$
< 10	0.997	$y = -0.002x^5 + 0.075x^4 - 0.887x^3 + 4.78x^2 - 11.83x + 11.86$
10 to 20	0.702	$y = -0.006x^3 + 0.309x^2 - 4.658x + 23.39$
20 to 40	1	$y = 4.613e^{-0.02x}$
40 to 50	1	$y = 0.000x^5 - 0.134x^4 + 12.08x^3 - 541.3x^2 + 12109x - 10819$
50 to 60	1	$y = 0.000x^5 - 0.040x^4 + 4.422x^3 - 243.5x^2 + 6700.x - 73630$
60 to 70	1	$y = 0.000x^5 - 0.039x^4 + 5.097x^3 - 332.8x^2 + 10856x - 14145$
> 70	1	$y = -0.005x^6 + 2.445x^5 - 458.2x^4 + 45789x^3 - 3E+06x^2 + 8E+07x - 1E+09$

The average summary data for all *k* values were provided in Table 36. The data were summarized over all hours of wakefulness; the mean hours of wakefulness were 40.5 hours and ranged between 0 to 94 hours. However, it is more desirable to consider the probability ratio based on hours of wakefulness.

Table 36: Summary Data for Number of Lapses (*k* = 1, 2, 3, 6, 9, 10)

k-value	Mean	Minimum	Maximum	# of Data pts
1	1.401	0.752	3.275	56
2	1.659	0.025	8.317	58
3	0.722	0.278	1.938	57
6	1.571	0.030	2.530	47
9	2.933	1.51E-04	5.086	47
10	3.910	3.49E-06	7.110	47

The probability ratios calculated previously can be used to derive PSF multiplier values for direct use in the SPAR-H HRA method, or can be used as a means to inform in the selection of appropriate PSF values as in ATHEANA HRA method. This data can be used to modify the nominal human error probability when the length of wakefulness is known. In the case of 24 hours of wakefulness, three studies provided data averaged for each *k* value. These data are presented in Table 37. The ratio data were used to modify the nominal human error probability through performance shaping factor coefficients. Using *k* = 3, the error probability would be reduced since the ratio is less than one. In the case of all other *k* values, the error probability would increase since the value is greater than one. If *k* = 2 the probability ratio is 1.722.

Table 37: Summary of Probability Ratios at 24 Hours of Wakefulness

Study Id #	Hours of Wakefulness	*k* = 1	*k* = 2	*k* = 3	*k* = 6	*k* = 9	*k* = 10
47	24	1.793	1.937	0.484	2.531	4.479	5.612
51	24	1.730	1.724	0.677			
108	24	1.289	1.504	0.587	1.892	3.800	5.135
Average Probability Ratio for 24hrs		1.604	1.722	0.583	2.211	4.140	5.374

Uncertainty Analysis of Probability Ratios for Number of Lapses

The descriptive statistics for all the data provided in the studies are listed in Table 38, (e.g., hours of wakefulness, *N*-control, *N*-test, μ-Control, μ-Test, σ-Control, and σ-Test). The average number of subjects per study was approximately 40.63 (25.44). The average mean value for the overall data for the control group was 3.1 (1.88); for the test group, it was 8.9 (6.82).

Table 38: Descriptive Statistics for Number of Lapses Information

	Hours of Wakefulness	N- Control	N-Test	μ-Control	μ - Test	σ - Control	σ - Test
Mean	40.628	40	40	3.062	8.931	3.818	9.624
Standard Error	3.085	2	2	0.228	0.827	0.245	0.918
Standard Deviation	25.441	17	17	1.882	6.818	1.870	6.994
Sample Variance	647.225	295	297	3.544	46.483	3.495	48.923
Minimum	0	6	6	0.020	0.100	0.050	0.251
Maximum	94	74	74	4.5	25	11.314	25.5
Count	68	68	68	68	68	58	58
Confidence Level(95.0%)	6.158	4	4	0.456	1.650	0.492	1.839

The probability ratios calculated show significant variability due to sparse data. Data are subdivided into twenty hour intervals (i.e., < 20, 20-40, 40-60, 60-80, and > 80). For number of lapses data, the 95% confidence intervals for the calculated probability ratios over each time block are shown in Figure 20. Using the sample size, mean, and standard deviation of the data for each time block, the 95% confidence intervals for $k = 1$ are calculated using the *t*-distribution and the results are provided in Figure 20 and Table 39.

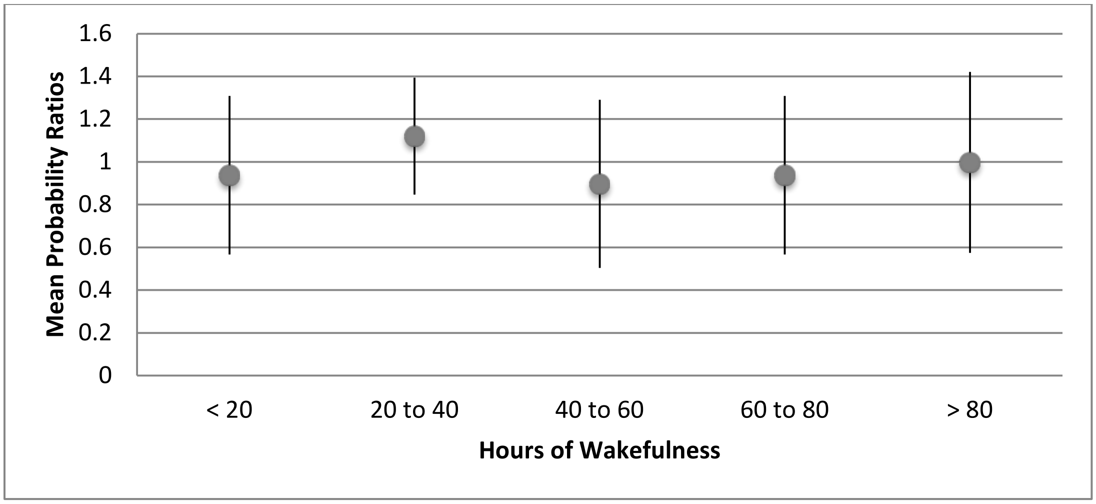

Figure 20: Mean Probability Ratios for Number of Lapses (*k* = 1)

Table 39: Mean Probability Ratios for Number of Lapses and 95% CI (*k* = 1)

Time Block	N	Mean	95% CI
< 20 hrs	11	0.937	[0.57, 1.31]
20 to 40 hrs	24	1.120	[0.85, 1.39]
40 to 60 hrs	10	0.897	[0.50, 1.29]
60 to 80 hrs	11	0.937	[0.57, 1.31]
> 80 hrs	3	0.998	[0.57, 1.42]

For *k* = 1, all five time-blocks report mean probability ratio values in the range [0.89, 1.12] as shown in Table 39. The largest mean probability ratio value occurs between twenty and forty hours of wakefulness and the smallest occurs between forty to sixty hours of wakefulness. The mean values and standard deviations of the probability ratios over each twenty hour time block are summarized in Table 40. The mean values and standard deviations results were used to calculate the 95% confidence intervals using a 2-tailed *t*-distribution. The 95% confidence intervals of the mean values over each twenty hour time block for each threshold value (k = 1, 3, 6, 9, and 10) are summarized in Table 40.

Table 40: Probability Ratios for Number of Lapses: Means and Standard Deviations

Threshold Value	< 20 hrs	20 to 40 hrs	40 to 60 hrs	60 to 80 hrs	> 80 hrs
k = 1	0.937 (0.25)	1.120 (0.47)	0.897 (0.05)	0.937 (0.12)	0.998 (0.24)
k = 2	1.479 (0.16)	1.485 (0.16)	2.999 (0.01)	6.209 (0.01)	4.888 (0.01)
k = 3	0.979 (0.58)	1.713 (1.25)	1.090 (0.07)	1.095 (0.07)	1.015 (0.06)
k = 6	1.583 (1.70)	1.769 (0.69)	2.692 (0.21)	2.666 (0.23)	2.339 (0.17)
k = 9	2.317 (2.63)	2.978 (3.79)			

There was insufficient data to calculate a reliable mean for k = 9 beyond 40 hours and for k = 10 when the data were divided into twenty hour time blocks. The mean values for k = 3, 6, and 9 are greater than 1, except for k = 3 under 20 hours of wakefulness. The mean probability ratios for k = 1 were less than one. The probability ratios less than 1 do not represent the raw data well, it may be desirable to substitute a value of 1 (no change); the number of lapses is expect to increase or at least remain the same as hours of wakefulness increases. For practical applications, an appropriate value for the threshold k needs to be selected based on the situation being studied. Note that the variation of probability ratio with number of hours of wakefulness is not linear. There is not a steady increase in the derived probability ratio values as hours of wakefulness increase.

The number of lapses data collected directly from the studies show a non-linear decline in performance as hours of wakefulness increase. Figure 21 shows the non-linear increase in the mean number of lapses over hours of wakefulness. This non-linearity is to be expected, especially due to the confounding effect of several other factors; such as circadian rhythms, time-of-day influence, and time-on-task.

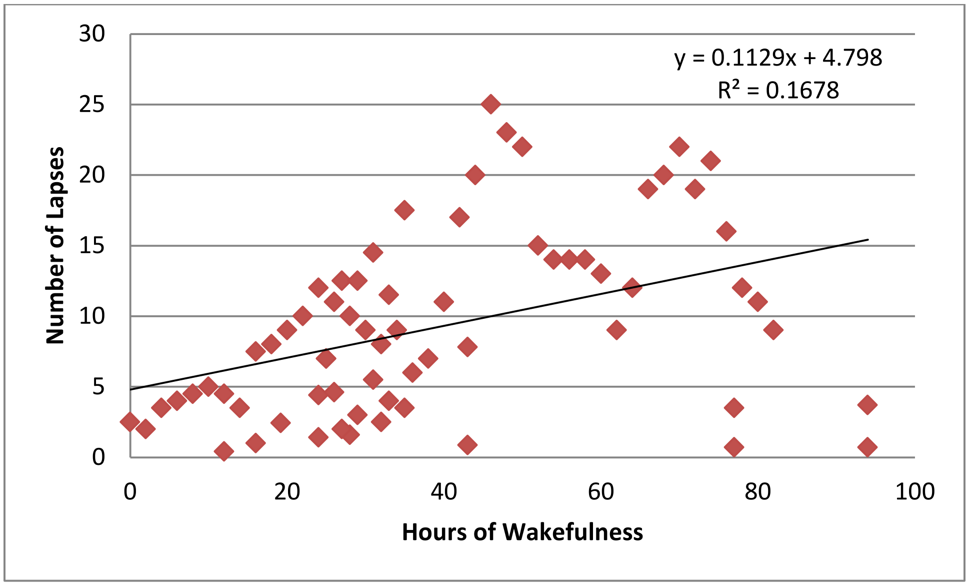

Figure 21: Number of Lapses (Test) vs. Hours of Wakefulness

Data on Reaction Time

The studies (using the *Study Id #* from the 108 list, Tables 23-25) that were used in evaluating the reaction time are listed in Table 41. The table lists studies that reported reaction time, but not hours of wakefulness, studies that did not supply variation information, studies where the difference between the mean values could be calculated, and the studies from which β and ES could be calculated.

Table 41: Studies w.r.t. Data on Reaction Time

Reaction Time	
Studies reporting reaction time	(1, 2, 3, 4, 5, 6, 7, 10, 13, 14, 15, 16, 17, 19, 20, 21, 23, 25, 28, 29, 33, 34, 35, 36, 41, 42, 45, 48, 52, 53, 54, 58, 59, 61, 62, 70, 71, 72, 75, 76, 83, 86, 87, 95, 96, 97, 98, 100, 101, 102, 103, 104, 105, 106)
Studies without hrs of wakefulness	(10, 13, 29, 34, 45, 54, 58, 59, 61, 62, 72, 75, 76, 83, 86, 87, 90
Studies without standard deviations	(5, 6, 14, 15, 16, 20, 21, 28, 29, 34, 35, 36, 52, 54, 62, 75, 102)
Difference between the mean values	(1, 2, 3, 4, 7, 17, 19, 23, 25, 33, 34, 41, 42, 48, 53, 70, 71, 76, 87, 95, 96, 97, 98, 100, 101, 103, 104, 105, 106)
Effect size	(1, 2, 3, 4, 7, 17, 19, 23, 25, 33, 41, 42, 48, 53, 70, 71, 95, 96, 97, 98, 100, 101, 103, 104, 105, 106)
Studies used	(1, 2, 3, 4, 7, 17, 19, 23, 25, 33, 34, 41, 42, 48, 53, 70, 71, 76, 87, 95, 96, 97, 98, 100, 101, 103, 104, 105, 106)

Quantitative Effect of Sleep Deprivation on Reaction Time

The initial analysis was to calculate the difference between the mean values of the control and test conditions for each data point of hours of wakefulness provided. The general trend of this data supports the hypothesis that as hours of wakefulness increase the difference between the test condition and control condition increases. The data plotted in Figure 22 have been converted to milliseconds.

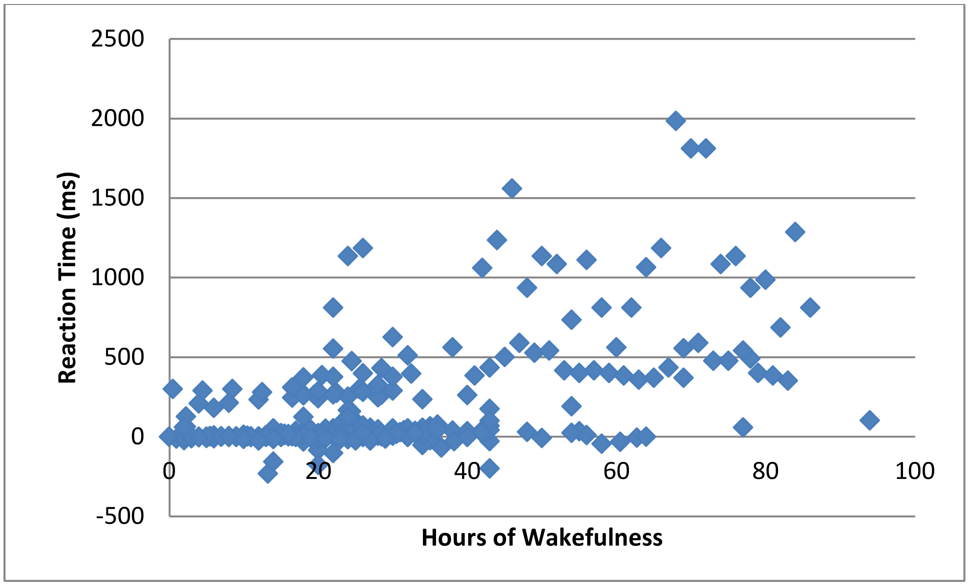

Figure 22: Difference between the Means for Reaction Time (μ_T-μ_C)

Three outliers were removed from Figure 22. Two data points from Frey et al. (2004) study identification #53-Frey_2004 (-17700 ms, 43 hours) and (-1600 ms, 43 hours) and one data point from Storer et al. (1989) study identification #70-Storer_1989 (1590.33 ms, 24 hours) were removed. The data were clustered about the reaction time axis up to twenty hours of wakefulness and the spread of the data (i.e., variance) increased beyond twenty hours of wakefulness.

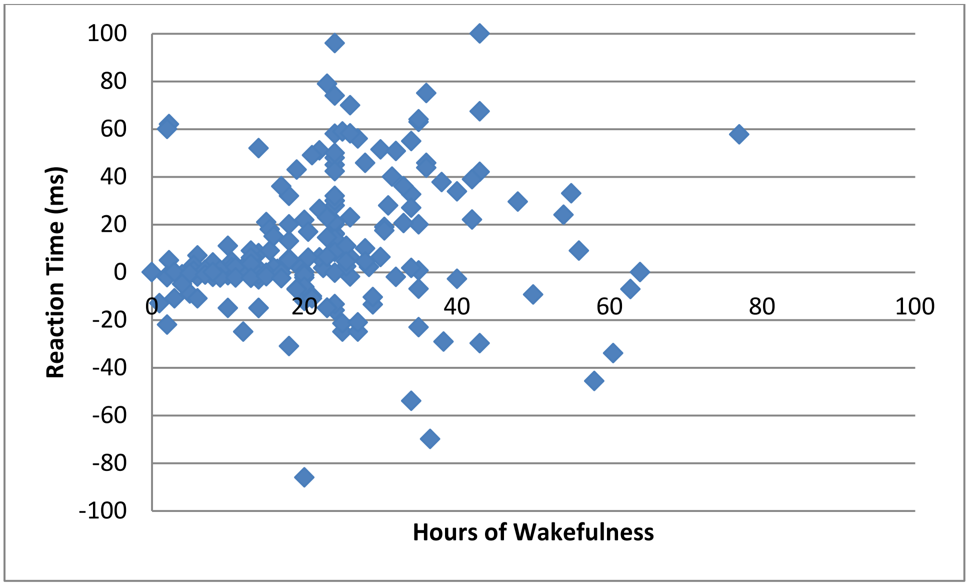

Figure 23: Difference between the Means for Reaction Time (μ_T-μ_C) (Values > 100 and < -100 Removed)

The vertical axis of Figure 22 was truncated to show only the range of reaction times from -100 to +100 in order to produce Figure 23. This figure shows that reaction time was affected differently before and after the twenty hour of wakefulness mark. Before twenty hours of wakefulness, the data were clustered near zero. This means reaction time for the test and control condition does not differ greatly up to twenty hours of wakefulness, but the difference between the test and control condition increased after twenty hours of wakefulness. The number of data points per study is presented in Table 42.

Table 42: Number of Data Points for Reaction Time

Study Id #	# Data Points per Study	Study Id #	# Data Points per Study
1	1	51	6
2	1	52	9
3	4	53	6
4	3	70	5
5	15	71	2
9	1	87	1
14	8	95	9
17	6	96	24
19	2	97	4
20	3	98	24
21	10	100	6
23	12	101	28
25	3	103	44
33	14	104	22
42	20	105	3
47	1		
48	4	106	1

There were 306 data points from thirty-four studies. The average difference between the mean values of test and control conditions was 180.84 with a standard error of 14.9. The maximum difference between test and control conditions was 1985 from Doran et al. (2001), study identification #103-Doran_2001, at 68 hours of wakefulness. The maximum of the control condition being greater than the test condition was a negative 232 from Williamson and Feyer (2000), study identification #5-Williamson_2000, at 13.27 hours of wakefulness. The reaction time after sleep deprivation (i.e., test condition) was greater than the pretest (i.e., control condition) in the majority of the data with 224 occurrences.

The next data comparison was to determine the percentage change of reaction time using Equation 15. The percentage change in reaction time is shown in Figure 24.

The number of data points per study for percentage increase is listed in Table 43. Twenty different studies provided the data.

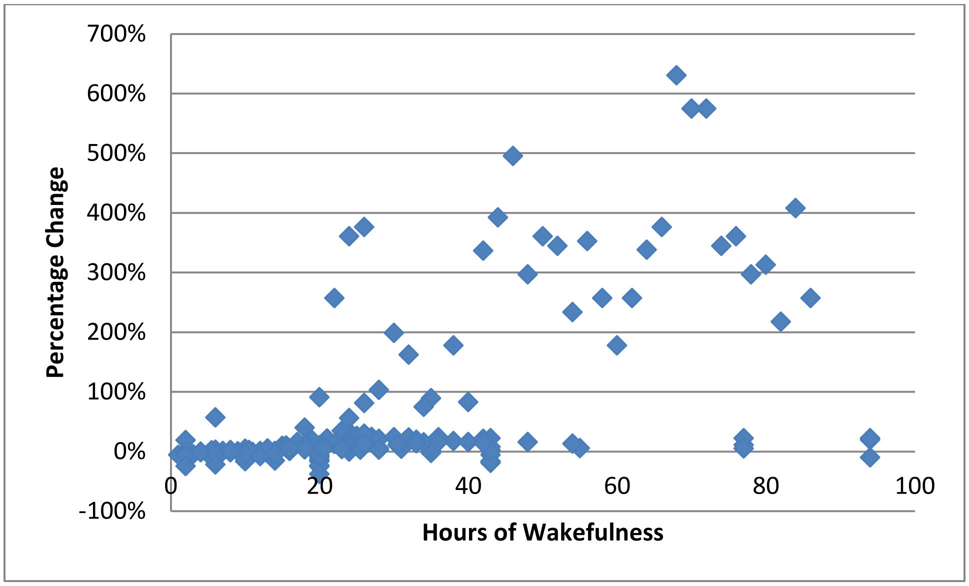

Figure 24: Percentage Change for Reaction Time

Table 43: Number of Data Points for Reaction Time Percentage Increase

Study Id #	# Data Points per Study	Study Id #	# Data Points per Study
1	1	48	4
2	1	52	9
3	4	53	8
4	3	70	6
5	15	71	2
9	1	87	1
17	6	96	12
19	2	97	4
20	3	98	24
23	12	100	6
25	3	103	44
33	14	105	3
42	20		
47	1	106	1

The data show little difference between the test and control conditions up to the twenty hour mark with even greater variance occurring after forty hours of wakefulness. There were 212 data points from 27 studies. The average percentage increase was 54.06%. The maximum percentage difference between test and control conditions was 630% from Doran et al. (2001), study identification #103-Doran_2001, at 68 hours of wakefulness. The maximum of the control condition being greater than the test condition was a negative 37.7% from Webb (1985), study identification #23-Webb_1985, at 20 hours of wakefulness.

The next step was to determine the effect size (Equation 8) and reliability index (β) values (Equation 19) for reaction time; these are plotted in Figure 25. The effect size and β values show the standardized difference between the reaction time for the control and test condition caused by hours of wakefulness. Three outliers (i.e., less than -1000) from Frey et al. (2004), study identification #53-Frey_2004, and one from Lichtor et al. (1989), study identification #71-Lichtor_1989, were removed.

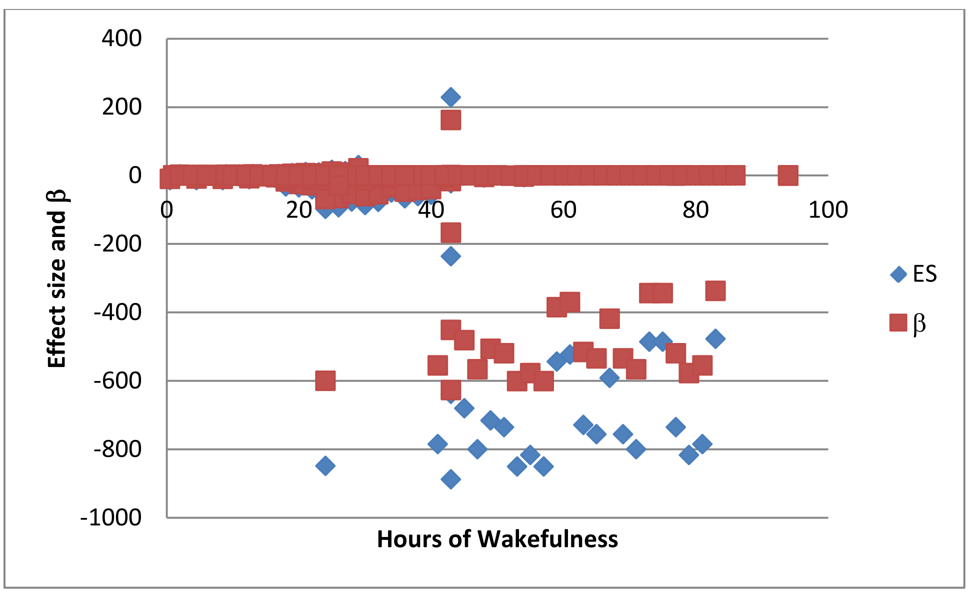

Figure 25: ES and β for Reaction Time

The majority of the calculated ES and β values for reaction time were either centered about zero (i.e., no significant difference between the control and test condition values) or heading in the negative direction (i.e., test condition reaction time greater than control condition). A negative ES implies deterioration in performance. For reaction time, the scatter of ES and β increased significantly after 40 hours of wakefulness. The number of data points per study for ES is listed in Table 44.

Table 44: Number of Data Points per Study for ES Calculation (Reaction Time)

Study Id #	# Data Points per Study	Study Id #	# Data Points per Study
1	1	71	1
2	1	87	1
3	4	95	9
4	3	96	24
17	6	97	4
23	12	98	28
25	3	100	6
33	13	101	26
42	19	103	42
47	1	104	22
48	3	105	3
53	5	106	1

The data points with ES greater or less than 10 were removed, and re-plotted in Figure 26. All the data from #47-Lamond_2007, #71-Lichtor_1989, and #104-Wesenten_2005 were removed. Twelve data points from #42-Jones_2006, four from #53-Frey_2004, six from #96-Scott_2006, three (ES) from #101-Lamond_1999 were removed. The remaining data points are listed in Table 45.

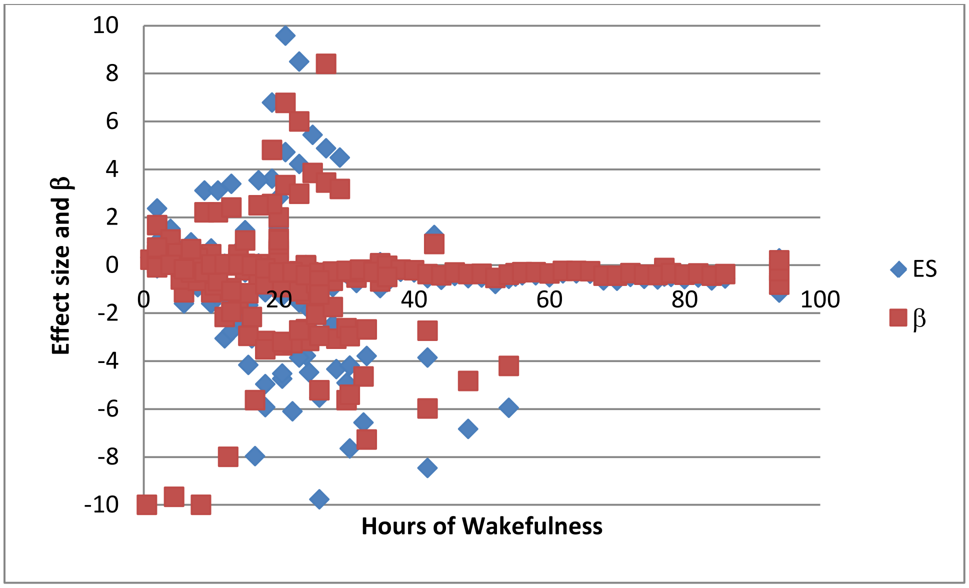

Figure 26: ES and β for Reaction Time (Values > 10 and < -10 Removed)

Table 45: Number of Data Points per Study for ES and β for Reaction Time (Values >10 Removed)

Study Id #	ES	β	Study Id #	ES	β
1	1	1	87	1	1
2	1	1	95	9	9
3	4	4	96	18	18
4	3	3	97	4	4
17	6	6	98	28	28
23	12	12	100	6	6
25	3	3	101	23	24
33	13	13	103	42	42
42	7	7	105	2	2
48	3	3			
53	1	1	106	1	1

The probability of error, as defined as larger reaction time after sleep deprivation than at the baseline condition, is calculated using the β from Equation 17. The probability of $T > C$ using Equation 19 is plotted in Figure 27.

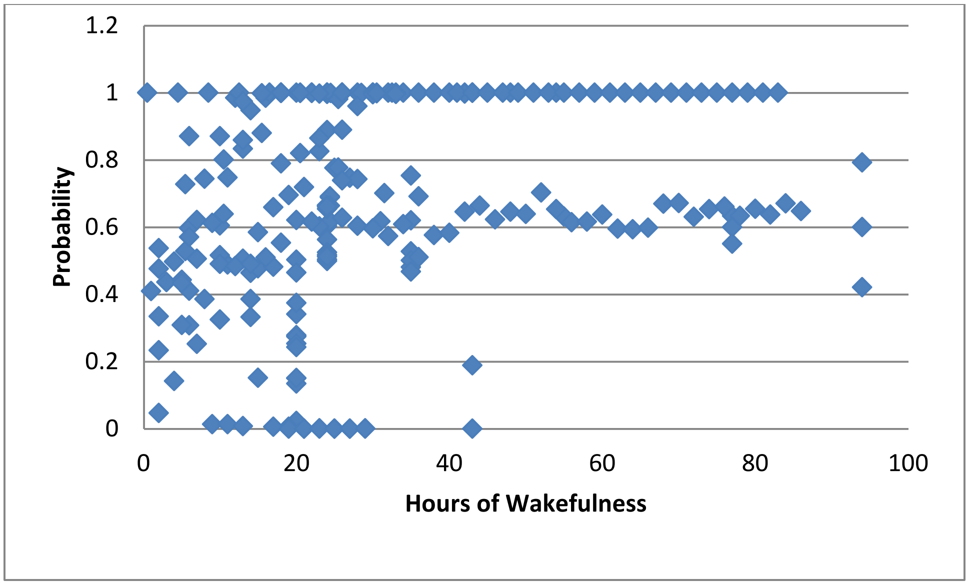

Figure 27: Probability P(*T* > *C*) for Reaction Time

The probability of $T > C$ for reaction time has a cluster of data at the probability of one. This shows that a majority of test condition reaction times are larger than the control condition. The probability of error approaches one as hours of wakefulness increase.

Reaction Time Regression

Two types of regression were performed on the reaction time data. The first regression was a within-study regression to develop a predictive model of reaction time based on hours of wakefulness. This model was developed using all available data from all studies reporting reaction time. This model was then used in a between-studies regression to examine the effect of study variables and subject characteristics on performance. A second linear regression was performed on a smaller sample of studies

(5 studies) that were similar in study design and investigated performance using a simple reaction time task.

A linear regression was performed on the reaction time data. An intercept (b_0), linear coefficient (b_1), and curvilinear coefficient (b_2) of a quadratic model were found by a multi-variate regression for each study separately. The hours of wakefulness were used as the independent variable and reaction time was used as the dependent variable. Studies that had only one time measure were graphed in order to find the regression coefficients (#1-Nilsson_2005, #2-Thomas_2000, #7-Robbins_1990, #9-Babkoff_2005, #10-Swann_2006, #14-Buck_1972, #23-Webb_1985, #47-Lamond_2007, and #106-Drake_2001). The resulting coefficients are listed in Table 46.

Table 46: Reaction Time vs. Hours of Wakefulness: Within-Study Regression Coefficients

Study #	b_0	b_1	b_2	*N*	*W* - b_0	*W* - b_1
1	1.037	31.5	0	11	0.021	0.653
2	0.765	24	0	17	0.024	0.768
4	663	0	0.086	13	16.232	0
5	1957.600	-24.021	1.355	39	143.779	-1.764
7	0.943	35	0	23	0.041	1.516
9	0.866	24	0	12	0.020	0.542
14	-0.888	24	0	14	-0.023	0.633
17	968	0	0.0191	14	25.522	0
20	192.756	13.137	-0.055	8	2.904	0.198
21	-0.730	22.421	-0.447	9	-0.012	0.380
23-Y	12.16	0	0	12	0.275	0
23-O	0.691	20	0	6	0.008	0.226
25	644	0	0.091	12	14.554	0
33	217.313	0.884	0.085	16	6.548	0.027
42	205.118	2.162	-0.017	32	12.361	0.130
47	1.447	24	0.000	30	0.082	1.356
48	599.226	2.005	-0.021	32	36.112	0.121
52	89.533	4.831	-0.033	12	2.023	0.109
52	228.55	0	0.002	12	5.165	0
70	170.658	67.968	-1.944	26	8.356	3.328
71	335	0	0.130	6	3.785	0.000
95	286.336	4.911	-0.011	12	6.471	0.111
96	310.518	0.149	0.024	3	1.754	0.001
97	1683.750	0	0.196	26	82.444	0
98	168.771	0.221	0.012	17	5.403	0.0071
100	559.567	0.539	0.007	31	32.668	0.0315
102	216.714	15.669	-0.322	12	4.897	0.3541
103	124.742	33.565	-0.210	13	3.054	0.8217
104	11.984	15.407	-0.129	12	0.271	0.3482
105	117.5	0	0.514	25	5.532	0
106	1.031	36	0	12	0.023	0.814

The intercept (b_0), linear coefficient (b_1), and second order coefficient (b_2) for all the studies were averaged to derive an equation for predicted reaction time. The simple average of regression coefficients from Table 46 is listed in Table 47. These equations were then used to perform a between-study regression to find the relationship between-study characteristics and the performance variable (i.e., reaction time).

Table 47: Overall Reaction Time Equation Based on Within-Study Regression

	b_0	b_1 (H)	b_2 (H^2)
Simple Avg. y =	315.01	12.2	-0.022
Weighted Avg. y =	13.56	0.346	0.001

The within-study regression results were used to examine the effect of study variables and subject characteristics on reaction time. These study variables were type of industry (i.e., medical, military, general industry, transportation and academia as the default), percentage of male subjects, age of subjects, type of task (i.e., PVT, simple reaction time, grammatical reasoning, or real-world task), and task characteristics (simple or complex, self or work paced, and primary or secondary). The resulting coefficients are listed in Table 48.

Table 48: Between-Studies Regression Coefficients for Reaction Time vs. Hours of Wakefulness

	Intercept	Medical	Military	Industry	Transpor.	Sex of Group	Age
b_0	737.808	21.227	178.779	0	770.494	1.165	0.754
b_1	3.207	15.680	-1.674	0	-11.115	-0.061	-0.022
b_2	-0.066	-0.403	-0.114	0	0.239	0.002	0.001

	PVT	SRT	Gramm Reas.	Real-world	Complex	Work Pace	Primary
b_0	-191.367	158.552	0	1408.340	155.683	39.468	-673.602
b_1	7.949	-3.910	0	-7.010	-6.581	-1.068	11.921
b_2	-0.039	0.436	0	0.033	0.296	0.025	-0.115

	Intercept	Medical	Military	Industry	Transpor.	Sex of Group	Age
$W - b_0$	28.061	5.156	11.213	0	66.089	-0.013	0.369
$W - b_1$	0.213	1.020	-0.095	0	-0.752	-0.004	-0.002
$W - b_2$	-0.005	-0.020	-0.002	0	0.034	0.000	0.000

	PVT	SRT	Gramm Reas.	Real-world	Complex	Work Pace	Primary
$W - b_0$	-11.957	19.036	0	82.941	-0.287	-8.547	-25.682
$W - b_1$	0.320	-0.401	0	0.141	-0.586	-0.276	0.542
$W - b_2$	-0.002	0.026	0	0.003	0.014	0.001	-0.007

This between-study regression identifies the effect of study characteristics that drive the outcomes of the studies. The regression results in Table 48, found that if the study was conducted in the environment of general industry, or if the task used was a grammatical reasoning task, the comparison between studies was not significantly affected. The analysis was performed again without *industry* and or *grammatical reasoning* study variables; the second between-study regression results are in Table 49.

Table 49: Between-Studies Regression for Reaction Time: Non-Significant Variables Removed

	Intercept	Medical	Military	Transpor.	Sex of Group	Age
b_0 *	737.808	21.227	178.779	770.494	1.165	0.754
b_1 *	3.207	15.680	-1.674	-11.115	-0.061	-0.022
b_2 *	-0.066	-0.403	-0.114	0.239	0.002	0.001

	PVT	SRT	Real-world	Complex	Work Pace	Primary
b_0 *	-191.367	158.552	1408.340	155.683	39.468	-673.602
b_1 *	7.949	-3.910	-7.010	-6.581	-1.068	11.921
b_2 *	-0.039	0.436	0.033	0.296	0.025	-0.115

	Intercept	Medical	Military	Transpor.	Sex of Group	Age
$W - b_0$ *	28.061	5.156	11.213	66.089	-0.013	0.369
$W - b_1$ *	0.213	1.020	-0.095	-0.752	-0.004	-0.002
$W - b_2$ *	-0.005	-0.020	-0.002	0.034	0.000	0.000

	PVT	SRT	Real-world	Complex	Work Pace	Primary
$W - b_0$ *	-11.957	19.036	82.941	-0.287	-8.547	-25.682
$W - b_1$ *	0.320	-0.401	0.141	-0.585	-0.276	0.542
$W - b_2$ *	-0.002	0.026	0.003	0.014	0.001	-0.007

The between-study regression coefficients in Table 49 can be used to transform data from any study into a specific set of study variables. For example, if an analyst were interested in performance on the PVT task, studies that did use the PVT to evaluate performance can be transformed to the PVT space using the between-study regression results. The b_2 coefficients were small across all the variables, meaning that the linear component (b_1) was a better representation of the study characteristics that affected reaction time performance than the curvilinear component (b_2).

Predictive Modeling of Reaction Time vs. Hours of Wakefulness

The calculation of effect sizes allows for the consideration of a larger variety of studies; however, in the case of regression for predictive modeling, the studies and tasks need to be very similar. The pool of studies was reduced to five studies that could be used in a predictive model regression analysis of reaction time vs. hours of wakefulness. Five studies were found to use simple reaction time as the performance task: Dinges and Powell, 1988; Jones et al., 2006; Roach et al., 2006; Thorne et al., 2005; and Wilson et al., 2007.

Five studies that used a simple reaction time measure were used to perform a linear regression for within study characteristics using reaction time as the dependent variable and the hours of wakefulness as the independent variable for linear regression. An intercept (b_0) and linear coefficient (b_1) were calculated for each study. The within-study (i.e., each individual study) regression coefficients, the number of data points from each study, the R^2 values (raw and adjusted), and the residual fitting errors between actual reaction time data and the predicted reaction time (ε_{min}, ε_{mean}, ε_{max}) are listed in Table 50.

Table 50: Reaction Time Predictive Model: Within-Study Regression Results

Study	No. of Data Pts.	b_0	b_1	R^2	R^2 Adjusted	ε_{min}	ε_{mean}	ε_{max}
Wilson et al., 2007	5	213.50	2.47	0.330	0.107	0.33	5.17	9.26
Roac et al., 2006	15	208.62	3.14	0.842	0.829	0.04	8.36	27.16
Jones et al., 2006	20	209.39	1.49	0.733	0.719	0.03	8.54	26.87
Dinges and Powell, 1988	16	188.10	0.60	0.646	0.620	0.90	5.21	14.10
Thorne et al., 2005	21	296.21	2.90	0.088	0.040	5.75	63.16	463.09
All Data	77	237.90	1.46	0.04	0.03			

A regression of the five studies, using all 77 data points, results in Equation 24, which uses the coefficient values from row "All Data" in Table 50:

$$RT_{all\ data} = 237.9 + 1.46H \quad (24)$$

where,

RT = reaction time
H = hours of wakefulness.

All 77 data points from the five studies are plotted in Figure 28. The linear regression equation is included in the plot.

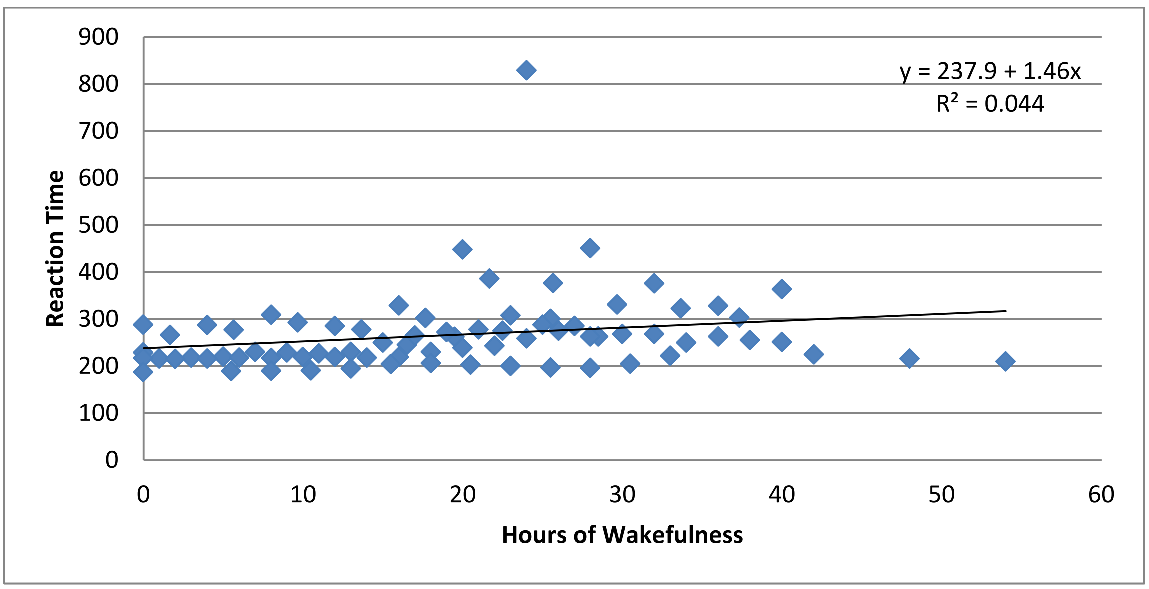

Figure 28: Regression of Reaction Time Data from Five Studies (77 Data Points)

The resulting equation of all the data from five studies has poor predictive capability with a low R^2 value of 0.044. The individual regressions done on each study (within-study regression), of three of the five studies (#11-Roach_2006, #14-Jones_2006, and #24-Dinges_1988) had fairly high R^2 values, greater than 0.6. The regressions of the other two studies (#12-Wilson_2007 and #31-Thorne_2005) had low R^2 values, 0.330 and 0.088 respectively.

A validation of the predictive equation coefficients can be carried out by removing one study from the five studies and performing the regression using the remaining four studies (i.e. leave-one-out cross-validation). The results of the leave-one-out validation are presented in Table 51, including the residual fitting errors between actual reaction time data and the predicted reaction time (ε_{min}, ε_{mean}, ε_{max}). The results show consistent results for the regression coefficients, with low R^2 values.

Table 51: Leave-one-out Cross-Validation Results

Study Removed	b_0	b_1	R^2	R^2 Adjusted	ε_{min}	ε_{mean}	ε_{max}
Removed Wilson	238.16	1.45	0.044	0.030	4.2	8.6	17.1
Removed Roach	245.42	1.19	0.026	0.010	0.6	20.2	35.2
Removed Jones	247.52	1.50	0.036	0.019	11.5	38.4	56.5
Removed Dinges	236.00	2.54	0.107	0.092	49.0	93.3	163.2
Removed Thorne	217.66	0.85	0.121	0.105	46.9	119.2	590.8

The data set was further reduced by including only data collected for 24 hours or less of wakefulness; only 50 data points remained. This was done in order to limit the effect of diurnal behavior of performance due to circadian rhythms. The reduced data set was then used to perform a with-in study regression. The R^2 values showed much improvement as shown in Table 52.

Table 52: Summary of Within-Study Regression Data for ≤ 24 Hours of Wakefulness

Study	No. of Data Pts.	b_0	b_1	R^2	R^2 Adjusted	ε_{min}	ε_{mean}	ε_{max}
Wilson et al., 2007	3	163.17	5.00	0.994	0.988	3.05	6.49	13.25
Roach et al., 2006	13	207.28	3.32	0.800	0.782	2.56	13.99	39.17
Jones et al., 2006	13	208.07	1.44	0.678	0.649	8.18	30.36	46.84
Dinges and Powell, 1988	9	185.21	0.86	0.761	0.728	40.27	65.18	88.55
Thorne et al., 2005	12	255.02	5.28	0.509	0.460	3.76	62.72	171.68
All Data	50	220.84	2.246	0.107	0.089			

A leave-one-out cross validation of the predictive coefficients was performed on the reduced data set; only data less than or equal to 24 hours of wakefulness were used from the remaining four studies. The results of the leave-one-out validation are presented in Table 53.

Table 53: Leave-one-out Cross-Validation Results ≤ 24 Hours of Wakefulness

Study Removed	b_0	b_1	R^2	R^2 Adjusted	ε_{min}	ε_{mean}	ε_{max}
Removed Wilson	220.88	2.26	0.102	0.082	3.88	36.97	181.84
Removed Roach	226.44	1.84	0.057	0.030	0.30	43.10	184.70
Removed Jones	225.18	2.54	0.110	0.084	0.44	40.14	172.10
Removed Dinges	227.27	2.69	0.168	0.146	1.80	33.71	167.08
Removed Thorne	202.28	2.03	0.300	0.281	1.40	18.21	59.00

The leave-one-out validation showed consistent results for the regression coefficients. However, the resulting R^2 values were still quite low, with the best R^2 value (0.281) obtained by leaving out Thorne et al. (2005). The average difference between the actual reaction time data and the predicted value from the leave-one-out validation is 34.4 ms.

The mean squared residual errors from the regression results were used to weight the regression coefficients. The residual mean squared values for the five studies are listed in Table 54.

Table 54: Residual Mean Squared Values ≤ 24 Hours of Wakefulness

Study	Residual MS
Wilson et al., 2007	2.7
Roach et al., 2006	175.7
Jones et al., 2006	64.7
Dinges and Powell, 1988	14.7
Thorne et al., 2005	1530.0

A weighted regression of the data (less than or equal to 24 hours of wakefulness from the five studies and 50 data points) results in Equation 25, using the residual mean square variance from the regression in Table 54:

$$\boldsymbol{RT_{Weighted} = 180.35 + 3.8H} \qquad (25)$$

where,

RT = reaction time
H = hours of wakefulness.

Equation 25 is the weighted regression model based on the amount of variance of the data, using mean square residual values. The regression results of all five studies and 50 data points are plotted in Figure 29 and the weighted regression is plotted in Figure 30.

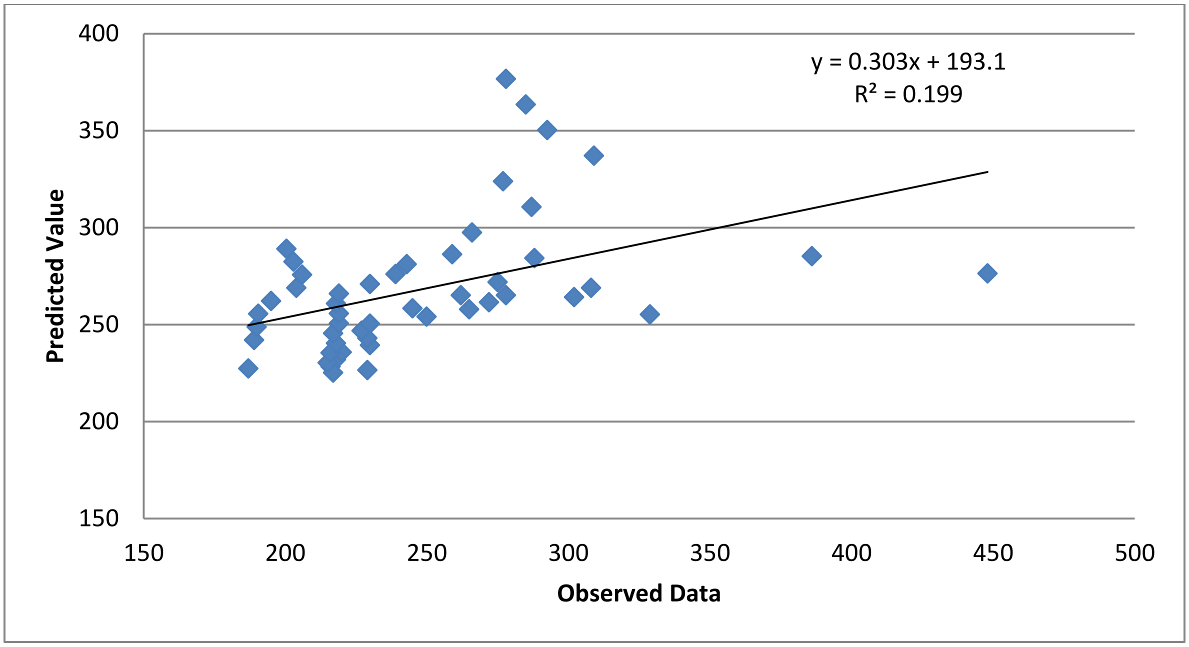

Figure 29: Simple Regression of 5 Studies with Reaction Time Data (≤ 24 Hours of Wakefulness)

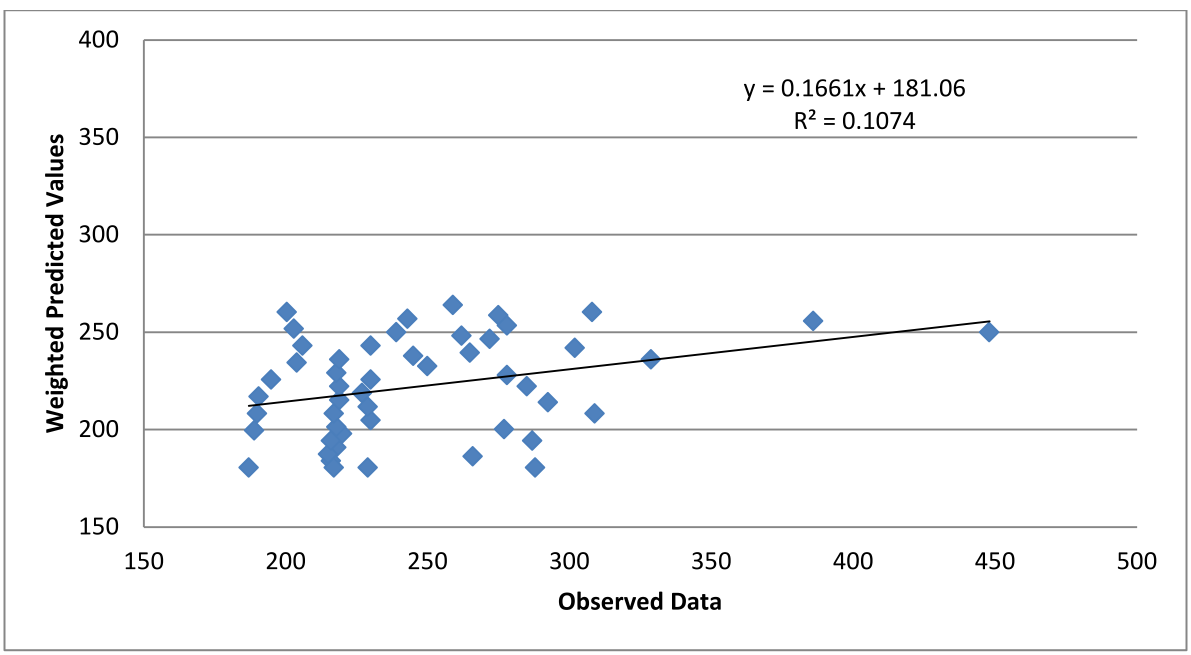

Figure 30: Weighted Regression of 5 Studies with Reaction Time Data (≤ 24 Hours of Wakefulness)

The low R^2 values for both the non-weighted and weighted regression results of 0.199 (un-weighted) and 0.107 (weighted) imply that linear regression may not be the best representation of the available data for predictive purposes. The individual study regression (with-in study) had reasonably high R^2 values; however, the predictability of reaction time using all the data from Figures 29-30 has a low reliability (based on R^2 values). Weighting does not seem to significantly improve the results. Overall, the predictability of reaction time using the data from the five studies for hours of wakefulness is not satisfactory.

Derivation of Probability Ratios for Reaction Time

The error under the control condition and test conditions were assumed to be $C > k$ and $T > k$ respectively, where k (i.e., threshold value) was a selected constant and C and T were reaction times for the control and test condition. The corresponding probabilities of error were calculated using Equations 21 and 22. In simple reaction time psychomotor tasks, a lapse is defined as failure to respond within 500 ms (Anderson et al., 2010); the k values were selected using this knowledge; the threshold k values selected were: $k =$ 250, 300, 400, 500, 750, and 1000. The probability ratios $P(T > k) / P(C > k)$, signifying deterioration in performance under the test condition, were plotted in Figure 31.

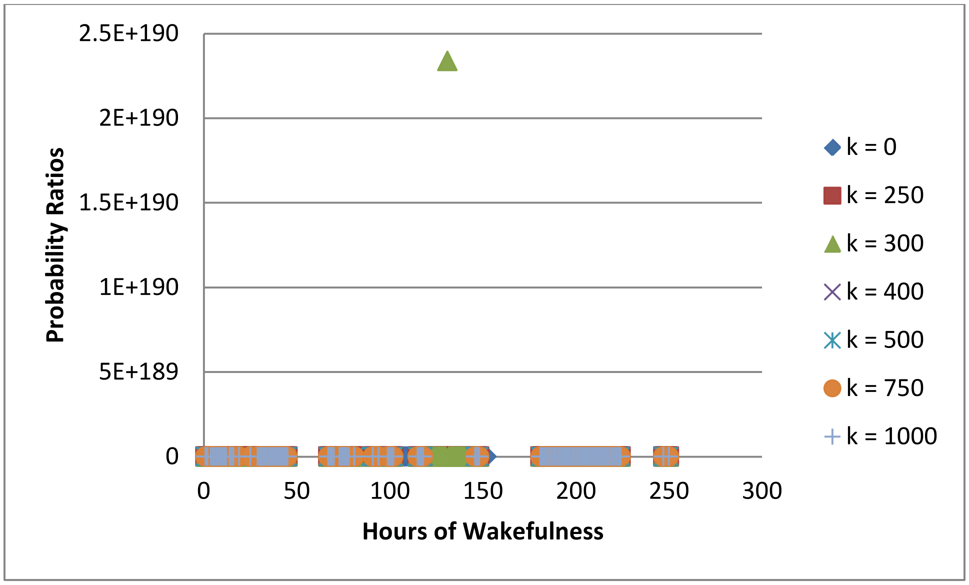

Figure 31: Probability Ratios for Reaction Time vs. Hours of Wakefulness

Seven data series were plotted in Figure 31. When the control condition probability was significantly closer to zero than the test condition, it caused the resulting ratio to *artificially inflate* and resulted in outliers. To improve the resolution of the data, values greater than ten were removed and the probability ratios were re-plotted in Figure 32.

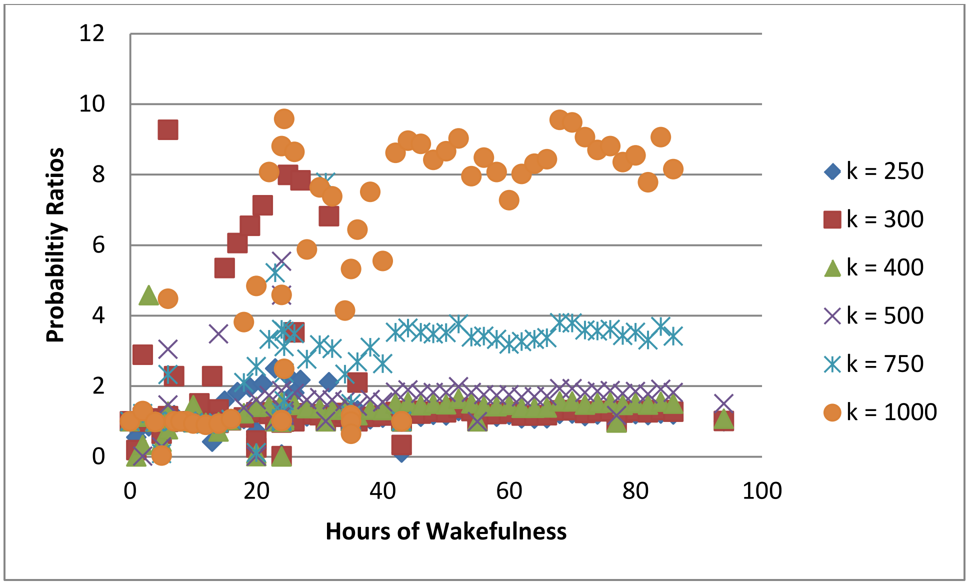

Figure 32: Probability Ratios for Reaction Time (Values >10 Removed)

Because outliers greater than ten were removed, the trend of data is much easier to observe in Figure 32. A threshold value of *k* = 1000 has a noticeably different trend than that of the other *k* values. And *k* = 300 has a larger spread of data under the 40 hours of wakefulness region than the other data. Separate plots of *k* = 250 (i.e., half the time of a lapse), *k* = 500 (i.e., the time of lapse), and *k* = 1000 (i.e., twice the time of a lapse) are plotted in Figures 33-36.

The probability ratios for *k* = 250 and *k* = 400 were plotted in Figure 33. Probability ratios for *k* = 250 data have a greater spread for PSF coefficients between fifteen and thirty hours of wakefulness. Best-fit equations for data subdivided by intervals of hours of wakefulness, less than twenty hours, twenty hours, twenty to forty hours, forty to sixty hours, and sixty to eighty hours are listed in Table 55. The probability ratios produced from *k* = 250 and *k* = 400 were not able to be fitted very well with best-fit equations, as indicated by the low R^2 values. The probability ratios for *k* =

400 did produce data that were able to be better described by best-fit equations than *k* = 250.

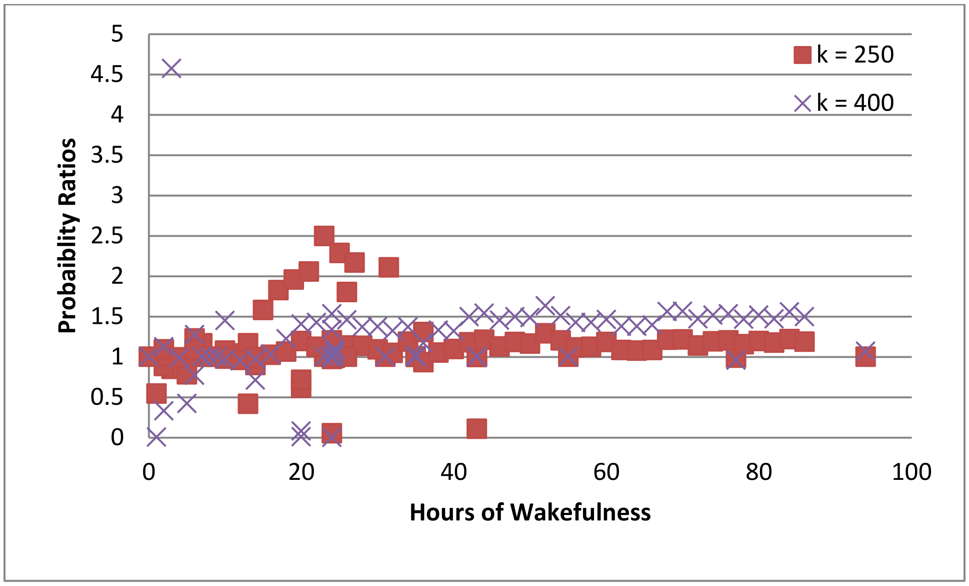

Figure 33: Probability Ratios for Reaction Time (*k* = 250, 400)
(Values >10 Removed)

Table 55: Probability Ratios Regression Models for Reaction Time (*k* = 250, 400)

Hours	R^2	***k* = 250**
< 20	0.450	$y = -3E-06x^6 + 0.000x^5 - 0.002x^4 + 0.013x^3 - 0.027x^2 + 0.005x + 0.898$
20 to 40	0.113	$y = -7E-06x^6 + 0.001x^5 - 0.087x^4 + 3.423x^3 - 74.27x^2 + 848.9x - 3993.$
40 to 60	0.678	$y = -1E-07x^6 + 5E-05x^5 - 0.007x^4 + 0.536x^3 - 22.00x^2 + 474.6x - 4210.$
60 to 80	0.457	$y = 6E-07x^5 - 0.000x^4 + 0.016x^3 - 0.723x^2 + 9.642x + 83.15$
Hours	R^2	***k* = 400**
< 20	0.171	$y = -2E-06x^6 + 0.000x^5 - 0.002x^4 + 0.033x^3 - 0.246x^2 + 0.830x + 0.439$
20 to 40	0.297	$y = -5E-06x^6 + 0.000x^5 - 0.063x^4 + 2.485x^3 - 54.17x^2 + 622.7x - 2949.$
40 to 60	0.861	$y = -6E-07x^6 + 0.000x^5 - 0.024x^4 + 1.703x^3 - 66.48x^2 + 1375.x - 11792$
60 to 80	0.335	$y = 5E-06x^5 - 0.001x^4 + 0.228x^3 - 15.12x^2 + 498.6x - 6543.$

PSF coefficients for k = 300 were plotted in Figure 34. Probability ratios for k = 300 data have a greater spread for PSF coefficients between zero and thirty-five hours of wakefulness. Best-fit equations for data subdivided by intervals of hours of wakefulness, less than twenty hours, twenty to forty hours, forty to sixty hours, and sixty to eighty hours are listed in Table 56. Best-fit equations for the subdivided data are listed in Table 56. Very low R^2 values were associated with the best-fit equations for k = 300. The probability ratios for k = 300 were able to be better described by best-fit equations than for other threshold values.

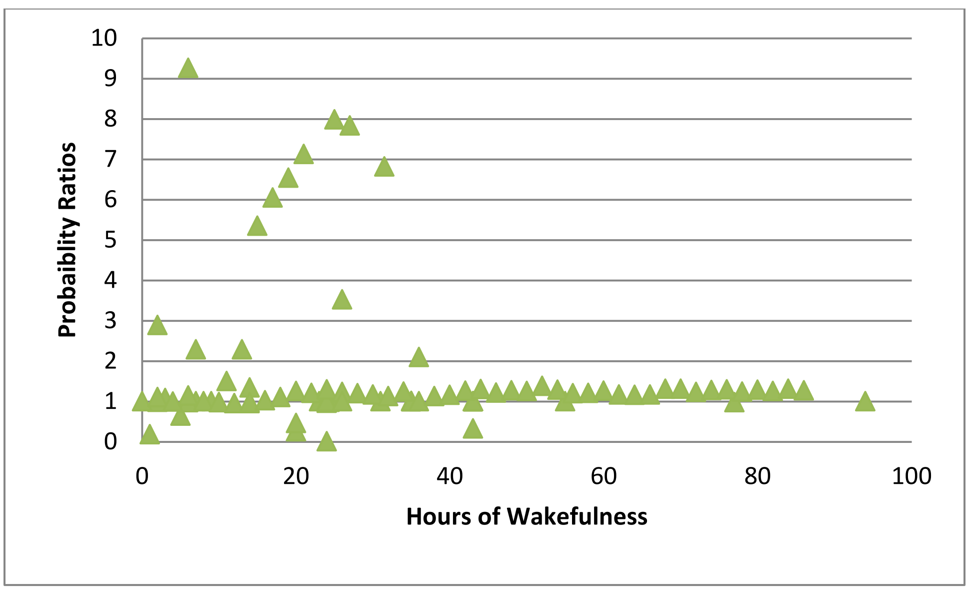

Figure 34: Probability Ratios for Reaction Time (*k* = 300) (Values >10 Removed)

Table 56: Probability Ratios Regression Models for Reaction Time (*k* = 300) (Values >10 Removed)

Hours	R^2	k = 300
< 20	0.220	$y = -2E\text{-}06x^6 + 4E\text{-}07x^5 + 0.003x^4 - 0.064x^3 + 0.387x^2 - 0.438x + 0.933$
20 to 40	0.124	$y = -2E\text{-}05x^6 + 0.004x^5 - 0.324x^4 + 12.52x^3 - 268.2x^2 + 3026.x - 14042$
40 to 60	0.717	$y = -2E\text{-}07x^6 + 7E\text{-}05x^5 - 0.009x^4 + 0.688x^3 - 27.81x^2 + 592.4x - 5203.$
60 to 80	0.385	$y = 2E\text{-}06x^5 - 0.000x^4 + 0.077x^3 - 4.883x^2 + 150.9x - 1831.$

The probability ratio for *k* = 500 and *k* = 750 were plotted in Figure 35. The data after 20 hours of wakefulness steadily increased. The data have a greater spread for PSF coefficients less than 20 hours.

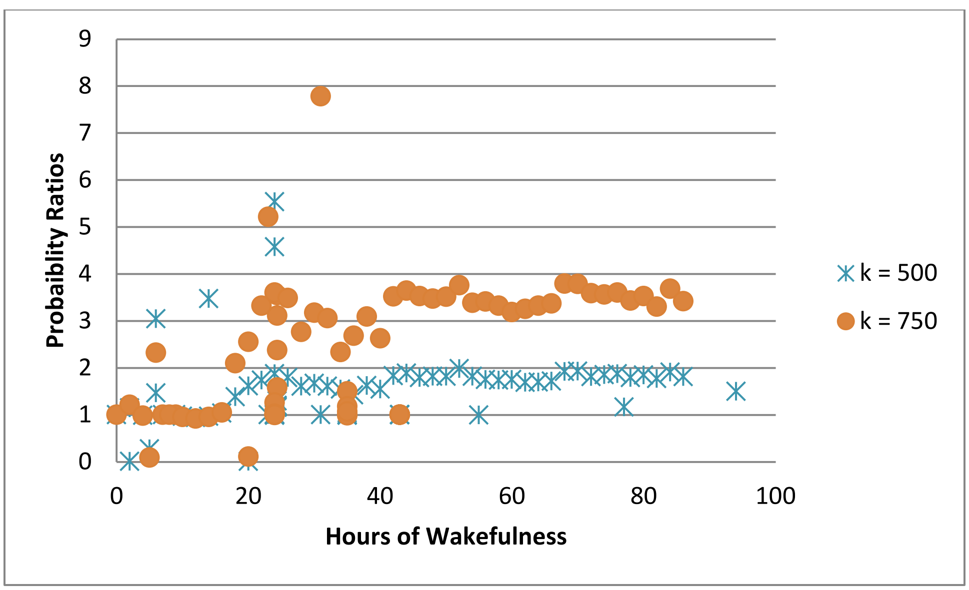

Figure 35: Probability Ratios for Reaction Time (*k* = 500, 750) (Values>10 Removed)

For *k* = 500, fifteen outlier data points (i.e., probability ratios greater than ten) were removed from the eighty-four probability ratios calculated, to give an overall mean value of 1.47. The probability ratios before twenty hours of wakefulness are approximately one, i.e., no change in performance. From twenty to forty hours of wakefulness the probability ratios fluctuate between one and two, then approaches a steady value of around 2.0 for k = 500 and 3.5 for k = 750 after forty hours of wakefulness. This shows that performance approaches a constant impairment value and does not increase linearly as hours of wakefulness increase. The affected performance values reflect the raw data that shows an increase in simple reaction time after twenty-four hours of wakefulness.

The best-fit equations for k = 500 and k = 750 are listed in Table 57. Low R^2 values of the best-fit lines for k = 500 and k = 750 do not provide meaningful fit equations. The best-fit equations for the threshold values of k = 500 and k = 750 do not fit the data well.

Table 57: Probability Ratios Regression Models for Reaction Time (k = 500, 750)

Hours	R^2	k = 500
< 20	0.228	$y = -4E{-}05x^5 + 0.001x^4 - 0.027x^3 + 0.182x^2 - 0.356x + 0.881$
20 to 40	0.066	$y = -4E{-}06x^6 + 0.000x^5 - 0.058x^4 + 2.271x^3 - 49.53x^2 + 570.8x - 2715.$
40 to 60	0.797	$y = -4E{-}07x^6 + 0.000x^5 - 0.015x^4 + 1.094x^3 - 43.30x^2 + 906.4x - 7846.$
60 to 80	0.352	$y = 7E{-}06x^5 - 0.002x^4 + 0.299x^3 - 19.91x^2 + 659.9x - 8709$
Hours	R^2	k = 750
< 20	0.341	$y = -6E{-}05x^5 + 0.002x^4 - 0.043x^3 + 0.274x^2 - 0.579x + 1.126$
20 to 40	0.410	$y = -4E{-}05x^6 + 0.007x^5 - 0.550x^4 + 21.63x^3 - 472.2x^2 + 5428.x - 25673$
40 to 60	0.948	$y = -7E{-}06x^6 + 0.002x^5 - 0.262x^4 + 17.70x^3 - 671.2x^2 + 13533x - 11336$
60 to 80	0.840	$y = -1E{-}06x^6 + 0.000x^5 - 0.094x^4 + 8.760x^3 - 454.6x^2 + 12546x - 14384$

The probability ratios for k = 1000 were plotted in Figure 36. These probability ratios form a very different pattern than the other threshold values. But they have a larger variation and center around a value of eight, after 40 hours of wakefulness. The best-fit equations for k = 1000, shown in Table 58, have the best R^2 values overall among the selected threshold values.

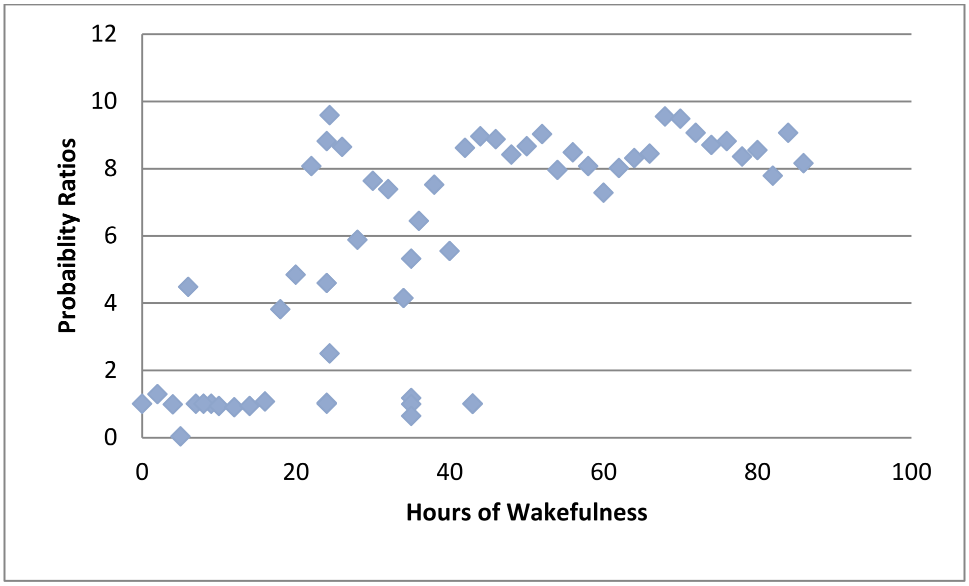

Figure 36: Probability Ratios for Reaction Time (*k* = 1000) (Values >10 Removed)

Table 58: Probability Ratio Regression Models for Reaction Time (*k* = 1000)

Hours	R^2	k = 1000
< 20	0.391	$y = -3E\text{-}05x^5 + 0.001x^4 - 0.034x^3 + 0.234x^2 - 0.393x + 1.046$
20 to 40	0.294	$y = -6E\text{-}05x^6 + 0.011x^5 - 0.834x^4 + 32.22x^3 - 691.0x^2 + 7804x - 36249$
40 to 60	0.937	$y = -2E\text{-}06x^6 + 0.000x^5 - 0.076x^4 + 5.197x^3 - 199.0x^2 + 4049.x - 34202$
60 to 80	0.911	$y = -5E\text{-}06x^6 + 0.002x^5 - 0.354x^4 + 32.98x^3 - 1720.x^2 + 47749x - 55077$

The best-fit line equations for k = 1000 had the best R^2 values overall. However, a poor fit was associated with data less than 10 hours of wakefulness (0.126), between twenty and thirty hours of wakefulness (0.101), and between twenty and forty hours of wakefulness (0.294). The best-fit for less than 10 hours of wakefulness was found for k = 400 with an R^2 = 0.301; the best-fit for between twenty and thirty hours of wakefulness was found for k = 750 with an R^2 = 0.471, and the best-fit for between twenty and forty hours of wakefulness was found for k = 750 with an R^2 = 0.410.

The threshold value of k = 1000 has a noticeably different trend than that of the other k values. PSF coefficients calculated for k = 1000 have a larger variation and center about a value of eight, after forty hours of wakefulness. The control/test condition reaction time being greater than 1000 ms (twice the length of a lapse at 500 ms) should occur less frequently than for example, k = 250. The higher PSF coefficient values increase the nominal human error probability (HEP) to a greater degree than the other selected threshold values (i.e., k = 250, 500, 750). Probability ratios for k = 250 data have a greater spread for PSF coefficients between fifteen and thirty hours of wakefulness.

Uncertainty Analysis of Probability Ratios for Reaction Time

The descriptive statistics data for all the data provided in the studies are listed in Table 59, (e.g., hours of wakefulness, N-control, N-test, μ-Control, μ-Test, σ-Control, and σ-Test). The average number of subjects per study was approximately 17.

Table 59: Descriptive Statistics for Reaction Time

Hours of Wakefulness		N- Control	N-Test	μ-Control (ms)	μ-Test (ms)	σ-Control	σ-Test
Mean	30.227	17	16	1445.469	1102.365	181.238	466.268
Standard Error	1.374	0	1	722.339	422.167	26.851	68.010
Standard Deviation	21.683	8	8	9637.202	6661.683	358.233	1073.184
Sample Variance	470.149	58	65	9.29E+07	4.44E+07	1.28E+05	1.15E+06
Minimum	0.000	6	3	0.830	-25.000	0.030	-4.250
Maximum	94.000	32	32	9.250E+04	7.480E+04	2641.292	5408.327
Count	249	249	249	178	249	178	249
Confidence (95.0%	2.706	1	1	1425.505	831.490	52.989	133.951

The probability ratios calculated show significant variability due to sparse data. Data are subdivided into twenty hour intervals (i.e., < 20, 20-40, 40-60, 60-80, and > 80 hours). Figure 37 shows the 95% confidence interval spread of the calculated probability ratios for each time block. Using the sample size, mean, and standard deviation of the data for each time block, the 95% confidence intervals for k = 500 are calculated using the t-distribution and the results are provided in Figure 37 and Table 60.

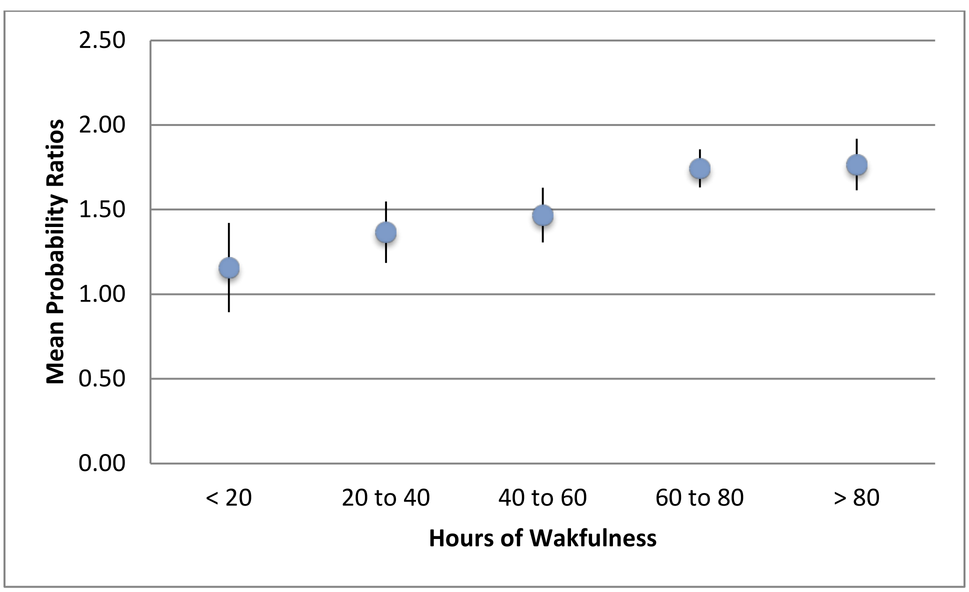

Figure 37: Mean Probability Ratios and 95% Confidence Intervals of the Mean for Reaction Time (k = 500)

Table 60: Mean Probability Ratios for Reaction Time and 95% CI (*k* = 500)

Time Block	N	PSF Mean	95% CI
< 20 hrs	17	1.16	[0.89, 1.42]
20 to 40 hrs	34	1.37	[1.19, 1.55]
40 to 60 hrs	17	1.47	[1.31, 1.63]
60 to 80 hrs	11	1.74	[1.63, 1.86]
> 80 hrs	5	1.77	[1.61, 1.92]

For *k* = 500, all five time-blocks report mean probability ratios in the range [1, 2], as shown in Table 60. The PSF coefficient values greater than 1.0 increase the HEP (human error probability). The largest mean probability ratio occurs beyond eighty hours of wakefulness, and the smallest occurs during less than twenty hours of wakefulness. The mean and standard deviation of the mean probability ratio values over each twenty hour time block for each threshold value (*k* = 250, 500, 750, and 1000) are summarized in Table 61.

Table 61: Probability Ratios for Reaction Time: Means and Standard Deviations

Threshold Value	< 20 hrs	20 to 40 hrs	40 to 60 hrs	60 to 80 hrs	> 80 hrs
k = 250	1.075 (0.28)	1.152 (0.44)	1.042 (0.24)	1.139 (0.07)	1.156 (0.08)
k = 500	1.157 (0.87)	1.367 (1.03)	1.468 (0.40)	1.744 (0.20)	1.766 (0.14)
k = 750	1.226 (0.47)	2.229 (1.59)	2.511 (1.19)	3.489 (0.20)	3.482 (0.14)
k = 1000	1.581 (1.22)	4.703 (3.29)	5.536 (3.60)	8.596 (3.60)	8.384 (0.48)

The *k* values (*k* = 250, 500, 750, and 1000) produce PSF coefficient values greater than 1 as expected. For practical applications, an appropriate value for the threshold *k* needs to be selected based on the situation being studied. Note that the variation of probability ratio with number of hours of wakefulness is not linear. There is not a steady increase in the derived probability ratios as hours of wakefulness increase. The reaction time data collected directly from the studies shows a non-linear decline in performance as hours of wakefulness increase. Figure 38 shows the non-linear reaction times over hours of wakefulness. This non-linearity is to be expected, especially due to the confounding effect of several other factors; such as circadian rhythms, time-of-day influence, and time-on-task.

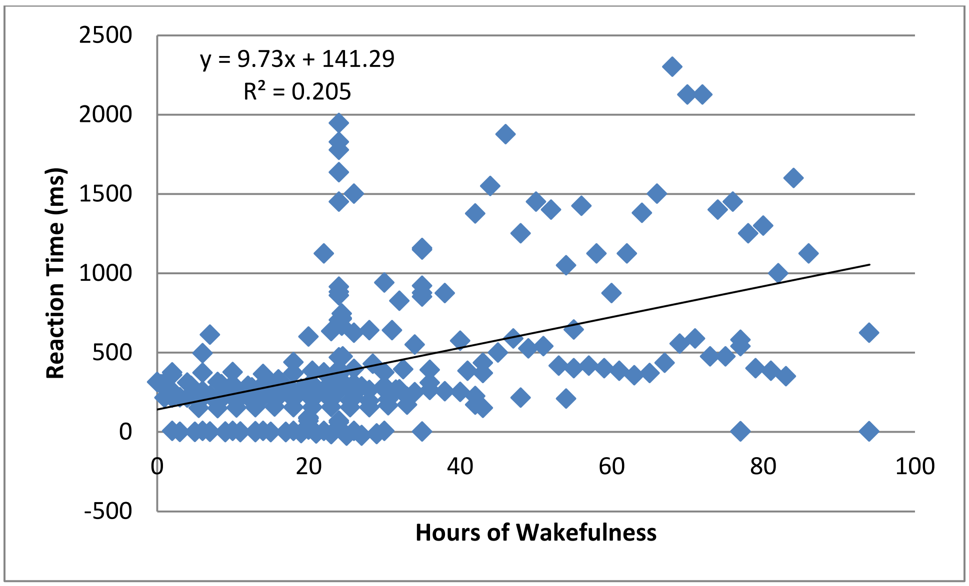

Figure 38: Reaction Times vs. Hours of Wakefulness (Test Condition Data)

Data on Accuracy

The studies that reported accuracy data from Tables 23-25 (i.e., list of 108 studies) are listed in Table 62. This table lists the studies that could not be used for further analysis due to limited reported data (i.e., no standard deviation information) and studies that could be used further.

Table 62: Accuracy Data Summary

	Study Identification Number
Studies reporting accuracy	(2, 3, 4, 5, 7, 9, 10, 14, 17, 18, 20, 21, 26, 27, 31, 32, 41, 43, 48, 49, 50, 53, 55, 56, 57, 60, 63, 64, 65, 66, 67, 68, 69, 70, 72, 75, 78, 79, 91, 92, 93, 94, 95, 99, 100, 101, 103)
Studies without hours of wakefulness	(27, 31, 45, 50, 55, 60, 68, 69, 72, 75, 83)
Studies without standard deviations	(5, 9, 14, 18, 20, 21, 26, 31, 56, 63, 65, 69, 75, 78, 91, 92, 93)
Differences between the means	(2, 3, 4, 5, 7, 9, 10, 14, 17, 18, 20, 21, 26, 32, 41, 43, 48, 53, 57, 63, 64, 65, 66, 67, 69, 70, 92, 93, 94, 95, 99, 100, 101, 103)
Effect size	(2, 3, 4, 5, 6, 7, 10, 17, 32, 41, 43, 48, 53, 56, 57, 64, 66, 67, 70, 94, 95, 100, 101, 103)
Studies used	(2, 3, 4, 5, 7, 9, 10, 14, 17, 18, 20, 21, 26, 32, 41, 43, 48, 49, 53, 56, 57, 63, 64, 65, 66, 67, 70, 78, 79, 91, 92, 93, 94, 95, 99, 100, 101, 103)

Quantitative Effect of Sleep Deprivation on Accuracy

The accuracy data were segregated and analyzed by the type reported in the original study. There were five types of accuracy reported: number correct, percentage correct, number of errors, percentage of error, and number of false positives; unfortunately after the accuracy data were subdivided, the sample sizes of the data were not large enough to draw significant conclusions. Due to this, the accuracy analysis is briefly covered in this section and the full analysis is included in Appendix D.

The differences between the mean values of accuracy under control and test conditions showed a decrease in performance as hours of wakefulness increased. The difference between the means was calculated as C-T for the number of errors, percentage error, and false positives. A reduction of performance occurs when the test value is larger than the control value. Data that reported accuracy as the number correct came from fourteen different studies. For the number correct data, threshold values of $k = 0$, 23, 50, and 75 were used to derive PSF coefficient values.

Accuracy as reported as percent correct was found for fourteen studies. The difference between the mean values centered about zero; i.e., there was a difference between the control and test conditions. Threshold values of $k = 0$, 0.25, 0.5, and 1 were used to derive the probability ratios for percentage correct.

Eight studies were found to report accuracy as number of errors, which increased as hours of wakefulness increased. The differences between the mean values were calculated as C-T. Threshold values of $k = 0$, 30, and 50 were used to derive PSF coefficients.

Accuracy reported as percentage of errors was calculated from seven studies. The difference between mean values centered on zero; i.e., there was no change from the control to the test condition. Threshold values of $k = 0$, 0.25, 0.5, and 1 were used to derive probability ratios for percentage of errors data.

The four studies that reported false positive data were analyzed. The number of false positives, i.e., reacting when there was no signal, increased as hours of wakefulness increased. Threshold values of $k = 0$, 1, 2, and 3 were selected.

In summary, accuracy is not affected as greatly as reaction time and number of lapses under sleep-deprived conditions. The draw on cognitive capacity that results from sleep deprivation may help increase arousal levels (Yerkes and Dodson, 1908) and help to maintain, or even improve, performance on the simple tasks that were the primary tasks employed in the studies under investigation.

Sensitivity to Normal Assumption

The above calculations or probability ratios assumed that *C* and *T* are normally distributed. To see how sensitive the results were to this assumption, the lognormal distribution was assumed for *C* and *T*. The threshold values selected are positive, so perhaps the application of lognormal distribution is more plausible. Also, the lognormal distribution parameters (λ, ζ) are calculated from the mean value and standard deviation (Equations 28-31). Then the probabilities of reaction time being beyond the threshold *k* are calculated as:

$$P_{C\_LN} = P(C > k) = \Phi(-(\ln(k) - \lambda_C) / \zeta_C)) \quad (26)$$

$$P_{T\_LN} = P(T > k) = \Phi(-(\ln(k) - \lambda_T) / \zeta_T) \quad (27)$$

$$\lambda_C = \ln(\mu_C) - 1/2(\zeta_C)^2 \quad (28)$$

$$\zeta_C = \ln(1 + (\sigma_C/\mu_C)^2) \quad (29)$$

$$\lambda_T = \ln(\mu_T) - 1/2(\zeta_T)^2 \quad (30)$$

$$\zeta_T = \ln(1 + (\sigma_T/\mu_T)^2) \quad (31)$$

where, k = threshold value, ln is the lognormal, and Φ is the cumulative distribution function (CDF) of a standard normal variable.

The probability ratios for $k = 500$ for reaction time data were plotted for both the normal and lognormal distribution. The result is shown in Figure 39, with probability ratio values greater than 10 removed as outliers.

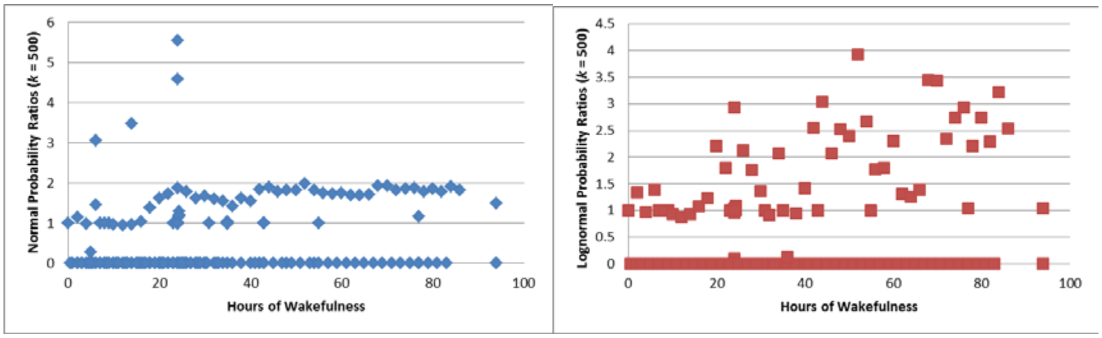

Figure 39: PSF Coefficients for *k* = 500 for Normal and Lognormal *C* and *T*

For k = 500, if C and T are assumed to follow a normal distribution, the derived probability ratio values after twenty hours vary from zero to two with little variability. If C and T are assumed to follow a lognormal distribution, the derived probability ratio values show more variability than an assumed normal distribution. Also, the range of values is greater [0 to 4]. The probability ratio value results show more variability after twenty hours; however, the assumed normal distribution shows more variability before twenty hours of wakefulness. Thus the derived probability ratio values appear to be sensitive to the distribution assumption.

Inter-rater Reliability

A random selection of nine studies was selected from the 108 study list (Tables 23-25). The studies selected were: #18-Babkoff_1985; #31-Borland_1986; #47-Lamond_2007; #48-Drummond_2006; #57-Englund_1985; #96-Scott_2006; #98-Dinges_1988; #100-Lieberman_2005; and #103-Doran_2001. Several of the studies selected reported statistical results in a table or in-text format; those studies matched coding results for both the main and auxiliary coders since the data were not open to interpretation. No further analysis was conducted on these studies. The studies that required coder interpretation from a graphical display of results were further explored. The mean value of the test condition was compared between coders. The percentage difference between the coders was found by adapting Equation 15 for percentage increase with the main coder value (M) replacing the test value (T) and the auxiliary coder value (A) replacing the control value (C). The mean of the absolute percentage of change between the main and auxiliary coders was 4.27%; this was found for one hundred and four data points from four studies. The maximum percentage change between the main and the auxiliary coder was 47.0%. On average, the small mean percentage change between the main and auxiliary coders was similar. Summary statistics are listed in Table 63. The data used for the inter-rater reliability calculation are presented in Appendix F.

Table 63: Summary of Inter-rater Reliability

Percentage Change Test	
Mean	4.27%
Standard Deviation	0.076
Minimum	0.00%
Maximum	46.96%
Count	104
Confidence Level (95.0%)	0.015

A Bland-Altman plot of the control condition between the main and auxiliary coder is plotted in Figure 40, and Figure 41 is a Bland-Altman plot of the test condition between the main and auxiliary coder. The reaction time values that were pulled from the studies and compared between raters typically required the reading of graphs; i.e., the reaction times were not numerically reported. Samples of studies were viewed by the main coder and an auxiliary coder. Each coder interpreted and recorded reaction times from the data presented in the study. The difference between the reaction time values recorded by the coders is plotted versus the reaction times.

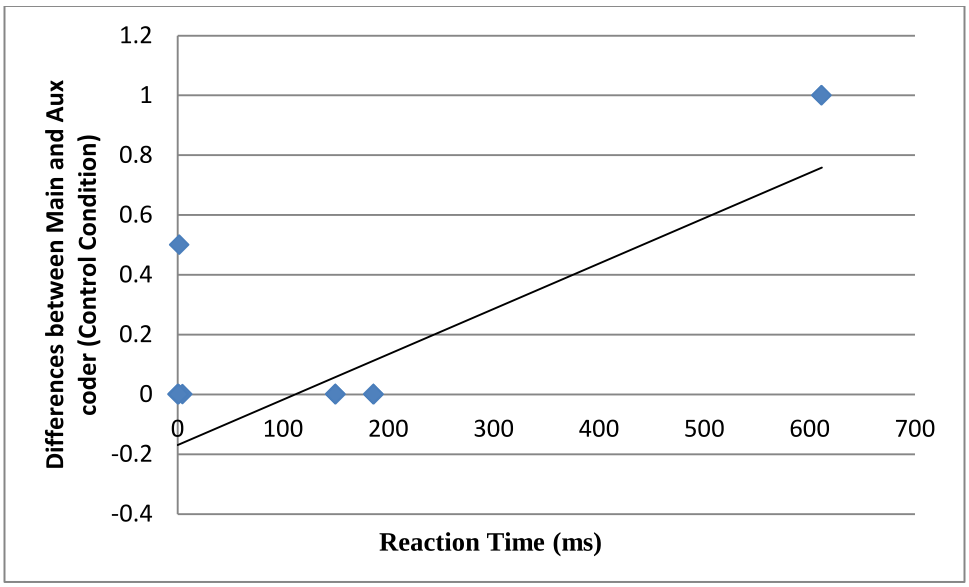

Figure 40: Bland-Altman Plot Differences between Main and Auxiliary Coder (Control)

Five studies were compared between the main and auxiliary coders. For the control condition, there was no reported difference between three studies, one study had a difference of 0.5 between coders, and one study had a difference of one between coders for the control condition. The control condition does not typically change over time; hence, a Bland-Altman plot of the control condition differences between the main and auxiliary raters does not provide insight into rater consensus.

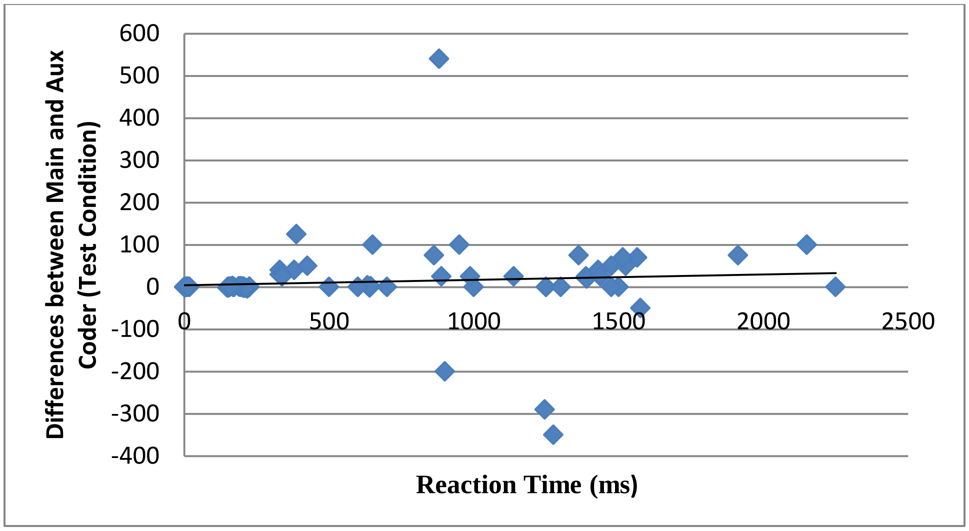

Figure 41: Bland-Altman Plot Differences between Main and Auxiliary Coder (Test)

There is one large positive outlier (difference = 540 MS) from study #103-Doran_2001 and three large negative outliers (difference = -290, -200, and -350 ms) also from study #103-Doran_2001. The positive outlier had the main rater with a reaction time 540 ms greater than the auxiliary rater, and the three negative outliers had the auxiliary rater with values less than the main rater. All four outliers came from reaction time studies which were measured in milliseconds. The overall average difference between the means of the main and auxiliary coder was 10.97, and the overall average of the absolute value of the difference between the means was 15.04. This shows a fair consensus between the raters since the data was often on the order of 1000 ms.

Summary

This chapter reported the results of the application of the methodology from Chapter IV. Data analysis was segregated by the number of lapses, reaction time, and accuracy. The data used in the analysis are provided in Appendix E. Analysis of the data included finding the difference between the mean values, percentage change between test and control conditions, and effect sizes. The data collected were used to derive probability ratios based on empirical data. Equations for the probability ratios were calculated for ten to twenty hour intervals of hours of wakefulness. Number of lapses and reaction times were identified to be negatively affected by sleep deprivation. Accuracy was not found to be consistently worse as hours of wakefulness increased.

The probability ratios could be used to inform the selection of PSF coefficients in HRA models. Note however, that these ratios are different for different performance measures (reaction time, accuracy, or number of lapses), and for different hours of wakefulness. The selection of PSF coefficients in HRA may be guided by these probability ratios in different ways, e.g., average over all three performance measures and hours (not recommended), or use probability ratios from that performance measure that is most relevant to the HRA situation of interest, varying with hours of sleep deprivation.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Summary of Accomplishments

The main goal of this research was to develop a methodology to use empirical data to inform PSF coefficient selection in order to improve current HRA methods. A variety of studies in the available literature on sleep deprivation effects on performance was synthesized for this purpose. This overarching research goal was achieved by defining five subsidiary objectives and approaching these in a systematic fashion.

The first objective was to review current HRA methods, THERP (Swain and Guttman, 1983), SPAR-H (Gertman et al., 2005), and ATHEANA (USNRC, 2000), to determine how sleep deprivation effects on performance were included. Sleep deprivation is not specifically addressed by any of the reviewed methods; therefore, a method to address the effect of sleep deprivation is needed. THERP provides error probabilities for specific situations, such as mis-turning a valve. ATHEANA does not provide error probabilities for performance shaping factor coefficients, but does provide a higher level of guidance in performing an HRA. SPAR-H has a given set of performance shaping factors and PSF coefficients which do not include sleep deprivation. Sleep deprivation is assumed to be included in the fitness-for-duty PSF of the SPAR-H method. Since fatigue, in particular sleep deprivation, is found to be a contributing factor in so many incidents, the importance of including sleep deprivation as a PSF needs to be considered (Griffith and Mahadevan, 2011).

Next, data collection for the sleep deprivation effect on performance through a meta-analysis synthesis method was performed. Literature from various sources was reviewed; the majority came from laboratory test studies. Studies which provided data on the performance metrics reaction time, accuracy, and number of lapses were mined for data. The resulting 108 studies were more critically evaluated for statistical data and were coded. The data were collected in a research synthesis procedure emulating the meta-analysis technique with predefined coding information.

Qualitative information such as study design, information on the subjects, experimental conditions, and task characteristics was collected. Quantitative information was also coded from the studies; this information included pretest (control) and posttest (test) mean values and standard deviation or standard error when available.

The data collected from the reviewed studies were evaluated to find the quantitative effect of sleep deprivation on performance (e.g., reaction time, accuracy, and number of lapses). The quantitative effect of sleep deprivation on performance was determined by calculating the difference between mean values, effect size, percentage change, and failure probabilities.

The fourth objective was to develop a method to derive PSF coefficients based on the collected data from objective three. Error was defined to occur when the control or test condition performance exceeded a threshold value (k). Assuming the defined error measure had a normal distribution, the probability of error occurring was then calculated (Equations 21 and 22).

Error probabilities were used to contrast the change in the performance under the control condition vs. the test condition. The ratio of the error probabilities based on the empirical data was used to derive PSF coefficients based on probability ratios. By developing this method for selecting PSF coefficients using technical data, reliability and reproducibility of HRA methods can be increased. The fifth objective in the research was to analyze the uncertainty in the derived performance shaping factor coefficient values and the inter-rater reliability for a sample of randomly selected studies.

Research Assumptions:

The effects of shift work, chronic sleep deprivation, napping (i.e., recovery), circadian rhythms, time-of-day influence, and time-on-task were not considered in this research, and the effect of acute sleep deprivation was assumed to be independent of these factors. The influence of circadian rhythms was not taken into account (e.g., what time of day that forty hour of wakefulness occurred) due to the infrequent recording of the time of day when the data collection occurred, nor were the influences of shift work, i.e., work hours that occurred outside of the standard *9 a.m.-5 p.m.* daytime schedule, or other schedules that included working outside of daytime hours. The tasks used to evaluate performance were assumed to be equivalent between various studies (e.g., the PVT was considered equivalent to simple reaction time (SRT) task). Also, the influence of study differences was not considered in the final quantitative analysis of the data, but was noted in the coding of the studies. Sleep deprivation was assumed independent of other performance factors, i.e., the interaction of other performance shaping factors with sleep deprivation was not considered, and the speed versus accuracy tradeoff was not factored into the analysis.

The quantitative analysis had three assumptions. One was the calculation of the error probabilities; performance measures under the control (*C*) and test (*T*) conditions were assumed to be normally distributed. The performance measure of the number of lapses was assumed to follow a normal distribution; even though it is a discrete variable. The third quantitative assumption was that outliers greater than 10 (Probability ratio values > 10) needed to be removed to prevent skewing the data.

Different tasks would necessarily require different lengths of time to complete; for example, pushing a button for the PVT test would be expected to take less time than a more complex task. This research has treated all the tasks as the same due to the data limitations and since the majority of the studies used simplified tasks for experimentation (e.g., PVT and SRT). The threshold performance values selected in this research were not specifically selected for each task. The majority of the data came from PVT and SRT tests, so the threshold selected values for k = 250, 500, 750, and 1000 for reaction time and k = 1, 2, 3, 6, 9, and 10 for number of lapses. In practical applications of this approach, a threshold value could be selected that is task specific.

Summary of Results

Many studies reported more than one performance metric (i.e., number of lapses, reaction time, and accuracy). More studies reported reaction time (65) than accuracy (40) or number of lapses (18). The control and test condition performance metric values were used to calculate an effect size and to derive probability ratio values from error probabilities.

The effect size data vs. hours of wakefulness for the number of lapses and reaction time data are presented in Figure 42 and Figure 43. No values calculated were greater than 10 or less than -10. Sixty-two effect sizes were calculated for the number of lapses data with a mean of -0.62.

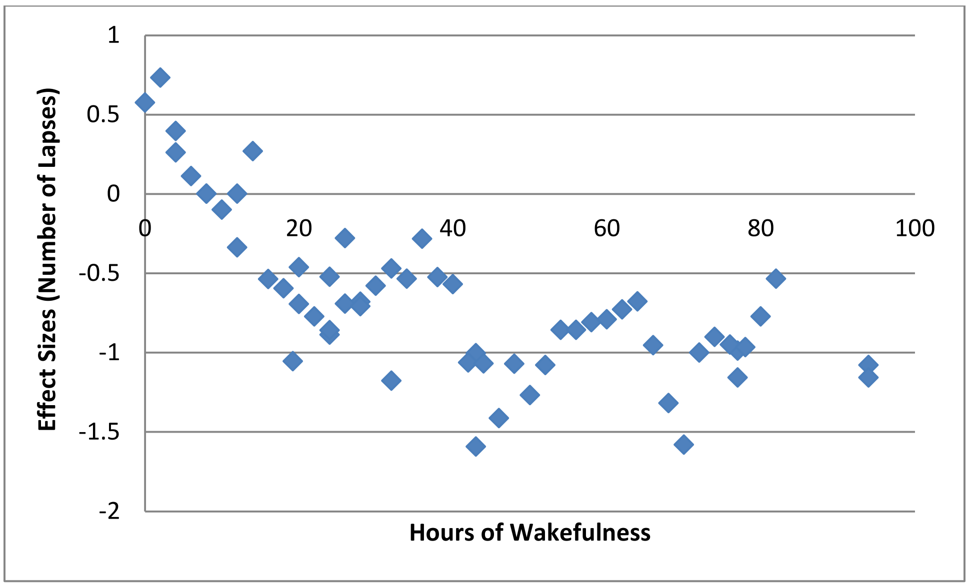

Figure 42: Effect Sizes for Number of Lapses

The lapse data shows three dips, after twenty hours of wakefulness (around twenty-four hours), after forty hours, and after sixty hour. The increase toward the positive, at these dips, may be influenced by diurnal effects on performance.

The effect size data vs. hours of wakefulness for reaction time data is presented in Figure 43. For reaction time, 51 effect size values < -10 with a mean of -361.5 were removed, and three effect size values > 10 with a mean of 91.6 were removed. The remaining 184 effect size values, with a mean of -0.56, are plotted in Figure 43.

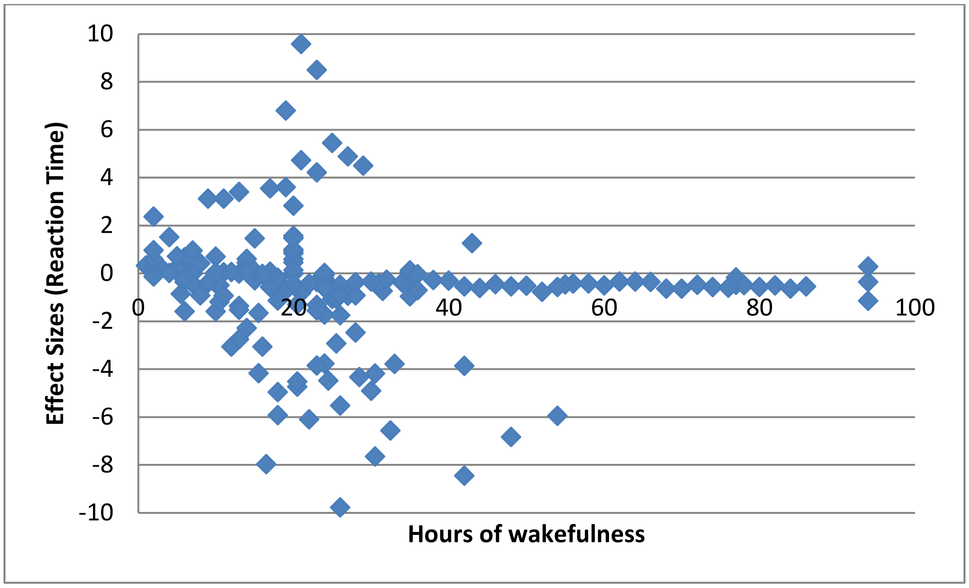

Figure 43: Effect Sizes for Reaction Time Data

The resulting effect sizes, for each reaction time at the test condition, are presented in Figure 43 with values > 10 and <-10 removed. There are both positive and negative effect sizes for reaction times recorded at less than forty hours of wakefulness. After forty hours of wakefulness the effect size is negative and approaches a constant value of -0.5; this is not a large effect size, but is does show that sleep deprivation has a negative effect on reaction time.

A subset of 18 studies (out of the 108 in Tables 23-25) that used the same type of task (the psychomotor vigilance task by Dinges and Powell, 1985) gave an average effect size for the reaction time data as -1.173, for accuracy data as -0.920, and for number of lapses data as -2.388.

The mean probability ratio values and standard deviations for reaction time (*k* = 250, 500, 750, and 1000) and number of lapses (*k* = 1, 2, 3, 6, 9) data are summarized in Table 64. The general trend, for both reaction time and number of lapses, shows an increase in the probability ratio values as hours of wakefulness increase.

Table 64: Summary of Mean Probability Ratios: Means (Standard Deviations)

Performance Metric	> 20 Hrs	20-40 Hrs	40-60 Hrs	60-80 Hrs	> 80 Hrs
Reaction Time					
k = 250	1.075 (0.28)	1.152 (0.44)	1.042 (0.24)	1.139 (0.07)	1.156 (0.08)
k = 500	1.157 (0.87)	1.367 (1.03)	1.468 (0.40)	1.744 (0.20)	1.766 (0.14)
k = 750	1.226 (0.47)	2.229 (1.59)	2.511 (1.19)	3.489 (0.20)	3.482 (0.14)
k = 1000	1.581 (1.22)	4.703 (3.29)	5.536 (3.60)	8.596 (3.60)	8.384 (0.48)
Number of Lapses					
k = 1	0.937 (0.25)	1.120 (0.47)	0.897 (0.05)	0.937 (0.12)	0.998 (0.24)
k = 2	1.479 (0.16)	1.485 (0.16)	2.999 (0.01)	6.209 (0.01)	4.888 (0.01)
k = 3	0.979 (0.58)	1.713 (1.25)	1.090 (0.07)	1.095 (0.07)	1.015 (0.06)
k = 6	1.583 (1.70)	1.769 (0.69)	2.692 (0.21)	2.666 (0.23)	2.339 (0.17)
k = 9	2.317 (2.63)	2.978 (3.79)			

The performance metric of accuracy was reported in five different ways (number correct, percentage correct, number of errors, percentage of error, and false positive). Unfortunately after the accuracy data were subdivided the sample sizes of the data were not large enough to draw significant conclusions.

Practical Application

This work developed a method to derive PSF coefficients from probability ratios based on empirical data, thus, reducing the reliance on expert opinion in HRA. The human performance data collected can be used in human reliability analysis (HRA), which is part of probabilistic risk assessment (PRA) applications. Typically, in HRA an error probability is calculated based on performance shaping factors and a base human error probability (HEP). Currently, SPAR-H (Gertman et al., 2005) uses fitness for duty as a performance shaping factor (PSF) that perhaps indirectly includes the influence of sleep deprivation on performance. In this research, it is shown how sleep deprivation test data could be used to inform the quantitative treatment of sleep deprivation as a PSF, i.e., use the results to select appropriate PSF level/values if using a standardized HRA, e.g., SPAR-H fitness-for-duty. The methodology developed in this research can be similarly applied to derive probability ratio values for other performance shaping factors used in HRA.

However, the application of human performance data from controlled laboratory studies to real-world applications is difficult due to several limitations. Two factors are not typically reported: (1) motivation of the subjects, and (2) whether accuracy was preferred to speed (reaction time) by the subjects. The tasks that are used in the existing studies also create difficulty in the synthesis of the data. Studies typically use primary tasks (i.e., one task at a time – no secondary task) and simplified tasks that can be better controlled. The simplification and isolation of tasks in the literature are not representative of general real-world tasks.

The need to have controlled experiments with simplified tasks in order to make the studies possible presents a difficulty in making real-world use of the results of the studies. This means that laboratory-based tests are not clear indicators of real-world performance (Kushida et al., 2005). A cognitive laboratory task may track the direction of the changes in function, but does not provide direct extrapolation estimates of ability to perform everyday tasks.

Another complication in extrapolation from simplified tasks to real-world tasks is that generally a single task is used in the laboratory. This enables the simplified test task to be free from distractions and confounding factors that do not compete for attention capacity. Testing is often done in isolation (i.e., one task at a time), but in real settings, often, more than one task is performed simultaneously. When using the study data, it cannot be determined how the reaction times, accuracy, and number of lapses would be affected if there were additional draws on attention. These performance metrics (reaction time, accuracy, and number of lapses) generally behave in accordance with the Yerkes-Dodson law of arousal (1908) that shows an increase in performance as arousal increases up to a point, after which the level of arousal performance starts to decrease. The Yerkes-Dodson law even shows a leveling off of performance on simplified tasks even as arousal (stress) increases (Yerkes and Dodson, 1908).

The laboratory tests generally report reaction time for simple tasks. The changes in reaction time in these sleep deprivation studies are on the order of milliseconds. Many real-world tasks do not require such immediate reaction to stimuli. Different tasks demand different reaction times leading to errors. For example, in an automobile crash there may be only a small window of time to react, unlike a control room setting where employees may have several minutes to hours to respond to a cue or to perform a task. Small changes in simple reaction times would not be significant if the time allowed to complete the task before an error could occur was on the order of minutes to hours. The effect of sleep deprivation on reaction time is more directly related to tasks that require quick reactions.

Accuracy and number of lapses data also suffer from issues similar to reaction time data. Sleep deprivation in general not only increases reaction time, but also affects accuracy and the number of lapses. Accuracy tends to decrease as hours of wakefulness increase; however, it is not clear how to extrapolate an increase in the number of false positives to a simple stimulus in the laboratory setting to a real-world task. The difference between the number of lapses after sleep deprivation (L_T) and before (L_C) was observed to increase after forty hours of continuous wakefulness. This generally implies that increased hours of wakefulness result in performance impairment. However, the application of the data to the number of lapses, typically measured in milliseconds, to a real-world task not requiring immediate action is not straightforward.

The differences in study methods and result collection techniques make it difficult to synthesize the results of the studies. Even if these difficulties were resolved, there remains the question of how to apply the results to real-world applications. Several other complicating factors also need to be considered. The effects of motivation and context on the laboratory tasks are not clearly addressed in the sleep deprivation studies. Another serious limitation is the lack of knowledge about the tradeoff between speed and accuracy during performance tasks. Speed-accuracy tradeoffs occur when speed (reaction time) is sacrificed to improve accuracy, or when accuracy is traded to maintain or increase speed (Fitts, 1954). The studies do not consistently mention if speed and accuracy were measured at the same time or if one was emphasized over the other. Finally, a common problem in the literature is bias against negative reporting, i.e., only studies that show positive support for the hypothesis (in this case, sleep deprivation adversely affects performance) tend to get reported.

Future Directions

This research focused on cognitive fatigue resulting from hours of wakefulness. While this research establishes a procedure to derive PSF coefficients from probability ratios for sleep deprivation effects on performance for HRA calculations of human error probabilities, much is still left to be done to fully represent fatigue effects in HRA methods. Recommendations for future research efforts, including the additional investigation into the use of time-of-day and time-on-task as independent variables in addition to hours of wakefulness, should be performed to better address the causes of cognitive fatigue. Also, other qualitative information that was coded could be evaluated for causal relationships. Another data collection means of establishing a relationship between effect size (ES) and reliability index (β) could be used to increase the amount of data available.

Future work should investigate and collect data in a similar method with time-of-day and time-on-task as the independent variable. The qualitative information coded could also be further evaluated to look for causal relationships between performance and study design or subjects. The regression of the number of lapses and reaction time studies identified some characteristics that drive performance outcomes, but not all study characteristics were evaluated.

This research assumed that the performance metrics of number of lapses, reaction time, and accuracy were normally distributed in the quantitative analysis. The results were shown to be sensitive to this assumption. Other distributions should be investigated to establish the best representation of the data.

Other PSFs that greatly impact human performance need to be investigated in a similar method as sleep deprivation was in this research. This research methodology can be used as a guideline for collecting data and deriving PSF coefficients for other PSFs. The current trend in HRA methods is focusing on the context of errors. The ATHEANA method is almost solely focused on defining error forcing situations. There is also a desire by industry users to increase HRA reliability and reproducibility of results. If the PSF coefficients are based on empirical data instead of expert judgment, the reproducibility of the model should improve.

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APPENDICES

A INTERESTING FATIGUE FACTS

Longest Documented Time Awake

Randy Gardner stayed awake for 264 hours (11 days) of continuous wakefulness not using any stimulants. He was a 17-year-old high school student in California. On the 4th day he experienced delusions (Ross, 1965).

Sleep Deprivation as a Treatment for Depression

Sleep deprivation has been shown to have a positive effect on depression. Approximately 60% of patients showed an immediate recovery. However, most depressed subjects relapsed the following night with sleep. The combination of sleep deprivation and medication can lessen the number of relapses. Many anti-depressants suppress REM sleep, which may be the link between improved mood in depressives and sleep deprivation (Wirz-Justice, 1999).

Psychosis and Sleep Deprivation

In Goes et al. (2007), MRI scans of the brain revealed that sleep deprivation caused the brain to become incapable of putting an emotional event into its proper perspective and forming a controlled and suitable response to the event. In another study in 2001, a link between mental illnesses, including psychosis and bipolar disorder, was found.

Diabetes Correlation with Sleep Deprivation

A correlation between chronic sleep deprivation and Type 2 diabetes was found in Gottlieb et al., 2005. In Spiegel et al. 2003, an impaired glucose tolerance (IGT) was found under sleep-deprived conditions.

Bibliography for Interesting Fatigue Facts:

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B FATIGUE ACCIDENTS

Three Mile Island – United States (March 28, 1979)

Reactor coolant escaped after the pilot-operated relief valve (PORV) stuck open. The mechanical failures were compounded with the failure of the operators to recognize that the plant was experiencing a loss of coolant. When the situation was noticed, the crew was not able to solve the problem until the relief crew came on and took over for the fatigued crew. The incident occurred between 04:00 and 06:00.

References:

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Davis-Besse: United States (June 9, 1985)

At 01:30 the Davis-Besse (Oak Harbor, OH) nuclear power plant went into automatic shutdown after a loss of cooler water and then the total loss of the main feed-water. The incident was compounded because the operator pushed the incorrect button and turned off the auxiliary feed-water system. The operator’s error was discovered by workers coming on for the next shift.

References:

Coren, S. (1996). Sleep Thieves: An Eye-Opening Exploration into the Science & Mysteries of Sleep. New York, Free Press.

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***Challenger* –** United States (January 28, 1986) - Poor decision making

NASA managers after working over 20 hour shifts made the critical decision on whether to launch with their knowledge of O-ring failures at low temperature.

References:

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Hinton Train Collision – Canada (February 8, 1986) - Operator incapacitated

On February 8, 1986, a VIA rail (passenger train) collided with a Canadian National Railway (freight train) near Hinton, Alberta, which is west of Edmonton. The accident was a result of the crew of the freight train becoming incapacitated, i.e., having fallen asleep.

References:

Halliday, H. A. (1997). Wreck! Canada's Worst Railway Accidents. Toronto, Robin Brass Studio.

Chernobyl – Ukraine (April 26, 1986) - Poor decision making

What happened: Critical automatic safety systems were turned off, and the reactor began to overheat at approximately 01:30. The sleep-deprived shift workers did not turn back on the automated safety systems, but instead turned off the cooling system. This caused the reactor to overheat and led to the explosion, which released radiation.

References:

Coren, S. (1996). Sleep Thieves: An Eye-Opening Exploration into the Science & Mysteries of Sleep. New York, Free Press.

Hammon, C. (Quanta Dynamics Incorporated). “If You Don't Snooze, You Lose: Getting A Good Night's Sleep Is Critical to Productivity and Creativity.”

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***Exxon Valdez* –** United States (March 24, 1989) Sleep-deprived operator – poor decision making

The Exxon Valdez oil tanker struck a reef in Prince William Sound, AK, and spilled 11 to 32 million gallons of crude oil. The accident was caused by the third mate not having maneuvered the vessel properly. The third mate only had had 6 hours sleep in the previous 48 hours, while the first mate had been working for 30 hours continuously. The estimated cleanup cost was $2 billion, including $41 million to help 800 birds and a few hundred sea otters.

References:

Dement, W. C. (1992). The Sleep Watchers. Stanford, CA, Stanford Alumni Association.

Eller, S. and P. Minkley (1998). "The High Price of Sleep Deprivation." (Accessed July 17, 2010 http://www.rtmagazine.com/issues/articles/1998.

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Hassen, F. (Posted Sun 24 Feb 2008). “Sleep Deprivation: Effects on Safety, Health and the Quality of Life.”

National-Transportation-Safety-Board (September 18, 1990). “Practices That Related to the *Exxon Valdez*.”

National-Transportation-Safety-Board (March 4, 1989). "Grounding of the US Tankship *Exxon Valdez* on Bligh Reef, Prince William Sound, near Valdez, Alaska."

American Airlines flight 1420– United States (June 1,1999) **–** Poor decision making

An American Airlines flight (1420) from Dallas, TX, to Little Rock, AR, overran the runway upon landing and crashed. Eleven were killed and 110 injured. Pilot fatigue and the resulting diminished judgment were given as part of the blame; the crew had been on duty for about 13 ½ hours at the time of the crash.

References:

Hirshkowitz, M. and P. Smith (2004) "Recognizing the Dangers of Sleep Deprivation." 2004. Web. 15 July 2010.

Malnic, E. (2001). "Crew Fatigue Cited in Fatal 1999 Crash of Jetliner in Ark." Los Angeles Times. Los Angeles.

National-Transportation-Safety-Board (2001). "Aircraft Accident Report: Runway Overrun during Landing; American Airlines Flight 1420." McDonnell Douglas MD-82, N215AA; Little Rock, Arkansas; 1 June 1999. N. T. S. Board.

Staten Island Ferry – United States (October 15, 2003) - Operator asleep

The assistant captain, while piloting the ferry, ran full speed into the dock. The pilot made no attempt to slow the ferry because he had fallen asleep at the controls. Eleven people died and seventy-one were injured.

References:

Hirshkowitz, M. and P. Smith (2004) "Recognizing the Dangers of Sleep Deprivation." 2004. Web. 15 July 2010.

Accidents in General – United States

It has been estimated that the United States loses over $56 billion and 25,000 lives each year because of sleep-related accidents. Driver fatigue is responsible for an estimated 100,000 motor vehicle accidents and 1500 deaths each year, according to the National Highway Traffic Safety Administration.

References:

Coren, Stanley. Sleep Thieves: an Eye-Opening Exploration into the Science & Mysteries of Sleep. New York: The Free Press, 1996. p. x, 241-4

Horne J, and L. Reyner. (1995) “Sleep Related Vehicle Accidents.” BMJ 310:565-567.

Leger D. (1991) “The Cost of Sleep-Related Accidents: A Report for the National Commission on *The Costs of Highway Crashes*.” US Department of Transportation, Washington, DC.

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C IMPACT FACTOR OF JOURNALS

Table 65: Impact Factor of Journals in 108 List as of 2010

Journal	Study Id #	Impact Factor	# Studies
Academy of Medicine	70	1.9	1
Accident Analysis and Prevention	37	1.647	1
Acta Psychologica	25	2.194	1
American Journal of Obstetrics and Gynecology	45	3.5	1
American Sleep Disorders Association and Sleep Research Society	24	NA	1
Anesthesia and Analgesia	71	NA	1
Applied Ergonomics	29	1.105	1
Archives Italiennes de Biologie	103	0.9	1
Aspects of Human Efficiency	14	NA	1
Aviation Space and Environmental Medicine	31	0.8	1
Behavior Research Methods, Instruments, & Computers	18, 23, 57, 102	NA	4
Biological Psychiatry	100	8.7	1
Biological Psychology	40, 85, 93	3.7	3
Biological Rhythms, Sleep, and Performance	55	NA	1
Brain and Cognition	95	2.4	1
British Journal of Psychology	99	2.114	1
Canadian Journal of Psychology	92	NA	1
Chronobiology International	11, 33, 77	3.5	3
Clin Neurophysiol	51	3	1
Comprehensive Psychiatry	89	2.082	1
Critical Care Med	81	6.6	1
Ergonomics	27, 30, 35, 36, 54, 56, 65, 66, 72, 76	1.6	10
Human Factors	61, 75	1.5	2
International Journal of Aviation Psychology	21	NA	1
International Journal of Chronobiology	80	NA	1
International Journal of Industrial Ergonomics	73	0.8	1
International Journal of Occupational Environ Health	74	1.4	1
International Journal of Occupational Safety and Ergonomics	82	0.407	1
Irish Journal Med Science	69	NA	1
J Cogn Neurosci	28, 44	4.9	2

Table 66: Impact Factor of Journals in 108 List as of 2010 Continued

Journal	Study Id #	Impact Factor	# Studies
J Exp Psychol	19	2.9	1
Journal Applied Psychol	26	NA	1
Journal Medical Education	62	NA	1
Journal of Applied Physiology	88, 108	2.2	2
Journal of Biological Rhythms	43	4.63	1
Journal of Pineal Research	90	5.21	1
Journal of Sleep Research	1, 2, 9, 10, 13, 16, 38, 39, 41, 46, 47, 50, 53, 79, 86, 98, 101, 104	3.5	18
Journal of the American Medical Association (JAMA)	68	25.6	1
Laryngoscope	87	1.9	1
Nature	32	31.4	1
Nature Neuroscience	17	14.2	1
Neuroimage	3	5.7	1
Neuropsychopharmacology	48	6.8	1
Occupational Environmental Medicine	5	3.3	1
Organizational Behavior and Human Decision Proces	6	2.549	1
Perceptual and Motor Skills	15	0.333	1
Physiology and Behavior	96	2.8	1
Psychological monographs: General and applied	20	NA	1
Psychological Research	91	1.952	1
Psycholophysiology	8, 52, 64, 106	3.926	4
Radiology	60	6	1
Safety Science	42	1.22	1
Sleep	12, 58, 59, 63, 67, 94, 97, 105, 107	4.48	9
Somnologie - Schlafforschung und Schlafmedizin	22	NA	1
The American Journal of Surgery	34, 49	2.6	2
The Journal of Neuroscience	4	7.5	1
The Lancet	83, 84	28.6	2
Waking and Sleeping	78	NA	1
Western Journal of Medicine	7	NA	1

D ACCURACY ANALYSIS RESULTS

Data on Accuracy

The studies that reported accuracy data from Tables 23-25 (i.e., list of 108 studies) are listed in Table 62. This table lists the studies that could not be used for further analysis due to limited reported data (i.e., no standard deviation information) and studies that could be used further.

Table 62: Accuracy Data Summary

All Accuracy Data	No. of Studies	Study Identification Numbers
Studies reporting accuracy	47	(2, 3, 4, 5, 7, 9, 10, 14, 17, 18, 20, 21, 26, 27, 31, 32, 41, 43, 48, 49, 50, 53, 55, 56, 57, 60, 63, 64, 65, 66, 67, 68, 69, 70, 72, 75, 78, 79, 91, 92, 93, 94, 95, 99, 100, 101, 103)
Studies without hours of wakefulness	11	(27, 31, 45, 50, 55, 60, 68, 69, 72, 75, 83)
Studies without standard deviations	17	(5, 9, 14, 18, 20, 21, 26, 31, 56, 63, 65, 69, 75, 78, 91, 92, 93)
Differences between the means	34	(2, 3, 4, 5, 7, 9, 10, 14, 17, 18, 20, 21, 26, 32, 41, 43, 48, 53, 57, 63, 64, 65, 66, 67, 69, 70, 92, 93, 94, 95, 99, 100, 101, 103)
Effect size	24	(2, 3, 4, 5, 6, 7, 10, 17, 32, 41, 43, 48, 53, 56, 57, 64, 66, 67, 70, 94, 95, 100, 101, 103)
Studies used	38	(2, 3, 4, 5, 7, 9, 10, 14, 17, 18, 20, 21, 26, 32, 41, 43, 48, 49, 53, 56, 57, 63, 64, 65, 66, 67, 70, 78, 79, 91, 92, 93, 94, 95, 99, 100, 101, 103)

Five different measures of accuracy were reported: number correct, percentage correct, number of errors, percent error, and number of false positives. The accuracy data were segregated and analyzed by the type reported in the original study. The following subsections look at each accuracy measure separately.

Data on Number Correct

The nineteen studies that reported accuracy information in the form of number of correct responses are listed in Table 67. Among these, twelve studies also reported hours of wakefulness and could be used for further analysis.

Table 67: Summary Accuracy Data for Number Correct Data

# Correct	No. of Studies	Study Identification Numbers
Studies reporting # correct	19	(5, 21, 27, 41, 45, 55, 57, 60, 64, 65, 66, 67, 68, 69, 70, 78, 79, 94, 99)
Studies without hours of wakefulness	7	(27, 45, 55, 60, 68, 69, 79)
Studies without standard deviation	5	(5, 21, 65, 69, 78)
Difference between the means	12	(5, 21, 41, 57, 64, 65, 66, 67, 69, 70, 94, 99)
Effect size	9	(5, 41, 64, 66, 67, 68, 70, 94, 99)
Studies used	14	(27, 41, 45, 55, 57, 60, 64, 66, 67, 68, 70, 78, 94, 99)

The difference between the mean values of the control and test conditions (μ_C and μ_T) respectively) for twelve studies was calculated. The result was plotted in Figure 44. A negative result of $\mu_T - \mu_C$ mean values means that the number reported correct for the test condition is greater than the control condition. Before 40 hours of wakefulness, the difference between the mean values increased with hours of wakefulness. After 40 hours of wakefulness the data were clustered in four groups.

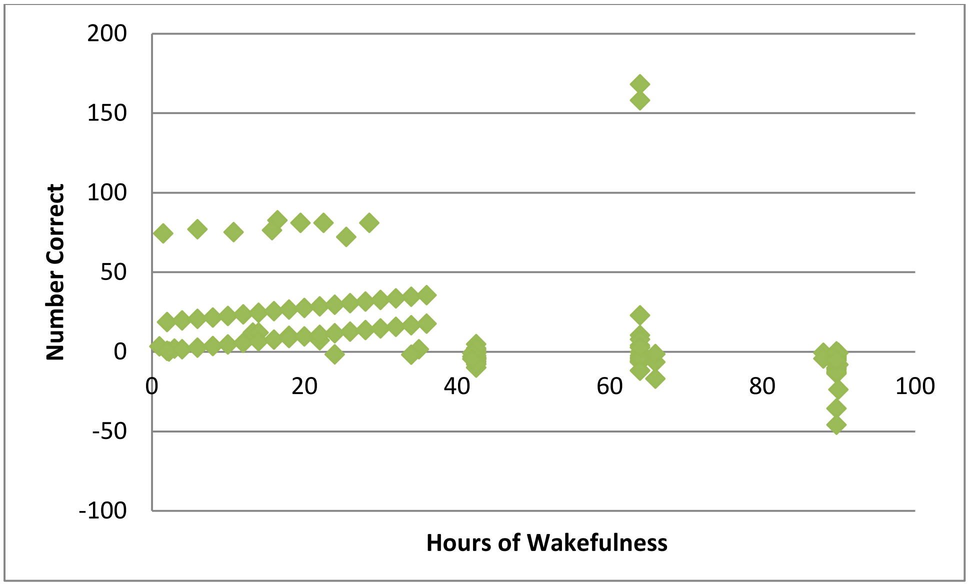

Figure 44: Difference between Mean Values (μ_T-μ_C) for Number Correct Data

Accuracy reported as the number correct data points per study is provided in Table 68. One hundred and twenty-eight data points came from eleven studies. Different data points resulted from data collected at multiple hours of wakefulness.

Table 68: Number of Data Points from Each Study for Number Correct

Study Id #	# of Data Points
5	5
21	5
41	36
57	4
64	2
65	20
66	9
67	1
70	2
94	27
99	17

The percentage change in the number correct accuracy data is plotted in Figure 45 (calculated using Equation 15). The number of data points per study from which the percentage change could be calculated is listed in Table 69. The cluster of data comes from multiple data points reported at the same hours of wakefulness.

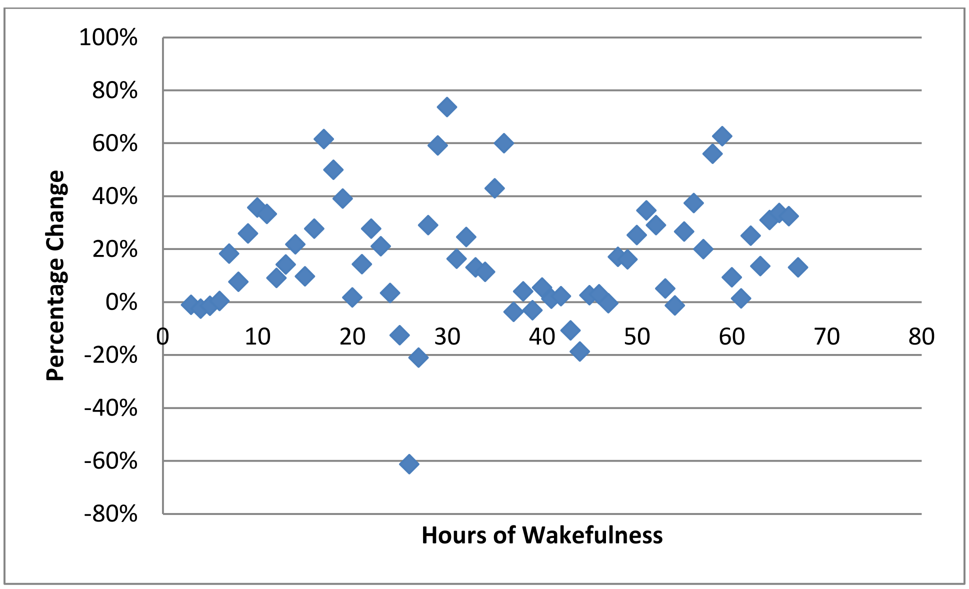

Figure 45: Percentage Change for Number Correct Accuracy Data

Table 69: Number Data Points for Percentage Change for Number Correct Accuracy Data

Study Id #	# of Data Points
5	1
27	2
64	2
65	20
66	9
67	1
70	2
94	20

Effect size (Equation 8) and reliability index (β) values (Equation 17) for accuracy data reported as the number correct were calculated and plotted in Figure 46. The effect size and β values show the standardized difference between the number of correct responses reported for the control and test condition caused by hours of wakefulness. Eight studies reported one hundred data points used for this computation, as listed in Table 70.

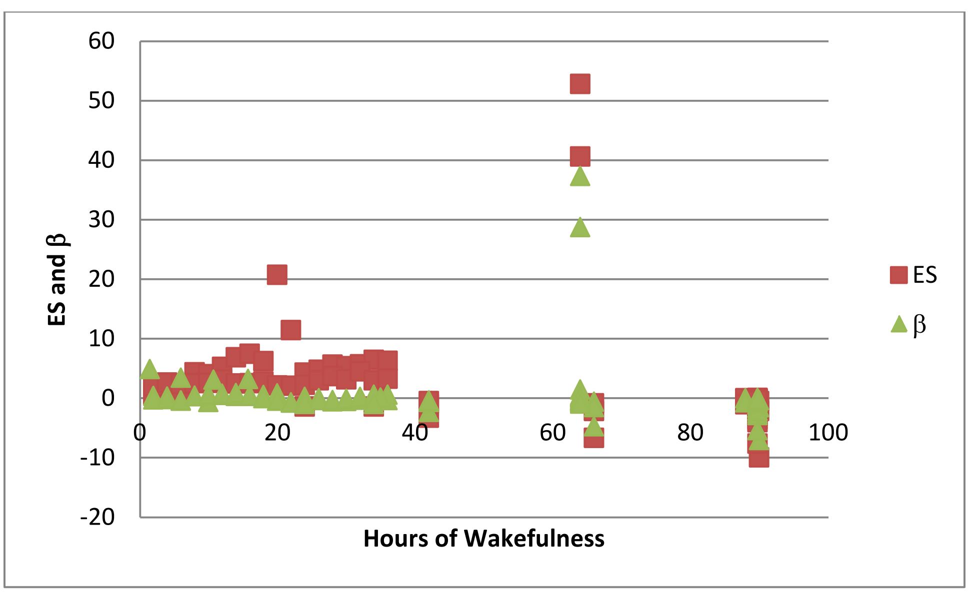

Figure 46: ES and β for Number Correct Accuracy Data

Table 70: Number of Data Points for ES and β Calculation for Number Correct Accuracy Data

Study Id #	# of Data Points
41	36
57	4
64	2
66	9
67	1
70	2
94	27
99	17

Similar to the percentage change analysis of Figure 46, the ES and β results have four data clusters at 40 or more hours of wakefulness. ES ranged from a minimum -9.97 to the maximum of 52.8 and β ranged from -7.05 to 37.33. Seventy-nine ES values were calculated from eight studies. Ninety-eight β values were calculated from eight studies; a larger number of β values was calculated due to the standard deviation information available for both the control and test condition. ES values were generally positive before forty hours of wakefulness and negative after forty hours of wakefulness. The effect size was calculated by subtracting the control condition from the test condition (*T*-*C*). The negative ES values show that the number correct data for the control condition were larger than for the test condition.

The probability ratio was calculated for threshold values k = 0, 25, 50, 75, and 100. Values greater than 100 were removed as outliers; the remaining data were plotted in Figure 47. The probability ratio could only be calculated for nine discrete values of hours of wakefulness and the results were grouped into three clusters. There are not enough data available to draw a conclusion. No further analysis was performed.

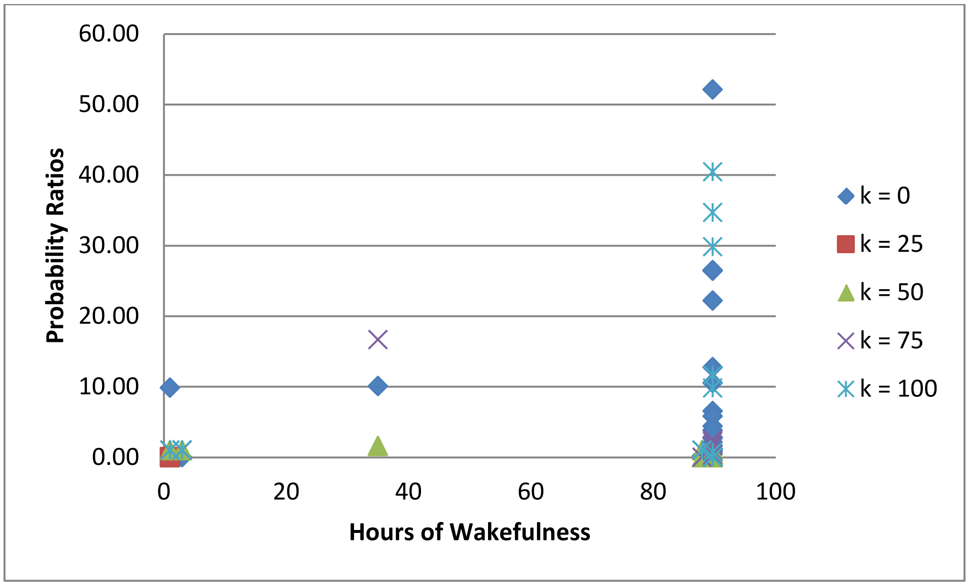

Figure 47: Probability Ratio for Number Correct Data vs. Hours of Wakefulness

Data on Percentage Correct (% Correct)

The studies that reported accuracy performance in the form of percentage correct are listed in Table 71. Percentage correct was reported in eighteen studies. Four studies did not report hours of wakefulness and could not be used, leaving fourteen for further analysis.

Table 71: Summary of Percentage Correct Data

% Correct	No. of Studies	Study Identification Numbers
Studies reporting % correct	16	(2, 3, 4, 7, 9, 17, 18, 50, 53, 55, 57, 60, 63, 67, 72, 92, 93, 101)
Studies without hours of wakefulness	4	(50, 55, 60, 72)
Studies without standard deviaiton	5	(9, 18, 63, 92, 93)
Difference between the means	14	(2, 3, 4, 7, 9, 17, 18, 53, 57, 63, 67, 92, 93, 101)
Effect size	8	(2, 3, 4, 7, 17, 53, 57, 101)
Studies used	14	(2, 3, 4, 7, 9, 17, 18, 53, 57, 63, 67, 92, 93, 101)

The first analysis of the percentage correct accuracy data was to calculate the difference between the mean values of the control and test conditions for each data point of hours of wakefulness given, Figure 48. The spread of data is more variable after 45 hours of wakefulness. Before 40 hours of wakefulness, the difference between the control and test conditions approaches zero; meaning that there is little or no change between the mean value of control and test conditions.

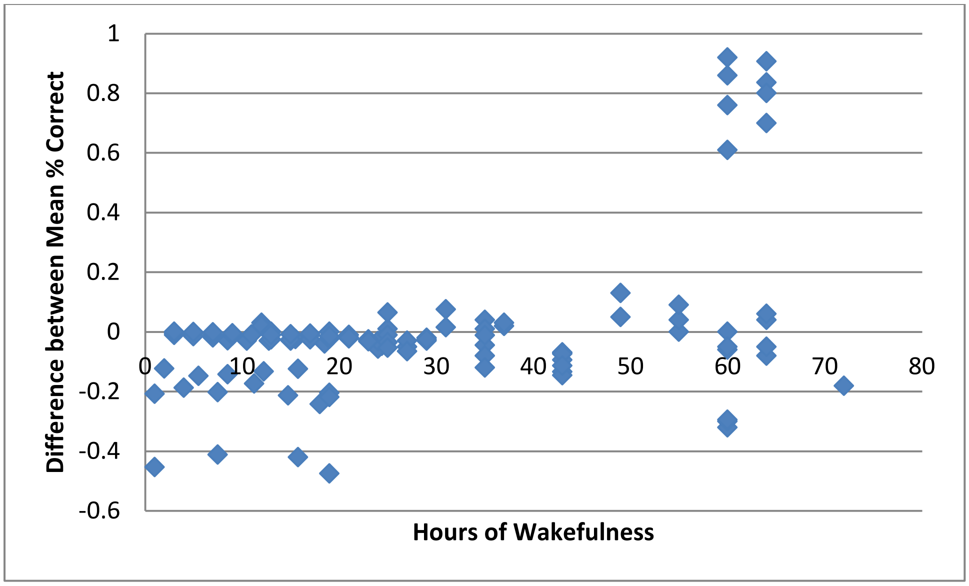

Figure 48: Difference between the Mean Values (μ_T-μ_C) for Percentage Correct Data

The number of data points per study for accuracy as reported as percentage correct are shown in Table 72. Fourteen studies provided one hundred and sixteen data points; three studies reported only one data point each.

Table 72: Number of Data Points for Percentage Correct Accuracy Data

Study Id #	# of Data Points
2	1
3	4
4	2
7	3
9	5
17	2
18	1
53	7
57	17
63	10
67	1
92	13
93	8
101	42

Percentage change in accuracy based on percentage correct data was calculated by using Equation 15, and plotted in Figure 49. A general trend of the data is not revealed. After forty hours of wakefulness, the data are approximately equally above and below the zero line. No conclusive statement can be made regarding the effect of sleep deprivation on performance from the percentage correct accuracy data.

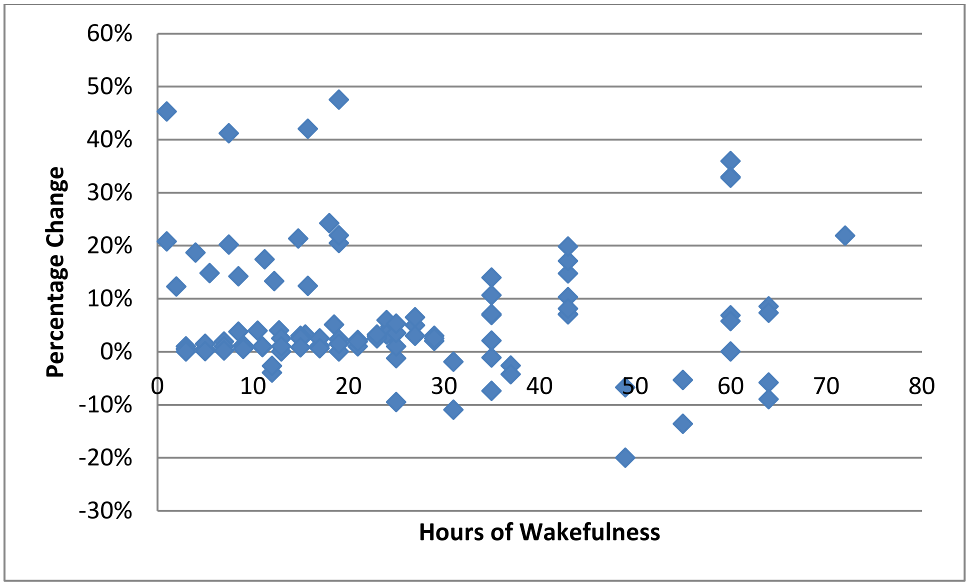

Figure 49: Percentage Change for Percentage Correct Accuracy Data

The effect size (ES) and reliability index (β) were calculated for data using mean values and standard deviation information. Figure 50 is a plot of the ES and β data calculated from Equations 8 and 17 respectively. The number of data points from each study for ES and β calculation are listed in Table 73.

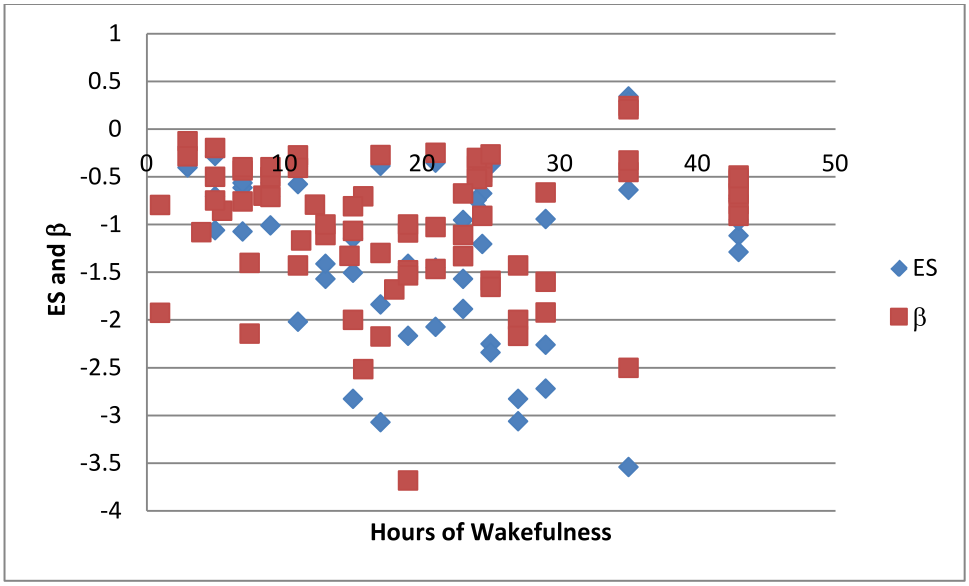

Figure 50: ES and β for Percentage Correct Accuracy Data

Table 73: Number of Data Points for ES and β for Percentage Correct Accuracy Data

Study Id #	# of Data Points
2	1
3	4
4	2
7	3
17	2
53	7
57	16
101	39

The ES and β values ranged from -3.54 to 0.39 and -3.68 to 0.24. Effect sizes and β values spread in the negative direction as hours of wakefulness increased. The majority of the ES and β values were negative; a negative ES represents deterioration in performance. For percentage correct data, a negative ES means that the percentage correct response is reduced over an increase of hours of wakefulness. Eight studies provided seventy-four data points, with thirty-nine coming from a single study (#101-Lamond_1999).

The probability ratio of error in the control and test conditions is calculated using Equations 23 and 24. Threshold values of k = 0, 0.25, 0.5, and 1 were selected based on the overall mean of the control test condition, which was approximately 0.90. A k value of 0.5 would make $T > k$ when the test condition reported a percentage correct greater than 50%. Probability ratios for percentage correct accuracy data are plotted in Figure 51.

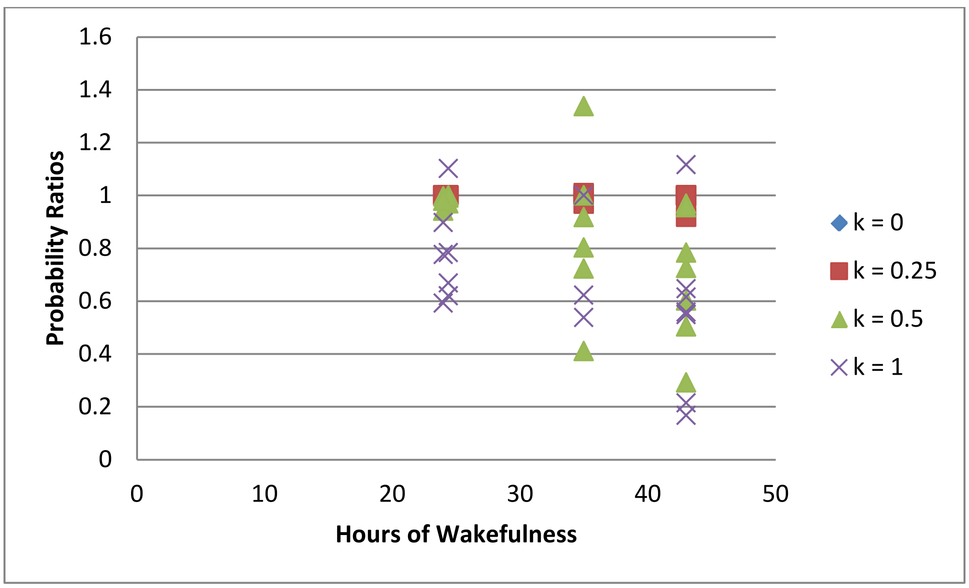

Figure 51: Probability Ratio for Percentage Correct vs. Hours of Wakefulness

The resulting probability ratios clustered at three discrete values of hours of wakefulness. Probability ratios were primarily less than or equal to one. A PSF coefficient less than one would improvement in the overall error probability. The data do not extend beyond 45 hours of wakefulness. Performance may deteriorate after 45 hours of wakefulness, but cannot be determined by the available data. A best-fit trend-line could not be fitted to the data due to the limited data points and that only three discrete values of hours of wakefulness provided data for analysis. The limited data points and hours of wakefulness make further analysis difficult.

Data on Number of Errors (# Errors)

The ten studies that reported accuracy performance in the form of number of errors are listed in Table 74. Two studies did not report hours of wakefulness and could not be used, leaving eight studies for further analysis.

Table 74: Summary for Number of Errors Accuracy Data

Number of Errors	No. of Studies	Study Indetification Numbers
Studies reporting number of errors	10	(5, 10, 20, 49, 67, 72, 83, 92, 100, 103)
Studies wthout hours of wakefulness	2	(72, 83)
Studies without standard deviaiton	3	(5, 20. 92)
Difference between the means	7	(5, 10, 20, 67, 92, 100, 103)
Effect size	5	(10, 6, 7, 100, 103)
Studies used	8	(5, 10, 20, 49, 67, 92, 100, 103)

The difference between the mean values of the control and test conditions for accuracy data reported in the form of number of errors is plotted in Figure 52. For up to 40 hours of wakefulness, the difference between the control and test conditions is centered about zero (i.e., there is little to no difference between the control and test condition mean values). The spread of data is larger after 40 hours of wakefulness; the data are negatively increasing. This means the number of errors at the test condition is increased relative to the control condition as hours of wakefulness increase.

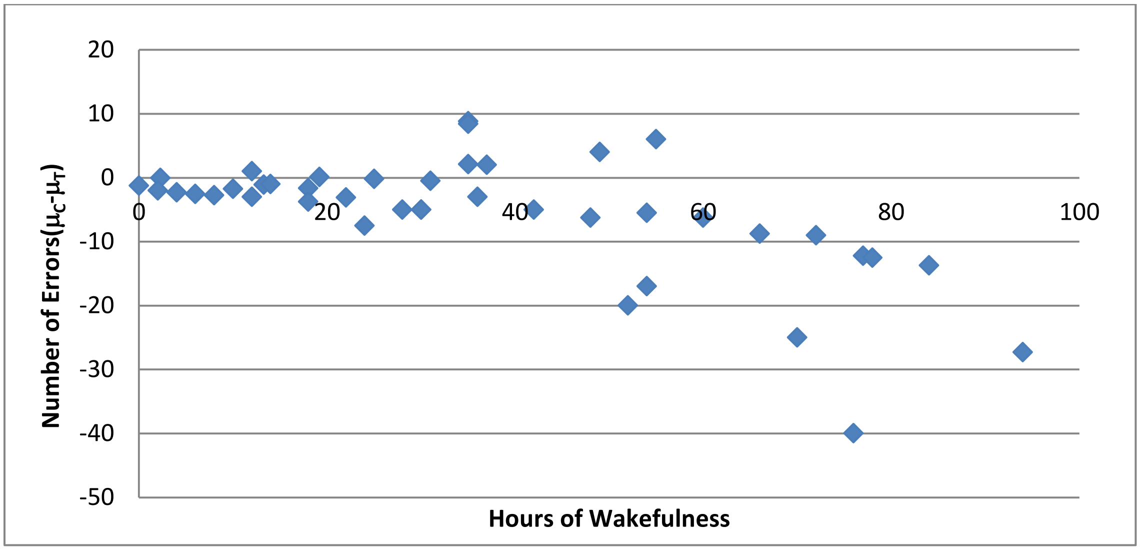

Figure 52: Difference between the Mean Values (μ_C-μ_T) for Number of Errors Accuracy Data

Accuracy data reported as the number of errors data points per study are provided in Table 75. The seven studies provided forty-two data points. One study (i.e., #10-Swann_2006) reported only one data point and one study (i.e., #103_Doran_2001) reported nineteen data points. The percentage change for number of errors data is shown in Figure 53.

Table 75: Number of Data Points for Number of Errors Accuracy Data

Study Id #	# of Data Points
5	5
10	1
20	6
67	3
92	6
100	2
103	19

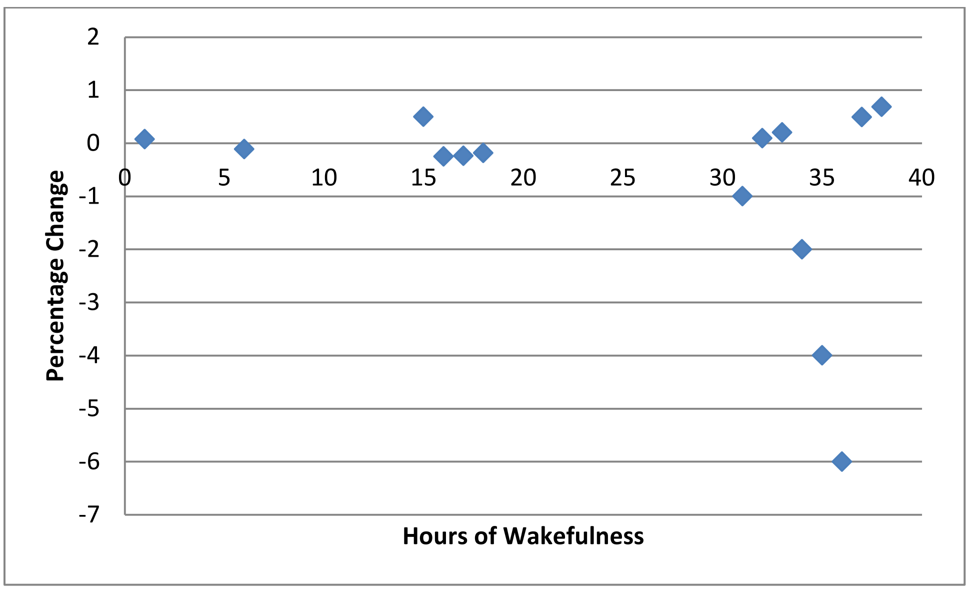

Figure 53: Percentage Change for Number of Errors Accuracy Data

The next step was to calculate the effect size (ES) (Equation 8) and reliability index β (Equation 17) for the number of errors at each available data point; these are plotted in Figure 54. The ES and β values show the standardized difference between the number of errors for the control and test conditions as caused by discrete values of hours of wakefulness. Multiple data points are used from one study. Table 76 provides the study identification numbers for studies reporting accuracy as number of errors and the number of data points from each study.

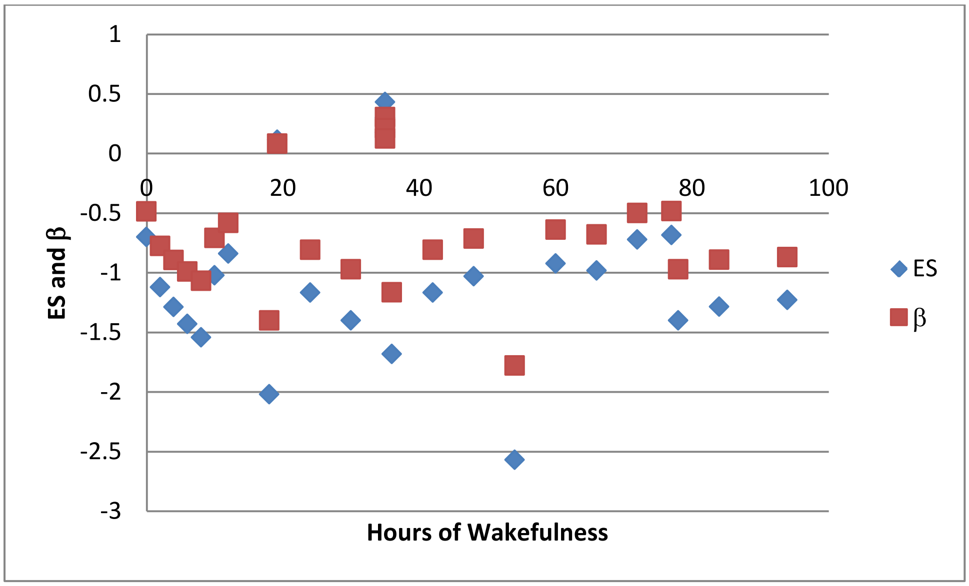

Figure 54: ES and β for Number of Errors Accuracy Data

Table 76: Number of Data Points for ES and β for Number of Error Accuracy Data

Study Id #	# of Data Points
10	1
67	3
100	2
103	19

A probability ratio between the error region of the test condition and control condition for the accuracy data reported as number of errors was plotted in Figure 55. Threshold values of $k = 0$, $k = 30$, and 50 were selected.

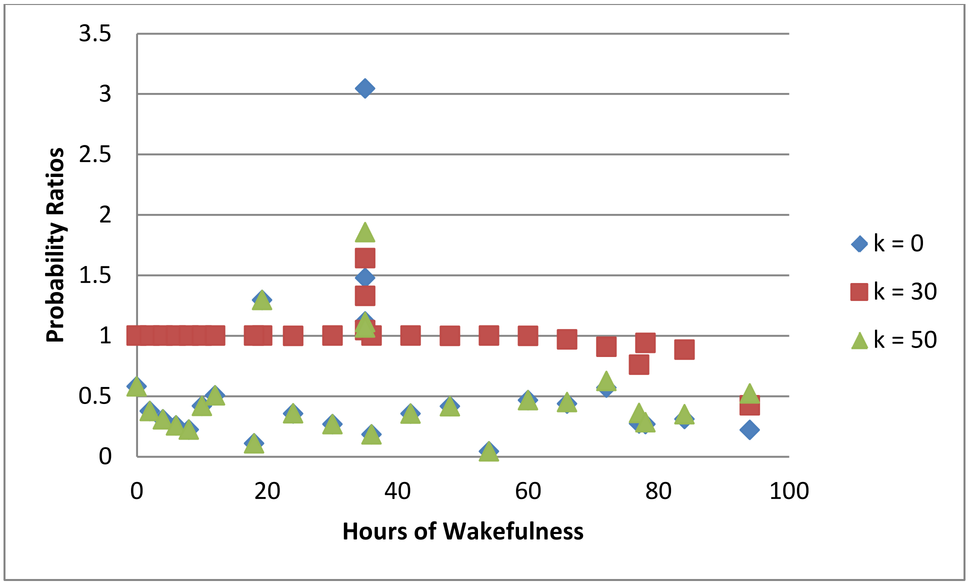

Figure 55: Probability Ratio for Number of Errors Accuracy Data vs. Hours of Wakefulness

The control and test condition mean values for the number of errors ranged from 0 to 40. The best-fit equations for k = 0, 30, and 50 are listed in Table 77. The data were subdivided into less than twenty hours, twenty to forty hours, forty to sixty hours, and sixty to eighty hours block intervals.

Table 77: Probability Ratio Equations for Number of Error Data (*k* = 0 and *k* = 50)

Hours	R^2	$k = 0$
< 20	0.997	$y = 5E\text{-}06x^6 - 0.000x^5 + 0.004x^4 - 0.032x^3 + 0.123x^2 - 0.249x + 0.579$
20 to 40	0.65	$y = -0.030x^3 + 2.755x^2 - 81.58x + 794.4$
40 to 60	1	$y = 0.000x^3 - 0.142x^2 + 7.066x - 115.3$
60 to 80	1	$y = 0.000x^4 - 0.029x^3 + 3.108x^2 - 144.1x + 2495$

Hours	R^2	$k = 30$
< 20	NA	NA
20 to 40	0.495	$y = -0.006x^3 + 0.555x^2 - 16.43x + 160.8$
40 to 60	1	$y = -4E\text{-}06x^3 + 0.000x^2 - 0.032x + 1.537$
60 to 80	1	$y = 0.000x^4 - 0.048x^3 + 4.956x^2 - 226.1x + 3857.$

Hours	R^2	$k = 50$
< 20	0.997	$y = 5E\text{-}06x^6 - 0.000x^5 + 0.004x^4 - 0.032x^3 + 0.123x^2 - 0.249x + 0.579$
20 to 40	0.817	$y = -0.020x^3 + 1.879x^2 - 55.63x + 541.9$
40 to 60	1	$y = 0.000x^3 - 0.142x^2 + 7.081x - 115.5$
60 to 80	1	$y = 5E\text{-}05x^4 - 0.014x^3 + 1.538x^2 - 72.69x + 1281$

A threshold value of $k = 30$ produced probability ratios of approximately one; a PSF coefficient of one would not change the overall error probability. Threshold values of $k = 0$ and $k = 50$ produced probability ratios of less than one; this would improve the overall error probability, with some data spread above one just before 40 hours of wakefulness. The threshold value of $k = 50$ had the lowest R^2 values. The data were subdivided into less than twenty hours, twenty to forty hours, forty to sixty hours, and sixty to eighty hours block intervals.

The differences between the mean values for the control and test conditions, Figure 52, show an increase in the number of errors as the hours of wakefulness increase. However, the probability ratio derivation for the accuracy data reported as the number of errors does not show a deterioration of performance as hours of wakefulness increase.

Data on Percentage of Errors (% Errors)

Nine studies that reported accuracy as percentage of errors are listed in Table 78. Two studies did not report hours of wakefulness and could not be used, leaving seven studies for further analysis.

Table 78: Summary of Percentage of Errors Accuracy Data

% Errors	No. of Studies	Study Indentification Numbers
Studies reporting % errors	9	(14, 26, 31, 32, 43, 56, 75, 91, 95)
Studies without hours of wakefulness	2	(31, 75)
Studies without standard deviation	6	(14, 26, 31, 56, 75, 91)
Difference between the means	5	(14, 26, 32, 43, 95)
Effect size	4	(32, 43, 56, 95)
Studies used	7	(14, 26, 32, 43, 56, 91, 95)

For the percentage of errors, the difference between the mean values of the control and test conditions is plotted in Figure 56. There was only one data point beyond 40 hours of wakefulness, and there was no difference between the control and the test condition mean values. The difference between the mean values of the number of errors was calculated by *C-T*. A trend in the negative direction can be seen in Figure 56; this means that the percentage of reported errors increases as hours of wakefulness increase.

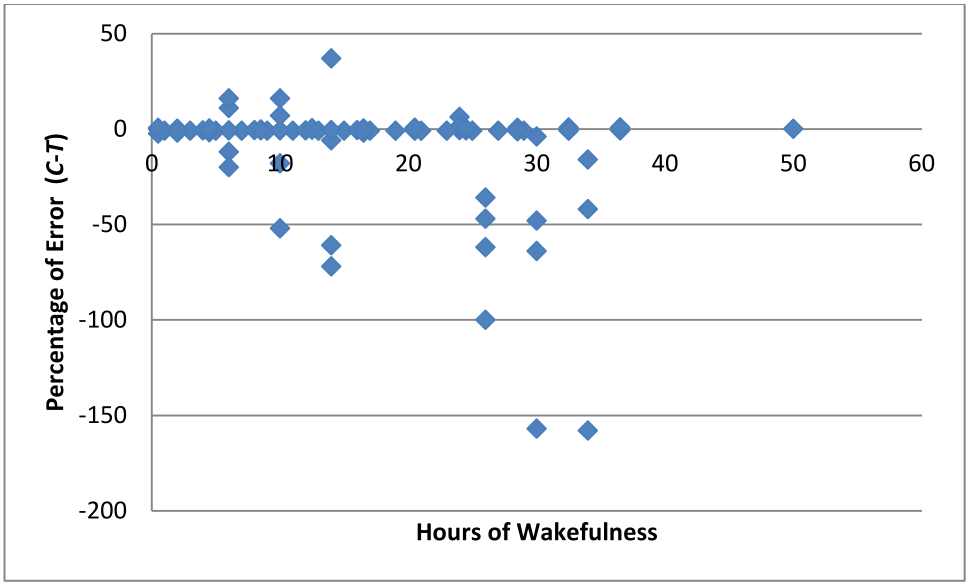

Figure 56: Difference between Mean Values (μ_C-μ_T) for Percentage Error Accuracy Data

Accuracy data reported as the percentage of error data points per study are provided in Table 79. The five studies provided forty-two data points; two studies provided more than twenty data points (i.e., #26-Collins_1977 and #95-Sagaspe_2006).

Table 79: Number of Data Points to Calculate Difference between the Mean Values (*C-T*) for Percentage Error Accuracy Data

Study Id #	# of Data Points
14	7
26	27
32	15
43	8
95	29

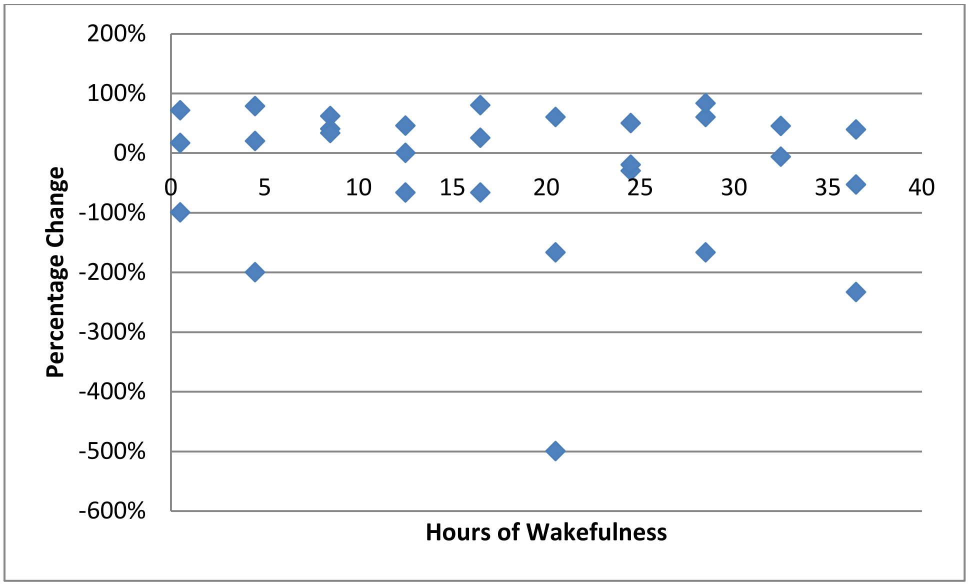

Figure 57: Percentage Change for Percentage Error Accuracy Data

ES (Equation 8) and β (Equation 17) values for accuracy reported as the percentage of error were calculated next and plotted in Figure 58. The studies that reported percentage error and the number of data points per study are listed in Table 80. Four studies reported accuracy as percentage error and provided data to calculate ES and β from Equations 8 and 17 respectively. Sixty-three ES and fifty-three β data points were calculated. The data did not extend beyond 40 hours of wakefulness. ES values centered around zero, i.e., no change in performance as hours of wakefulness increase.

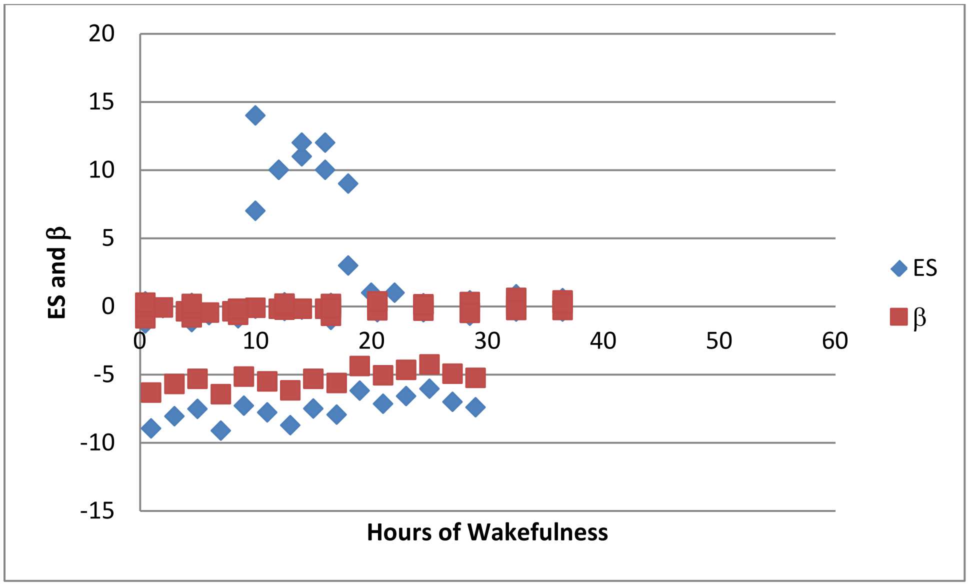

Figure 58: ES and β for Percentage Error Accuracy Data

Table 80: Number of Data Points per Study ES and β for Percentage Error Accuracy Data

Study Id #	# of Data Points
14	7
26	27
32	15
43	8
56	12
95	29

The probability ratio for threshold values k = 0, 0.25, 0.5, and 1 was calculated using Equations 23 and 24. The probability ratios were concentrated between zero and one for less than 40 hours of wakefulness. No data were available for after 40 hours. The resulting probability ratios were plotted in Figure 59. The best-fit equations for percentage error are provided in Table 81.

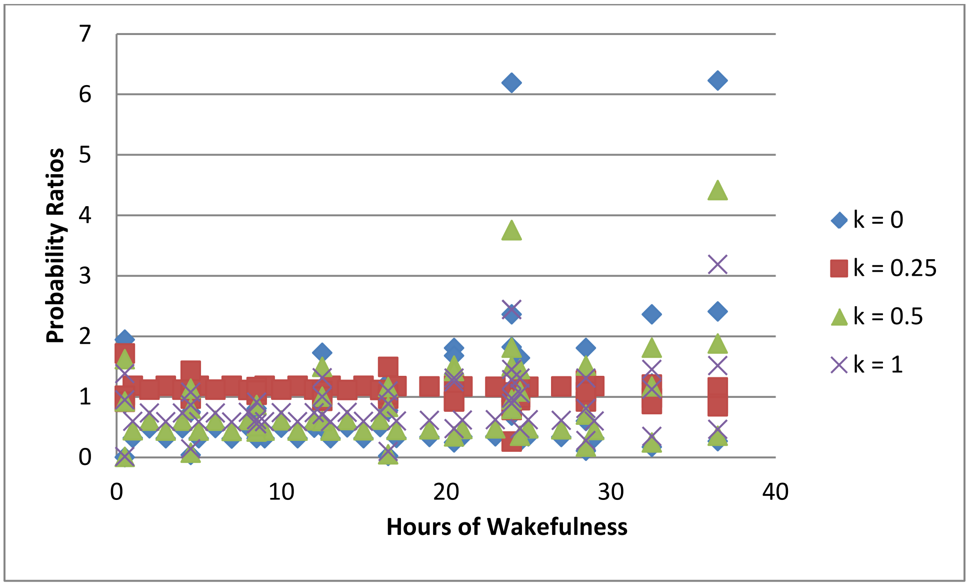

Figure 59: Probability Ratios for Percentage Error Accuracy Data vs. Hours of Wakefulness

Table 81: Probability Ratio Equations for Percentage Error Data

Hours	R^2	Best-Fit Equations
< 20	0.214	$y = 2E\text{-}07x^6 - 2E\text{-}05x^5 + 0.000x^4 - 0.009x^3 + 0.077x^2 - 0.294x + 0.929$
20 to 40	0.148	$y = -2E\text{-}08x^6 + 2E\text{-}06x^5 - 5E\text{-}05x^4 + 0.000x^3 + 0.000x^2 - 0.026x + 1.222$
40 to 60	0.223	$y = 1E\text{-}07x^6 - 1E\text{-}05x^5 + 0.000x^4 - 0.006x^3 + 0.051x^2 - 0.192x + 0.846$
60 to 80	0.215	$y = 8E\text{-}08x^6 - 7E\text{-}06x^5 + 0.000x^4 - 0.004x^3 + 0.032x^2 - 0.108x + 0.794$

Probability ratios for k = 0 and 0.5 were concentrated along 0.5; and for k = 0.25 they were concentrated about 1.2. Data showed a trend toward probability ratio values increasing as hours of wakefulness increased. The equations were not improved by plotting the data for less than twenty hours separately from the data over twenty hours. The R^2 values were all less than 0.250; the limited amount of data does not enable meaningful best-fit equations to be found.

Data on False Positives (False +)

Six studies that reported accuracy as false positives are listed in Table 82. Two studies did not report hours of wakefulness and could not be used, leaving four studies for further analysis.

Table 82: Summary of False Positive Accuracy Data

False Positives	No. of Studies	Study Indentification Numbers
Studies reporting False +	6	(5, 27, 48, 53, 55, 100)
Studies without hours of wakefulness	2	(27, 55)
Studies without standard deviation	1	(5)
Difference between the means	4	(5, 48, 53, 100)
Effect size	3	(48, 53, 100)
Studies used	4	(5, 48, 53, 100)

Four studies reported accuracy in the form of false positives and provided data to find the difference between the mean values of the control and test conditions; the result is plotted in Figure 60. The difference between the mean values of the number of errors was calculated by *C-T*. Thou there was only a small sample of data available, an increase in the number of false positives as the hours of wakefulness increases can be seen by the negative direction of the data in Figure 60.

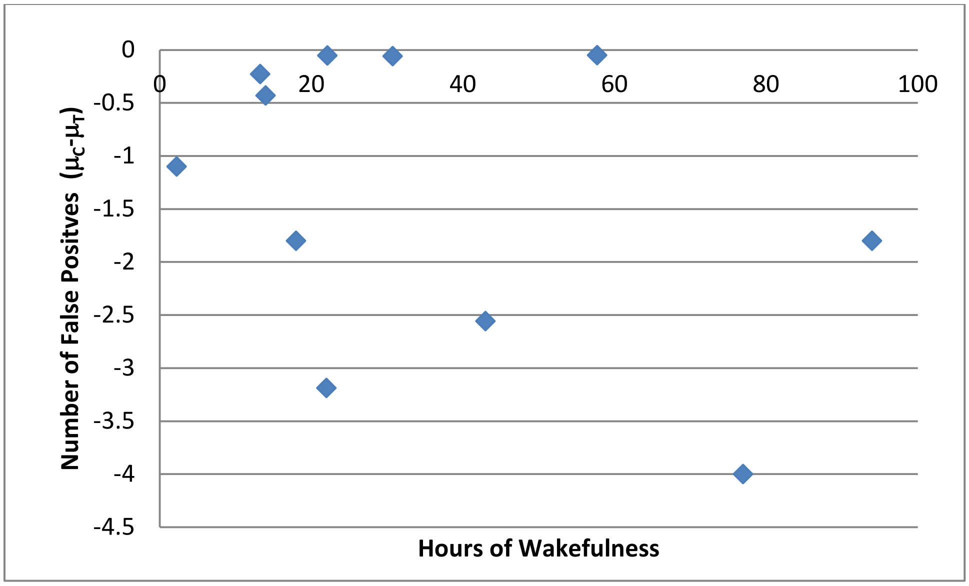

Figure 60: Difference between the Mean Values (μ_C-μ_T) for False Positive Accuracy Data

The number of data points from each study reporting as false positives are provided in Table 83. Three studies provided six data points. False positives were the smallest data set subdivided from the accuracy data.

Table 83: Number of Data Points per Study Difference between Mean Values (μ_C-μ_T) for False Positives Accuracy Data

Study Id #	# of Data Points
48	3
53	1
100	2

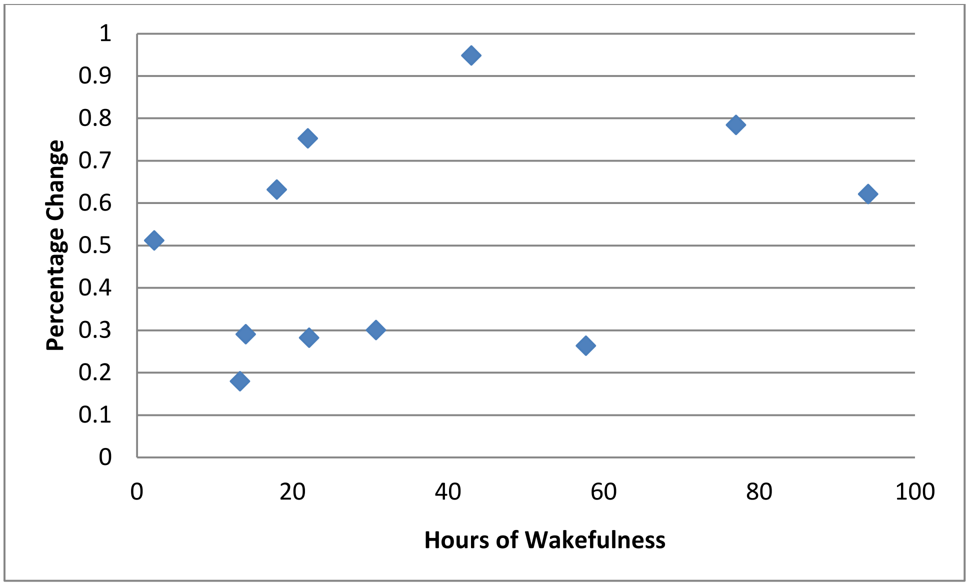

Figure 61: Percentage Change for False Positives Accuracy Data

Only three studies reported accuracy as false positives (see Table 84) and provided data to calculate ES and β from Equations 8 and 17 respectively. The results are plotted in Figure 62.

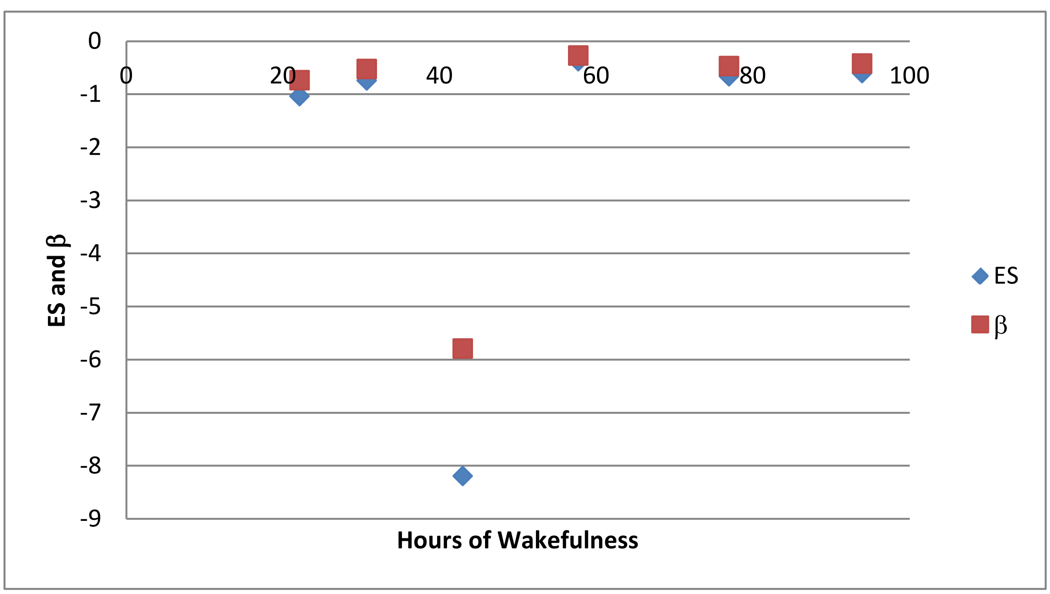

Figure 62: ES and β for False Positives Accuracy Data

Table 84: Number of Data Points to Calculate ES and β for False Positives Accuracy Data

Study Id #	# of Data Points
48	3
53	1
100	2

The effect sizes ranged from 0.38 to 2.2, and β ranged from 0.27 to 5.8 for accuracy data reported as false positives. Only six ES and β values were calculated from three studies.

The probability ratios for threshold values of k = 0, 1, 2, and 3 were calculated using Equations 23 and 24. The average number of false positives for the control condition mean value is 1.7, and the test control mean value is 2.5. The threshold values were selected in relation to the overall average values of false positives. Resulting probability ratios were plotted in Figure 63.

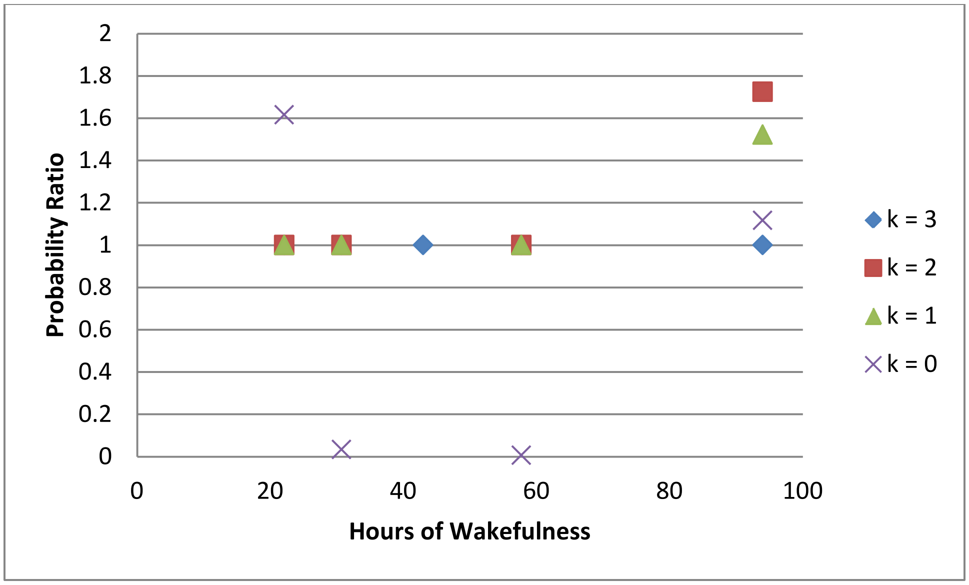

Figure 63: Probability Ratios for False Positives Accuracy Data vs. Hours of Wakefulness

Table 85: Probability Ratio Equations for False Positives Accuracy Data

R^2	Best-fit Equations
1	$y = -6E\text{-}05x^3 + 0.012x^2 - 0.697x + 11.73$
1	$y = 3E\text{-}06x^3 - 0.000x^2 + 0.011x + 0.875$
1	$y = 4E\text{-}06x^3 - 0.000x^2 + 0.016x + 0.826$
0.774	$y = 1e^{2E\text{-}14x}$

The probability ratios for false positive data were based on four data points per selected threshold values for k = 0, 1, and 2 and five data points for k = 3. Derived probability ratios for k = 1, 2, and 3 before 80 hours of wakefulness were one; i.e., there was no change between the control and test performance. Only the k = 0 threshold value produced probability ratios that differed from one before 80 hours of wakefulness, two less than one, and one greater than one. The limited number of data points does not provide enough information to draw conclusions.

The differences between the mean values of the control and test conditions show a decrease in performance as hours of wakefulness increase. The difference between the means was calculated by *C-T* for the number of errors, percentage of error, and false positives. A reduction of performance occurs when the test condition is larger than the control condition. Unfortunately after the accuracy data were subdivided by number correct, percentage correct, number of errors, percentage of error, and false positives, the sample sizes of data were not large enough to draw significant conclusions. The derived probability ratios did not consistently predict an increase in error probability (for accuracy data) as hours of wakefulness increase. Accuracy does not seem to be affected as significantly as reaction time and number of lapses under sleep deprivation. However, due to the sparseness in accuracy data, the statistics and inferences do not appear to be significant.

Summary and Conclusion for Accuracy Data

Accuracy data were grouped by number correct, percentage correct, number of errors, percentage of error, and false positives. Data that reported accuracy as the number correct came from fourteen different studies. The differences between the means increased up to 40 hours of wakefulness; after 40 hours of wakefulness the data clustered and were not further analyzed. Threshold values of k = 0, 23, 50, and 75 were used to derive probability ratio values. The data clustered about four points and were not further analyzed.

Accuracy as reported as percentage correct was found in fourteen studies. The difference between the mean values centered about zero; i.e., there was a difference between the control and test conditions. Threshold values of k = 0, 0.25, 0.5, and 1 were used to derive the probability ratios for percentage correct. Probability ratios less than one were found for k = 0.25 and 0.5 and probability ratios of approximately one were found for k = 0 and 1. A probability ratio of one does not change the overall error probability, i.e., no change in performance under sleep deprivation.

Eight studies were found to report accuracy as number of errors. The number of errors increased as hours of wakefulness increased. The differences between the mean values were calculated by C - T. Threshold values of k = 0, 30, and 50 were used to derive probability ratios. For k = 0 and k = 50, the probability ratios were less than one and the probability ratio values were continuously close to one when a threshold value of 30 was used in the analysis.

Accuracy as reported as percentage of errors was calculated from seven studies. The difference between mean values centered around zero, i.e., no change from the control to the test condition. Threshold values of k = 0, 0.25, 0.5, and 1 were used to derive probability ratios for percent of errors data. The probability ratios were centered at 0.5 for k = 0 and k = 5 and 1.2 for k = 1.2. The probability ratios did not continuously increase and remained consistent as hours of wakefulness increased.

The four studies that reported false positives data were analyzed. The number of false positives, i.e., reacting when there was no signal, increased as hours of wakefulness increased. Threshold values of k = 0, 1, 2, and 3 were selected. The produced probability ratios centered around one; however k = 0 has some data spread.

In summary, accuracy is not as affected as reaction time and number of lapses under sleep-deprived conditions. The draw on cognitive capacity that results from sleep deprivation may help increase arousal levels (Yerkes and Dodson, 1908) and help to maintain, or even improve, performance on the simple tasks that were the primary tasks employed in the studies under investigation. Another reason why accuracy is not as affected by sleep deprivation is the tradeoff between reaction time and accuracy (i.e., speed-accuracy tradeoff). Reaction time is often sacrificed to maintain or improve accuracy (Fitts, 1954). The studies do not consistently mention if reaction time and accuracy were measured at the same time or if one was emphasized over the other. Accuracy was not reported in the same manner in each study. In the studies that reported accuracy as a performance metric, accuracy was reported through several measures: number of errors, number of false positives and hit rates, the number of false starts, number of errors, and number of responses.

E META-ANALYSIS CODING DATA

Table 86: Study Descriptors Raw Data Part 1a

Study Identifiers			Study Context				Sample Descriptors				Experimental Condition			
Study ID #	1st Author	Publication Year	Type of publicatio	Industry	Environment	Country	Specialty of Field	Sex of Group	Mean ge	Notes of interest	Comparison	Experiment blinding	Assignment of	Generalizabilty of Sample
1	Nilsson_2005	2005	Journal	Academic	lab	Sweden		NA	a		2GC	practice se	Random & matched on ger	
2	Thomas_2000	2000	Journal	Academic	lab	USA		>95% male	24.7		RM	NA	NA	
3	Choo_2005	2005	Journal	Academic	lab	Japan		50-95% male	21.8		RM	NA	Counterbalanced	
4	Chee_2004	2004	Journal	Academic	lab	Japan		50-95% male	23		RM	practice se	Counterbalances	
5	Williamson_200	2000	Journal	Transporta	lab	Australia		>95% male	35.6		RM	practice se	Counterbalanced	
6	Kobbeltvedt_20	2005	Journal	Military	field	Norway		>95% male	23		2GC	NA	Random	
7	Robbins_1990	1990	Journal	Medical	field	US	medical sta	NA	NA		RM	NA	NA	medical house s
8	Angus_1985	1985	Journal	Academic	lab	Canada	Students?	<5% male	21.5		RM	subjects to	NA	
9	Babkoff_2005	2005	Journal	Academic	lab	Israel	students	50% male	23.8		RM	practice se	Counterba	students
10	Swann_2006	2006	Journal	Academic	lab	Australia	recruited	95% male	24.5		RM	subjects to	Counterba	st
11	Koslowsky_199	1992	Journal	Academic	lab						Meta-analysis			
12	Pilcher_1996	1996	Journal	Academic	lab						Meta-analysis			
13	Belenky	2003	Journal	Military	lab	US	CMV licen	75% male	m = 37, f=	14 days in	group com	NA	NA	volunteers
14	Buck_1972	1972	book secti	Academic	lab	US		100% male	NA		RM	NA	NA -repea	NA
15	Killgore_2006	2006	Journal	Academic	lab	US	volunteers	75% male	25.2 (5.7)		RM	NA	NA	volunteers were
16	Marmuff_2005	2005	Journal	Academic	lab	US	college stu	50% male	21.64=[18-40]		RM	subjects bl	randomize	college students
17	Yoo_2007	2007	Journal	Academic	lab	US	NA	NA	NA		RM		randomly a	NA
18	Babkoff_1985	1985	Journal	Academic	lab	Israel	volunteers	95% male	21=18 -24		RM	subjects tr	NA - subjects tested in pai	
19	Williams_1967	1967	Journal	Military	lab	US	enlisted me	95% male	24		RM	NA	appears random selection i	
20a	Williams_1959	1959	Journal	Military	lab	US	enlisted me	95% male	20.5		RM	NA	NA	NA
20b	Williams_1959	1959	Journal	Military	lab	US	enlisted me	95% male	27.5		RM	NA	NA	NA
21	Wilson_2007	2007	Journal	Transporta	lab	US		50-95% male	25		RM	subjects tr	NA	NA
21b	Wilson_2007	2007	Journal	Transporta	lab	US		50-95% male	25		RM	subjects tr	NA	NA
22	Gundel_2007	2007	Journal	German ae	lab	Germany		>95% male	40.5	aerospace	RM		randomly a	sample correspo
23a	Webb_1985	1985	Journal	NA	lab	US	NA	ostly males	55		RM	NA	NA	NA
23b	Webb_1985	1985	Journal	NA	lab	US	NA	ostly males	22.5		RM	NA	NA	NA
24	Dinges_1997	1997	Journal	Academic	lab	US		50/50	22.9		RM			convenience sar
25	Sanders_1982	1982	Journal	Academic	lab	Netherland	students	95% male	19-28 = 23.5		RM	subjects tr	counter ba	convenience sar
26	Collins_1977	1977	Journal	Transporta	lab	US	students	95% male	21-30 = 25	FAA	RM	practice se	counter ba	convenience sar
27	Porcu_1998	1998	Journal	Military	lab	Italy	volunteers	95% male	33.5	Italian air f	RM	practice se	NA	volunteers
28	Wojtczak_jaros	1978	Journal	Shiftwork	at factory	Poland	shift worke	95% male	22-45		RM	NA	NA	shiftworkers
29	Dorrian_2007	2007	Journal	Transporta	rail training	Australia	train driver	95% male	NA		RM	subjects tr	NA	train drivers
30	Maury_1993	1993	Journal	Shiftwork	lab	France	chemical p	95% male	40	French shi	2GC	NA	NA for gr	French shiftwor
31	Borland_1986	1986	Journal	Military	lab	England	shift worke	95% male	23 = 20-26	royal airfo	RM	NA	NA	English military
32	Dawson_1997	1997	Journal	Academic	lab	Australia	NA	NA	NA	Australian	RM	NA	counter ba	NA
33	Roach_2006	2006	Journal	Academic	lab	Australia	volunteers	35% male	21.7	Australian	RM	subjects tr	NA	young and healt
34	Reznick_1987	1987	Journal	Medical	field (cond	US	residents	NA	29 (25-34)	medical	RM	subjects tr	counterbal	doctors
35	Daniel_1989	1989	Journal	Shiftwork	lab	Czechoslo	shiftwork	95% male	25.3 (4.08)	chemical i	RM	NA	NA	shiftworkers
36	Buck_1975	1975	Journal	Academic	lab	Canada		>95% male	18-22		RM	practice se	counter ba	NA
37	Lenne_1997	1997	Journal	Academic	lab	Australia	students	95% male	23.6 (21-2	college stu	RM	practice se	counter ba	volunteers
38	Sallinen_2004	2004	Journal	Academic	lab	Finland	process operators		(28-56)		RM		counter balanced	
39	Akerstedt_2005	2005	Journal	Transporta	lab	Sweden	experience	50% male	37(12)	shiftworke	RM	practice session		
40	Boksem_2005	2005	Journal	Academic	lab	Netherland	students	50% male	22	not shiftw	RM	subjects bl	NA	volunteers
41	Monk_1997	1997	Journal	Academic	lab	US	paid volun	50% male	[19-28]	paid volun	RM	practice se	NA	volunteers
41b	Monk_1997	1997	Journal	Academic	lab	US	paid volun	50% male	[19-28]	paid volun	RM	practice se	NA	volunteers
41c	Monk_1997	1997	Journal	Academic	lab	US	paid volun	50% male	[19-28]	paid volun	RM	practice se	NA	volunteers
42	Jones_2006	2006	Journal	Academic	lab	Austria	volunteers	50% male	[18-34]	non shiftw	RM	NA	NA	volunteers from
43	Hull_2003	2003	Journal	Academic	lab	US	volunteers	75% male	[20-41]	paid but no	RM	NA	NA	volunteers
44	Wright_2006	2006	Journal	Academic	lab	US					RM			
45	Halbach_2003	2003	Journal	Medical	lab	US	ob gyn house staff and medical students				RM			medical resident
45b	Halbach_2003	2003	Journal	Medical	field	US	ob gyn house staff and medical students				RM			
45	Bliese_2006	2006	Journal	Academic	lab	US	volunteers	75% male	w=43, n=16: m=37, n		GC			
47	Lamond_2007	2007	Journal	Academic	lab	Australia	volunteers	50 % male	23.3 (4.3)		RM			
48	Drummond_2006	2006	Journal	Academic	lab	US		>50% male	21.1		RM	NA	NA	NA
49	Eastridge_2003	2003	Journal	Medical	lab	US	surgical re	75% male	28 (24-33)	medical stu	RM	practice se	random	medical resident
50a	Engle_Friedman	2003	Journal	Academic	lab and ca	US	students -	50% male	19.86 (bro	undergradu	RM	practice se	randomly a	student voluntee
50b	Engle_Friedman	2004	Journal	Academic	lab	US	students -	50% male	18.45	undergradu	2GC	practice se	randomly a	student voluntee
51	Caldwell_2003	2003	Journal	Military	lab	US	military	95% male	33.7 [26-44]		RM			
52	Rosa_1983	1983	Journal	Academic	lab	US	volunteers	00% male	22 [18-28]	ad in local	RM	practice se	counterbal	volunteers
53	Frey_2004	2004	Journal	Academic	lab	US	volunteers	50% femal	[18-25]		RM	practice se	part of double blind placebo	
54	Glenville_1979	1979	Journal	Academic	field	US	computer	00% male	[18-25]	NA	RM	practice session		shiftworkers
55	Webb_1982	1982	Journal	Academic	lab	US	students a	00% male	y=[18-22],	students a	RM & GC	practice se	NA	
56	Poulton_1978	1978	Journal	Medical	NA	England	doctors	50% male	27 [23-43]	doc chose	RM	practice se	na	doc chosen from
57	Englund_1985	1985	Journal	Military	lab	US	marines	00% male	20.5 [18-24]		RM	practice se	NA	military
57b	Englund_1985	1985	Journal	Military	lab	US	marines	00% male	20.5 [18-24]		RM	practice se	NA	military
57c	Englund_1985	1985	Journal	Military	lab	US	marines	00% male	20.5 [18-24]		RM	practice se	NA	military
57d	Englund_1985	1985	Journal	Military	lab	US	marines	00% male	20.5 [18-24]		RM	practice se	NA	military

Table 87: Study Descriptors Raw Data Part 1b

	Characteristics of task									
Study ID #	Descript of task	Pace (work or self)	Primary or secondary	Complexity of task	Multiple measures taken at same time(eg.speed accuracy	Predefined or Novel	Task Duration	Length of test	how was the task	how many times was the
1	SRT & working mem	work	primary	varied	NA	predefined	36-40 min	NA	NA	NA
2	SRT	work	primary	simple	yes RT & A	predefined	NA	NA	NA	NA
3	Letter matching	work	primary	complex	NA	novel	NA	NA	NA	NA
4	Working memory	work	primary	complex	NA	novel	NA	NA	NA	NA
5	Mackworth, SRT	work	primary/seco	simple	NA	predefined	NA	NA	NA	NA
6	Military tatical task	work	primary	complex	NA	novel	NA	NA	NA	NA
7	4 different tasks	work	primary	varied	yes RT & A	predefined	30-40min	NA	computer	3x
8	Logical reasoning	self	primary	complex	NA	predefined	NA	6 hrs	NA	NA
9		NA	primary	complex	yes RT & A	predefined	25-30 min	70min	NA	6x (1 per day)
10	TOJ - temporal order judgement	work	primary	simple	yes RT & A	predefined	10min	NA	NA	PVT x2, Novel
11		work	primary	simple					NA	NA
12		work	primary	simple					NA	NA
13	PVT	work	primary	simple	yes - speed and lapses	PVT	10 min		computer	NA
14		both	primary	simple	speed and accuracy	Step tracking task			computer	11 sessions in 5
15	Iowa gaming task	self	primary	simple		Iowa gaming			computer	
16	SRT - simple reaction time from CogState test battery		primary	simple	speed and accuracy	pre	6min		computer	12x
17	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
18	lexical decision task - clicking if stimulus i	work	primary	simple		lexical decision tas	3 sec response	3-45 min	computer	
19	Cognitive 2 additions every 2 sec	work	primary	simple	2-step		3min			
20a	reaction time task	work	primary	simple	no	novel - push button to indicate lig		approx 2 s	timer oper	72
20b	auditory and visual vigilance & of lapses	work	primary	simple	no	predefined - push	10 min	1 sec	Continuous	620
21	PVT and MATB	work	primary	simple	PVT all 3, MATB accuracy and	PVT - Dinges 199	10 min			
21b	MATB	work	primary	simple	MATB accuracy and speed					
22	MAT - 4 tasks	work	primary	simple	yes speed and accuracy	MAT	30min in 10mi	10		4x
23a	uses-N, reasoning - N, digit symbol - N, a	work	primary	simple	precision, attention, or cognitive taken 1 at a time					
23b	uses-N, reasoning - N, digit symbol - N, a	work	primary	simple						
24	PVT	work	primary	simple		PVT				3 x avged per da
25	id target on screen	?work	primary	simple	speed and accuracy emphasized		20min	80 trials	computer	
26	1 DoF compensatory tracking task 1) und	?work	primary	simple			2.5 min			
27	DSST (digit sub), DBT (Deux barrages),	work	primary	simple	yes	DSST, DBT, LCT	30 min	4, 10, unkn	pen & pap	4x at 2 hr interva
28	Meile's ball - place small balls in a narrow	work	primary	simple	RT on balls, and number symbols	Meile's ball & Toulouse-Pieron		1min		3 x per shift -bef
29	PVT	work	primary	simple	yes	PVT	10 min	2 hrs		4 x per "shift"
30	RT	NA	primary	simple		pictorial stimuli	NA	NA	computer	8x total (both ve
31	visual vigilance task - detect 3 consecutive	work	primary	simple	yes - response data (accuracy) and speed		30 min	3 hr	color video	4x
32	cognitive psychomotor performance (hand	work	primary	simple	NA	NA	NA	NA	computer	26x
33	PVT (10min, 5min, 90 sec)	work	primary	simple	yes but not reported - lapses	PVT	10min, 5min, 9	1hr session	hand held	14x
34	1) factual recall 2) Purdue Pegboard	1) self, 2) work	primary	simple, complex	1) accuracy, 2) speed and accura	1) novel, 2) Purdu	1) NA, 2) 30se	1hr session	1) pen and	1x
35	Disjunctive RT	NA	primary	NA	RT	NA	15 min	NA	Vienna rea	7x per shift for 1
36	tracking task on NRCstressalyser	self	primary	simple	RT, movement time	tracking task on N	15 min	45min	computer	3x every 4 hrs
37	secondary RT while driving on simulator	NA	secondary	simple	RT, driving	NA	NA	30 min	NA	6x (1 per day)
38	POMS and CRT	busy vs. monotor	primary	simple		POMS & CRT				
39	driving simulator task	work	primary	simple			2 hrs			
40	SRT	work	primary	simple	speed and accuracy		2 hrs 20 min	6 hrs	screen and figure reactor	
41	Mackworth clock Vigilance task	work	primary	simple	speed and accuracy & # hits		30 min		computer	
41b	Serial search task - look for E in 30 capita	self	primary	simple	speed					
41c	Logical reasoning - Baddely	self	primary	simple	speed and accuracy					
?42	PVT	work	primary	simple	speed and accuracy	PVT	10 min		computer	20 x
?43	Math addition - desynched circadian	work	primary	simple	speed and accuracy		4 min		computer	every 2 hrs duri
44		work	primary	simple						
45	Grooved peg board - timed to insert groov	self	primary	simple	time			30 min	hand	2x
45b	California Verbal learning Test II	work	primary	simple						
?46		work	primary	simple						
47	PVT	work	primary	simple	speed, lapse	PVT	10 min	30min		6x
48	Go-noGo task	work	complex	simple	hitrate, hit speed, false +	predefined	4.5 min		computer	
49	Laparoscopic surgical simulator	work	primary	complex	yes - RT, accuracy	predefined	20min	20 min	simulator	3x over 8 weeks
50a	SRT, MET (Math effort Task), VET (ver	work	primary	simple and subject	RT and % correct on MET	SRT, MET	SRT 10 min	1 hr	computer	2 x over 2 week
50b	SRT and MET (Math effort Task)	work	primary	simple and subject	RT and % correct on MET	SRT, MET, VET	SRT 7 min	NA	computer	
51	PVT	work	primary	simple	RT and lapses	PVT	10 min			6x per "shift"
52	auditory RT	work	primary	simple	RT		10 min			
53	PVT, 2ADD, DR, Dual, RCT	work	primary	simple	RT, accuracy and lapses (in som	pre		1.5 hrs		
54	SRT & 4CRT	work	primary	simple	RT and lapses	pre				
55	Battery of tests	work	primary	simple	RT, accuracy and lapses (in some tasks)					
56	adapt. Baddley gram reasoning - card sor	self	primary	simple	time and accuracy	semi pre	3 min	NA	paper and	NA
57	4CRT, Word Mem, Vis Vig, Log Reasoni	work	primary	simple		predefined	4CRT (6min),	blocks		depends
57b	Word mem	work	primary	simple						
57c	Visual Vig	work	primary	simple						
57d	Logical reasoning - Baddely	work	primary	simple						

Table 88: Study Descriptors Raw Data Part 2a

Study Identifiers			Study Context				Sample Descriptors				Experimental Condition			
Study ID #	1st Author	Publication Year	Type of Publicatio	Industry	Environment	Country	Specialty of Field	Sex of Group	Mean Age	Notes of interest	Comparison	Experiment blinding	Assignment of	Generalizabilty of
58	Saxena_200	2005	Journal	Medical	in field	Canada	Medical re	50% male	27 (t) 29.9	motivation	GC	subjects aware of goa		Medical re
59	Richardon_	1996	Journal	Medical	NA	US	doctors - h	50% male	38 [25.6-33.5]		RM	practice se	NA	interns
60	Christensen	1977	Journal	Medical	mock field	US	radiology r	NA	NA		RM		counterbalanced	
61	Rosa_1988	1988	Journal	Academic	lab	US	volunteers	00% male	[18-25]	paid volunt	RM	NA	NA	
62	Hart_1987	1987	Journal	Medical	NA	US	Medical in	NA	NA	1st year re	GC			
A	Bartley_19	1988	Journal	Medical	lab	US	surgical re	88% male			RM		counterbal	surgical re
63	Horne_1983	1983	Journal	Academic	lab		graduate students - w		[21-26]		RM		counterbalanced	
64	Hoddes_19	1973	Journal	Academic	lab	US	students	00% male	[18-22]		RM	practice se	NA	college stu
65	Webb_1984	1984	Journal	Academic	lab	US	volunteers	00% male	[18-22]		RM		NA	student vol
66	Haslam_198	1982	Journal	Military	lab	England	infantry	00% male	23.9 [21-26]		RM	practice se	NA	infatrymen
67	Binks_1999	1999	Journal	Academic	lab	US	students	49% male	C: 21.1 (4.	undergradu	GC	NA	NA	student vol
68a	Deaconson	1988	Journal	Medical	lab	US	surgical re	95% male	[26-35]	motivation - $200 bonus given to bestoveral				surgical re
68b	Deaconson	1988	Journal	Medical	lab	US	surgical re	95% male	[26-35]	motivation - $200 bonus given to bestoveral				surgical re
68c	Deaconson	1988	Journal	Medical	lab	US	surgical re	95% male	[26-35]	motivation - $200 bonus given to bestoveral				surgical re
68d	Deaconson	1988	Journal	Medical	lab	US	surgical re	95% male	[26-35]	motivation - $200 bonus given to bestoveral				surgical re
68e	Deaconson	1988	Journal	Medical	lab	US	surgical re	95% male	[26-35]	motivation - $200 bonus given to bestoveral				surgical re
69	Leonard_19	1998	Journal	Medical	in field	Ireland	house staf	50% male	25 = [23-28]		RM	experimen	randomly a	house staff
69b	Leonard_19	1998	Journal	Medical	in field	Ireland	house staf	50% male	25 = [23-28]		RM	experimenter not blinded		
69c	Leonard_19	1998	Journal	Medical	in field	Ireland	house staf	50% male	25 = [23-28]		RM	experimenter not blinded		
70	Storer_1989	1989	Journal	Medical	field	US	pediatric residents				RM		randomly	Medical sp
70	Storer_1989	1989	Journal	Medical	field	US	pediatric residents				RM			
70	Storer_1989	1989	Journal	Medical	field	US	pediatric residents				RM			
70	Storer_1989	1989	Journal	Medical	field	US	pediatric residents				RM			
71	Lichtor_198	1989	Journal	Medical	field	US	anesthia residents				RM		cross over design	
71	Lichtor_198	1989	Journal	Medical	field	US	anesthia residents				RM			
71	Lichtor_198	1989	Journal	Medical	field	US	anesthia residents				RM			
72	Linde_1999	1999	Journal	Academic	lab	Sweden	undergradu	00% male	[21-33]	motivation	RM			
72b	Linde_1999	1999	Journal	Academic	lab	Sweden	undergradu	00% male	[21-33]	motivation	RM			
73	Nag_1998	1998	Journal	Industry- t	field	India	textile wor	?	[20-59]		# of accid	NA	NA	industrial s
74	MacDonal	1997	Journal	Industry	field	UK	?	?	?		# of accid	NA	NA	industrial s
75	Tilley_198	1982	Journal	Industry	field	England	factory shi	00% male	43=[30-60]		RM		counterbalanced into	
75b	Tilley_198	1982	Journal	Industry	field	England	factory shi	00% male	43=[30-60]		RM		counterbalanced into	
76	Rosa_1993	1993	Journal	Industry	field	US	industrial s	00% male	37 = [25-5	gas control and storag		subjects br	?	
76b	Rosa_1994	1994	Journal	Industry	field	US	industrial s	00% male	38 = [25-5	gas control and storage stations on 8 hr and 12 hr shifts				
77	Langois_1	1985	Journal	Transporta	field	US	drivers in r	?	?		# of accid	NA	NA	
78	Akerstedt_	1977	Journal	Military	field	Sweden	voluntary	0% male	34=[23-43]		RM			
79	Richter_200	2005	Journal	Transporta	lab	Germany	volunteers	50%	29.5=[19-4	transport safety grou		practice	counterbalanced	
80	Hildebrandt	1974	Journal	Transporta	retrospecti	Germany	train drivers			state railw	# of accid	NA	NA	train driver
81	Donchin_1	1995	Journal	Medical	retrospecti	Israel	Medical	?	?	ICU	# of huma	told of goa	NA	
82	Oginski_20	2000	Journal	Industry	retrospecti	Poland	steel plant workers in Poland			data over	# of accid	NA	NA	shiftworke
83	Taffinder_1	1998	Journal	Medical	lab	England	surgical re	?	30=[26-33]		RM			surgical re
84	Smith_1994	1994	Journal	Industry	retrospecti	UK	experience	95% male	30.7 (8.7)	production	# of accid	NA	NA	shiftworke
85	Froberg_19	1977	Journal	Academic	lab						RM			
86	Philip_200	2004	Journal	Academic	lab	France	recruited	00% male	y:[20-25], O=[52-63]		RM		counterbalanced	
87	Powell_20	2001	Journal	Transporta	GM test tr	US		50% male		test done b	2GC		non-randomized	
88	Fiorica_19	1968	Journal	Academic	lab	US	volunteers	00% male	24 (1)		2GC			
89	Cutler_1979	1979	Journal	Academic	lab	US	college students		21.63(3.620=[18-33]		RM		randomly a	volunteers
90	Sharp_1988	1988	Journal	Medical	lab	US	surgical re	00% male		volunteers	RM			surgical re
90_b	Sharp_1989	1989	Journal	Medical	lab	US	surgical re	00% male		volunteers	RM			
90_c	Sharp_1989	1989	Journal	Medical	lab	US	surgical re	00% male		volunteers	RM			
91	Steyvers_	1993	Journal	Academic	lab	Netherland	paid volunt	00% male	[21-34]		RM			
92	Elkin_1974	1974	Journal	Academic	lab	Canada	college stu	50% male		paid under	2GC			volunteers
93	Webb_198	1986	Journal	Academic	lab	US	paid volunt	NA	[50-60]	paid colleg	RM	NA	NA	volunteers
94a	Haslam_1	1983	Journal	Military	lab	England	infantry	00% male	23.1 = [20	motivation	RM	NA	NA	volunteers
94b	Haslam_1	1983	Journal	Military	lab	England	infantry		23.1 = [20	motivation	RM	NA	NA	volunteers
94c	Haslam_1	1983	Journal	Military	lab	England	infantry		23.1 = [20	motivation	RM	NA	NA	volunteers
95a	Sagaspe_2	2006	Journal	Academic	lab	France	university	00% male	21.5 (2.3)= [18-26]		RM	NA	NA	volunteers
95b	Sagaspe_2	2006	Journal	Academic	lab	France	university	00% male	21.5 (2.3)= [18-26]		RM	NA	NA	volunteers
95c	Sagaspe_2	2006	Journal	Academic	lab	France	university	00% male	21.5 (2.3)= [18-26]		RM	NA	NA	volunteers
95d	Sagaspe_2	2006	Journal	Academic	lab	France	university	00% male	21.5 (2.3)= [18-26]		RM	NA	NA	volunteers

Table 89: Study Descriptors Raw Data Part 2b

Study ID #	Characteristics of task Descript of Task	Pace (work or self)	Primary or Secondar	Complexit y of task	Multiple Measures taken at	Predefine d or novel	Task Duration	Length of Test	How was the task administer	How many times was
58	5 min palm pilot PVT	work	primary	simple	RT and la	pre	5 min		palm pilot	daily (NA
59	DAT-divided attentio	work	primary	simple	NA		15 min		computer ba	NA
60	Mock up of lung with	self	primary	simple	no - detec	novel	NA	NA	mock up	2x both co
61	auditory vigilance	work pace	primary	simple		Baddley g	depends			
62	Sternberg short term	self	primary	simple	RT and ac	pre			computer	192
A	Battery of tests	work	primary	simple	yes	pre		1 hr		
63	Wilikinson vigilance t	work	primary	simple	false repo	pre			computer	12
64	Wilkinson add and Vi	work	primary	simple		pre		Wil Add - 1hr		4 x per 16
65	Aud Vig - Addition -	Aud vig -	primary	simple	no - # cor	pre		1 hr	computer	5 x
66	military tactical task -	work	primary	simple					paper and pencil - or ec	
67	PASAT(paced audito	work	primary	simple				2.5		
68a	Paced Aud Serial Ad	work pace	primary	simple	no - # of c	pre		30 min	tape recorde	6x
68b	Trail-making test - te	self paced	primary	simple	yes - time to complete and # of			30 min	paper	6x
68c	Grammatical reasonin	work	primary	simple	no - # of correct responses			30 min		6x
68d	Mod Minnestota Pap	self paced	primary	simple	no - # of correct resp		3 min	30 min	assembling i	?
68e	Purdue Pegboard - te	work	primary	simple	no # of correctly con		3 min	30 min	assembling i	?
69	Trail-making test - te	work	primary	simple	score- tim	pre	?	25 min		
69b	Stroop	work	primary	simple	no- score	pre	?	25 min		
69c	Grammatical reasonin	work	primary	simple	no- score	pre	?	25 min		
70	written cogntive test	work	primary	simple	?	pre	20 min			
70	intubation	work	primary	simple		novel				
70	vein cannulation	work	primary	simple		novel				
70	artery catheterization	work	primary	simple		novel				
71	visual reaction time	work	primary	simple						
71	Auditory RT	work	primary	simple						
71	Coordination accurac	work	primary	simple						
72	Auditory Attention ta	work	primary	simple			30 min		tape recorder	
72b	Coding Task	work	primary	simple						
73	normal work	NA	NA	NA	NA	NA	NA	NA	NA	NA
74	normal work	NA	NA	NA	NA	NA	NA	NA	NA	NA
75a	4CRT - four choice r	work	primary	simple	speed and	pre	10 min			1 per day
75b	SRT- serial reaction t	work	primary	simple	speed	pre	10 min			1 per day
76	Grammatical reasonin	work	dual	simple	speed and	pre	4	20 min	computer	
76b	Simple RT	work	dual	simple	speed and accuracy		4	20 min	computer	
77	driving	NA	NA	NA	NA	NA	NA	1 year	NA	NA
78	Shooting	self	primary	simple	yes - # of shots and # of hits					~tested ev
79	Mackworth clock	work	primary	simple	# of hits a	pre		60 min	hand held pa	8x
80	driving a train	NA	NA	NA	NA	NA				
81	regular work - filled c	NA	NA	NA	NA	NA	NA	NA	error report	NA
82	regular work - injury	NA	NA	NA	NA	NA	NA	NA	injury report	NA
83	virtual reality laparos	work	primary	complex	errors and time to complete, stress and arousal					20 x per se
84	regular work	NA	NA	NA	NA	NA	NA	12 months		NA
85		work	primary	simple						
86	simple reaction time -	work	primary	simple	speed and	pre?	10 min			6x
87	simple reaction time -	work	primary	simple	speed and	pre?	10 min			
88	Kugelmaschin - place	self	primary	simple		pre				
89	memory test - list of 2	self	primary	simple		pre	3 min		pen and paper	
90	1) SST - serial search task - lool		primary	simple	speed		1 min	20 min	apple compu	4x
90_b	VRT - verbal reasoning task - s		primary	simple	speed	preish		20	apple compu	4x
90_c	USRT - Wilkinson's unprepared		primary	simple	speed and	pre	15 min	20	apple compu	4x
91	CRT- choice reaction	work	primary	simple	speed and	pre - taskd	30 min		tv monitor and buttons (	
92	list of six 3-digit # au	work	primary	simple		pre		35 min	auditory - pe	6x (pace o
93	college level reading	self	primary	complex	accuracy		1) 5 & 3, 2	4 hr test b	computer	3x
94a	encoding - 6 figure m	work	primary	simple	accuracy		5 min			
94b	decoding - 6 figure m	work	primary	simple	accuracy		5min			
94c	decoding messages	work	primary	simple	accuracy		10 min			
95a	classic stroop	self	primary	simple	accuracy					10x
95b	emotional stroop	self	primary	simple						10x
95c	specific stroop - word	self	primary	simple						10x
95d	SRT - simple reaction	work	primary	simple	speed		10 min		Palm	10x

Table 90: Study Descriptors Raw Data Part 3a

Study Identifiers			Study Context				Sample Descriptors				Experimental Condition			
Study ID #	1st Author	Publication Year	Type of Publicatio	Industry	Environment	Country	Specialty of Field	Sex of Group	Mean Age	Notes of interest	Comparison Method	Experiment blinding	Assignment of Subjects	Generalizabilty of Sample
96a	Scott_2006	2006	Journal	Academic	lab	UK	university	100% male	22 (.3)		RM	NA	counterbalanc	volunteers
96b	Scott_2006	2006	Journal	Academic	lab	UK	university	100% male	22 (.3)		RM	NA	counterbalanc	volunteers
96c	Scott_2006	2006	Journal	Academic	lab	UK	university	100% male	22 (.3)		RM	NA	counterbalanc	volunteers
96d	Scott_2006	2006	Journal	Academic	lab	UK	university	100% male	22 (.3)		RM	NA	counterbalanc	volunteers
97	Venkatraman_2007	2007	Journal	Academic	lab	China	volunteers	0% male	21.3 (1.6)		RM	NA	NA	volunteers
98	Dinges_1998	1998	Journal	Academic	lab	US	volunteers	NA	NA		RM	NA	NA	volunteers
99a	May_1987	1987	Journal	Military/ac	field/lab	UK	infantry	100% male	NA	soldiers at	RM	NA	NA	soldiers
99b	May_1987	1987	Journal	Military/ac	field/lab	UK	infantry	100% male	NA	soldiers at	RM	NA	NA	soldiers
99c	May_1987	1987	Journal	Military/ac	field/lab	UK	infantry	100% male	NA	soldiers at	RM	NA	NA	soldiers
99d	May_1987	1987	Journal	Military/ac	field/lab	UK	infantry	100% male	NA	soldiers at	RM	NA	NA	soldiers
99e	May_1987	1987	Journal	Military/ac	field/lab	UK	infantry	100% male	cannot tell	soldiers at	RM	cannot tell	cannot tell	soldiers
99f	May_1987	1987	Journal	Military/ac	field/lab	UK	infantry	100% male	cannot tell	soldiers at	RM	cannot tell	cannot tell	soldiers
99g	May_1987	1987	Journal	Military/ac	field/lab	UK	infantry	100% male	cannot tell	soldiers at	RM	cannot tell	cannot tell	soldiers
99h	May_1987	1987	Journal	Military/ac	field/lab	UK	infantry	100% male	cannot tell	soldiers at	RM	cannot tell	cannot tell	soldiers
99i	May_1987	1987	Journal	Military/ac	field/lab	UK	infantry	100% male	cannot tell	soldiers at	RM	cannot tell	cannot tell	soldiers
99j	May_1987	1987	Journal	Military/ac	field/lab	UK	infantry	100% male	cannot tell	soldiers at	RM	cannot tell	cannot tell	soldiers
99k	May_1987	1987	Journal	Military/ac	field/lab	UK	infantry	100% male	cannot tell	soldiers at	RM	cannot tell	cannot tell	soldiers
99l	May_1987	1987	Journal	Military/ac	field/lab	UK	infantry	100% male	cannot tell	soldiers at	RM	cannot tell	cannot tell	soldiers
99m	May_1987	1987	Journal	Military/ac	field/lab	UK	infantry	100% male	cannot tell	soldiers at	RM	cannot tell	cannot tell	soldiers
99n	May_1987	1987	Journal	Military/ac	field/lab	UK	infantry	100% male	cannot tell	soldiers at	RM	cannot tell	cannot tell	soldiers
99o	May_1987	1987	Journal	Military/ac	field/lab	UK	infantry	100% male	cannot tell	soldiers at	RM	cannot tell	cannot tell	soldiers
100a	Lieberman_2005	2005	Journal	Military/ac	field/lab	US	infantry	100% male	31.6(.4)	training of	RM	cannot tell	cannot tell	soldiers
100b	Lieberman_2005	2005	Journal	Military/ac	field/lab	US	infantry	100% male	31.6(.4)	training of	RM	cannot tell	cannot tell	soldiers
100c	Lieberman_2005	2005	Journal	Military/ac	field/lab	US	infantry	100% male	31.6(.4)	training of	RM	cannot tell	cannot tell	soldiers
101a	Lamond_1999	1999	Journal	Academic	lab	Australia	college stu	cannot tell	[19-26]		RM	cannot tell	counterbalanc	volunteers
101b	Lamond_1999	1999	Journal	Academic	lab	Australia	college stu	cannot tell	[19-26]		RM	cannot tell	counterbalanc	volunteers
101c	Lamond_1999	1999	Journal	Academic	lab	Australia	college stu	cannot tell	[19-26]		RM	cannot tell	counterbalanc	volunteers
101d	Lamond_1999	1999	Journal	Academic	lab	Australia	college stu	cannot tell	[19-26]		RM	cannot tell	counterbalanc	volunteers
102	Thorne_2005	2005	Journal	Academic	lab	US	cannot tell	50 % male	[20-40]		RM	cannot tell	cannot tell	cannot tell
103	Doran_2001	2001	Journal	Academic	lab	US	cannot tell	100% male	[22-37]		2GC	cannot tell	randomized	volunteers
104	Wesenten_2005	2005	Journal	Academic	lab	US	student vo	80% male	[19-39]		baseline	cannot tell	cannot tell	volunteers
105	Jewett_1999	1999	Journal	Academic	lab	US	volunteers	cannot tell	[18-30]		2GC	cannot tell	cannot tell	volunteers
106	Drake_2001	2001	Journal	Academic	lab	US	volunteers	58% male	[21-35]		RM	cannot tell	cannot tell	volunteers
107	Van Dongen_2003	2003	Journal	Academic	lab	US	volunteers		[21-38]	not recent shiftworkers		randomized to group		volunteers
108	Rajaraman_2007	2007	Journal	Academic	lab	US	student vo	80% male	[19-39]		baseline	cannot tell	cannot tell	volunteers

Table 91: Study Descriptors Raw Data Part 3b

Study ID #	Descript of task	Pace (work or self)	Primary or secondar	Complexity of Task	Multiple Measures taken at	Predefine d/novel	Task Duration	Length of Test	How was the task administer	How many times
	Characteristics of task									
95b	emotional stroop	self	primary							10x
95c	specific stroop - words related to sleep	self	primary							10x
95d	SRT - simple reaction time	self	primary	simple	speed	predefined	10 min		Palm	10x
96a	SRT	self	primary	simple	speed				computer	8x
96b	2CRT	self	primary	simple	speed				computer	8x
96c	NCT - number cancelation task	self	primary	simple	speed				computer	8x
96d	TT - tracking task	self	primary	simple	accuracy				computer	8x
97	gambling task	self	primary	complex	speed	novel	5 min	2.5 hrs		30x
98	SRT- simple reaction time 1) visual, 2) auditory		primary	simple	speed		10 min	10 min		17x
99a	CF - flexibility of closure - target pattern id in 200 geo patterns									
99b	CS - speed of closure - find 25 partially obliterated words within 4 min						4 min		pen and paper	
99c	CV - verbal closure - id words when some of the letters are missing, scrambled, or embedded						4 min			
99d	FA - associated fluency - write as many synonyms as possible in 6 min						6 min			
99e	FI - ideational fluency - list as many names of things that are alike in a specified way						3 min			
99f	I - Induction - 15 items contain 5 sets of 4 letters are presented have 7 min to mark the odd one out						7 min			
99g	IP - integrative process - following directions find the data pt that would be arrived at after a list of directions						7 min			
99h	MS - memory span - auditory number span write down digit strings after hearing a list									
99i	N - number facility - state if simple addition and subtractions are done correctly						2 min			
99j	P - perceptual speed - find and cross out words that contain the letter a in 20 columns of 41 words									
99k	RL - logical reasoning - nonsense syllogisms test - does the conclusion of the content make sense or not						4 min			
99l	S - spatial orientation - ares shapes rotations or reflections of a target shape									
99m	SS - spatial scanning - 16 simple square mazes						3 min			
99n	VZ - visualization - paper folding test - subject has 3 mins to id the end results (from 3 drawings showing how the paper is folded and punched) from 5 alern									
99o	XU - flexibility of use - think up new uses for 4 common objects						5 min			
100a	4CRT	self	primary	simple	speed, accura	predefined	5 min		computer	3x
100b	Visual Vigilance task - infrequent - hard to dect signal				RT, accuracy	pre	20 min		computer	3x
100c	gram reasoning - adapted Baddeley				RT, lapses	pre	5 min		computer	3x
101a	gram reasoning - adapted Baddeley		primary	complex	speed and ac	pre	15 min			
101b	simple sensory task		primary	simple	accuracy		15 min			
101c	unpredicted tracking task	work	primary	simple	accuracy		15 min			
101d	vigilance task		primary	simple	speed and accuracy		15 min			
102	PVT - palm version		primary	simple	speed	pre	5 min			
103	PVT				speed, # of errors		10 min		computer	44 x
104	PVT				speed		10 min		computer	22 x
105	PVT				speed		10 min		computer	
106	PVT				speed		10 min	30 min	computer	4 x
107	PVT, digit sub, serial add							10min		tested eve
108	PVT				lapse		10 min		computer	41x

Table 92: Number of Lapses Raw Data Part 1a

Study Id #	1st Author_year	Effect Size Id #	Page #	Type of Comparison	Hours of Wakefulness	Time of Measure	Performance Var	Task Info	Calc Procedure	Var/task Info
10	Swann_2006	10.3	28	RM	19.2		lapses	-	directly	PVT
13	Belenky_2003	13.33	7	GC	3hrs	7:00	lapses	-	read from	PVT
13	Belenky_2003	13.34	7	GC	day1	7:00	lapses	-	read from	PVT
13	Belenky_2003	13.35	7	GC	day2	7:00	lapses	-	read from	PVT
13	Belenky_2003	13.36	7	GC	day3	7:00	lapses	-	read from	PVT
13	Belenky_2003	13.37	7	GC	day4	7:00	lapses	-	read from	PVT
13	Belenky_2003	13.38	7	GC	day5	7:00	lapses	-	read from	PVT
13	Belenky_2003	13.39	7	GC	day6	7:00	lapses	-	read from	PVT
13	Belenky_2003	13.4	7	GC	day7	7:00	lapses	-	read from	PVT
13	Belenky_2003	13.41	7	GC	5hrs	7:00	lapses	-	read from	PVT
13	Belenky_2003	13.42	7	GC	day1	7:00	lapses	-	read from	PVT
13	Belenky_2003	13.43	7	GC	day2	7:00	lapses	-	read from	PVT
13	Belenky_2003	13.44	7	GC	day3	7:00	lapses	-	read from	PVT
13	Belenky_2003	13.45	7	GC	day4	7:00	lapses	-	read from	PVT
13	Belenky_2003	13.46	7	GC	day5	7:00	lapses	-	read from	PVT
13	Belenky_2003	13.47	7	GC	day6	7:00	lapses	-	read from	PVT
13	Belenky_2003	13.48	7	GC	day7	7:00	lapses	-	read from	PVT
13	Belenky_2003	13.49	7	GC	7hr	7:00	lapses	-	read from	PVT
13	Belenky_2003	13.5	7	GC	day1	7:00	lapses	-	read from	PVT
13	Belenky_2003	13.51	7	GC	day2	7:00	lapses	-	read from	PVT
13	Belenky_2003	13.52	7	GC	day3	7:00	lapses	-	read from	PVT
13	Belenky_2003	13.53	7	GC	day4	7:00	lapses	-	read from	PVT
13	Belenky_2003	13.54	7	GC	day5	7:00	lapses	-	read from	PVT
13	Belenky_2003	13.55	7	GC	day6	7:00	lapses	-	read from	PVT
13	Belenky_2003	13.56	7	GC	day7	7:00	lapses	-	read from	PVT
13	Belenky_2003	13.57	7	GC	9hr	7:00	lapses	-	read from	PVT
13	Belenky_2003	13.58	7	GC	day1	7:00	lapses	-	read from	PVT
13	Belenky_2003	13.59	7	GC	day2	7:00	lapses	-	read from	PVT
13	Belenky_2003	13.6	7	GC	day3	7:00	lapses	-	read from	PVT
13	Belenky_2003	13.61	7	GC	day4	7:00	lapses	-	read from	PVT
13	Belenky_2003	13.62	7	GC	day5	7:00	lapses	-	read from	PVT
13	Belenky_2003	13.63	7	GC	day6	7:00	lapses	-	read from	PVT
13	Belenky_2003	13.64	7	GC	day7	7:00	lapses	-	read from	PVT
18	Babkoff_1985	18.1	615	RM	72		lapses	-	in text - %	
20	Williams_1959	20.6	6	RM	b4		lapses	-	read from graph	
20	Williams_1959	20.7	6	RM	30		lapses	-	read from graph	
20	Williams_1959	20.8	6	RM	54		lapses	-	read from graph	
20	Williams_1959	20.9	6	RM	69		lapses	-	read from graph	
20	Williams_1959	20.10	6	RM	78		lapses	-	read from graph	
21	Wilson_2007	21.11	228	RM	16-17	21:00	lapses	-	read from	PVT - lapses
21	Wilson_2007	21.12	228	RM	19-20	0:00	lapses	-	read from	PVT - lapses
21	Wilson_2007	21.13	228	RM	22-23	3:00	lapses	-	read from	PVT - lapses
21	Wilson_2007	21.14	228	RM	25-26	6:00	lapses	-	read from	PVT - lapses

Table 93: Number of Lapses Raw Data Part 1b

Study Id #	N: Control Assigned	N: Control Observed	N: Test Assigned	N: Test Observed	Mean Control	Mean Test	Standard Deviation Control	Standard Deviation Test	Standard Error Control	Standard Error Test	Diff Mean T-C	Poooled Stdev	B Stdev
10	12	12	12	12	0.71	2.42	0.589	2.217	0.17	0.64	1.71	1.622	2.294
13	13	13	13	13	1.2	1.2	3.606	3.606	1	1	0	3.606	5.099
13	13	13	13	13	1.2	1.3	3.606	4.507	1	1.25	0.1	4.081	5.772
13	13	13	13	13	1.2	1	3.606	5.048	1	1.4	-0.2	4.386	6.203
13	13	13	13	13	1.2	1.5	3.606	4.507	1	1.25	0.3	4.081	5.772
13	13	13	13	13	1.2	1.2	3.606	8.653	1	2.4	0	6.629	9.374
13	13	13	13	13	1.2	1	3.606	9.014	1	2.5	-0.2	6.865	9.708
13	13	13	13	13	1.2	1	3.606	9.374	1	2.6	-0.2	7.102	10.044
13	13	13	13	13	1.2	1.6	3.606	9.014	1	2.5	0.4	6.865	9.708
13	13	13	13	13	1.5	1.5	3.606	3.606	1	1	0	3.606	5.099
13	13	13	13	13	1.5	1.6	3.606	4.507	1	1.25	0.1	4.081	5.772
13	13	13	13	13	1.5	1.5	3.606	7.211	1	2	0	5.701	8.062
13	13	13	13	13	1.5	2.5	3.606	7.572	1	2.1	1	5.930	8.386
13	13	13	13	13	1.5	3	3.606	7.211	1	2	1.5	5.701	8.062
13	13	13	13	13	1.5	3	3.606	7.572	1	2.1	1.5	5.930	8.386
13	13	13	13	13	1.5	4	3.606	10.456	1	2.9	2.5	7.821	11.060
13	13	13	13	13	1.5	3.5	3.606	9.014	1	2.5	2	6.865	9.708
13	13	13	13	13	2.2	2.2	2.884	2.884	0.8	0.8	0	2.884	4.079
13	13	13	13	13	2.2	3	2.884	4.327	0.8	1.2	0.8	3.677	5.200
13	13	13	13	13	2.2	3.2	2.884	2.704	0.8	0.75	1	2.796	3.954
13	13	13	13	13	2.2	4.5	2.884	6.490	0.8	1.8	2.3	5.022	7.102
13	13	13	13	13	2.2	4.9	2.884	6.490	0.8	1.8	2.7	5.022	7.102
13	13	13	13	13	2.2	6	2.884	7.211	0.8	2	3.8	5.492	7.767
13	13	13	13	13	2.2	7	2.884	7.211	0.8	2	4.8	5.492	7.767
13	13	13	13	13	2.2	7	2.884	6.851	0.8	1.9	4.8	5.256	7.433
13	13	13	13	13	1.5	1.5					0		
13	13	13	13	13	1.5	4					2.5		
13	13	13	13	13	1.5	5.5					4		
13	13	13	13	13	1.5	10					8.5		
13	13	13	13	13	1.5	11					9.5		
13	13	13	13	13	1.5	12.5					11		
13	13	13	13	13	1.5	14					12.5		
13	13	13	13	13	1.5	17.5					16		
18	6	6	6	6	0.026	0.206					0.18		
20	74	74	74	74	0.2	0.2					0		
20	74	74	74	74	0.2	2					1.8		
20	74	74	74	74	0.2	6.5					6.3		
20	74	74	74	74	0.2	14					13.8		
20	74	74	74	74	0.2	18					17.8		
21	9	9	9	9	1.5	0.9					-0.6		
21	9	9	9	9	1.5	3.5					2		
21	9	9	9	9	1.5	3					1.5		
21	9	9	9	9	1.5	8.5					7		
21	9	9	9	9	1.5	3					1.5		
24	16	16	16	16	0.8								
24	16	16	16	16	0.8						-0.8		
24	16	16	16	16	1.2						-1.2		
24	16	16	16	16	2.9						-2.9		
24	16	16	16	16	3						-3		
24	16	16	16	16	2.9						-2.9		
24	16	16	16	16	3.2						-3.2		
24	16	16	16	16	2.9						-2.9		
24	16	16	16	16	4.1						-4.1		
24	16	16	16	16	2.8						-2.8		
47	30	30	30	30	2	18	6.573	24.648	1.2	4.5	16	18.037	25.509
51	15	15	15	15		0.1	0.968	0.465	0.25	0.12	0.1	0.759	1.074
51	15	15	15	15		0.4	0.968	0.968	0.25	0.25	0.4	0.968	1.369
51	15	15	15	15		1	0.968	2.324	0.25	0.6	1	1.780	2.517
51	15	15	15	15		1.4	0.968	2.905	0.25	0.75	1.4	2.165	3.062
51	15	15	15	15		1.6	0.968	3.098	0.25	0.8	1.6	2.295	3.246
51	15	15	15	15		2.5	0.968	4.260	0.25	1.1	2.5	3.089	4.369
53	25	25	25	25	0.02	0.867	0.050	0.750	0.01	0.15	0.847	0.532	0.752
53	25	25	25	25	0.17	7.8	0.850	10.700	0.17	2.14	7.63	7.590	10.734

Table 94: Number of Lapses Raw Data Part 2a

Study Id #	1st Author_year	Effect Size Id #	Page #	Type of Comparison	Hours of Wakefulness	Time of Measure	Performance Var	Task Info	Calc Procedure	Var/task Info
24	Dinges_1977	24.1	273	RM	restricted sleep	1100, 1600, 2	lapses	-	averaged	data over 3 te
24	Dinges_1977	24.2	273	RM	base B2 -7.41		lapses	-		
24	Dinges_1977	24.3	273	RM	P1 - 4.98		lapses	-		
24	Dinges_1977	24.4	273	RM	P2		lapses	-		
24	Dinges_1977	24.5	273	RM	P3		lapses	-		
24	Dinges_1977	24.6	273	RM	P4		lapses	-		
24	Dinges_1977	24.7	273	RM	P5		lapses	-		
24	Dinges_1977	24.8	273	RM	P6		lapses	-		
24	Dinges_1977	24.9	273	RM	P7		lapses	-		
24	Dinges_1977	24.10	273	RM	R1 - 7.94		lapses	-		
47	Lamond_2007	47.2	37	RM	24	9:00	lapse		read from	PVT
51	Caldwell_2003	51.7	27	RM	4	18:45	lapses	-	read from	PVT
51	Caldwell_2003	51.8	27	RM	8	22:45	lapses	-	read from	PVT
51	Caldwell_2003	51.9	27	RM	12	2:45	lapses	-	read from	PVT
51	Caldwell_2003	51.10	27	RM	20	10:45	lapses	-	read from	PVT
51	Caldwell_2003	51.11	27	RM	24	14:45	lapses	-	read from	PVT
51	Caldwell_2003	51.12	27	RM	28	18:45	lapses	-	read from	PVT
53	Frey_2004	53.3	308	RM	43		lapse	-		PVT
53	Frey_2004	53.16	308	RM	43		lapse	-		RCT
54	Glenville_1979	54.4	931	RM	ToT		lapses	F-test	in text	
58	Saxena_2005	58.2	1388	2GC	ll vs not on call		major lap	-	read from	PVT
58	Saxena_2005	58.3	1388	2GC	ll vs not on call		minor lap	-	read from	PVT
86	Philip_2004	86.7	107	RM		9:00	lapses	-		y
86	Philip_2004	86.8	107	RM		11:00	lapses	-		y
86	Philip_2004	86.9	107	RM		13:00	lapses	-		y
86	Philip_2004	86.1	107	RM		15:00	lapses	-		y
86	Philip_2004	86.11	107	RM		17:00	lapses	-		y
86	Philip_2004	86.12	107	RM		19:00	lapses	-		y
86	Philip_2004	86.19	107	RM		9:00	lapses	-		o
86	Philip_2004	86.2	107	RM		11:00	lapses	-		o
86	Philip_2004	86.21	107	RM		13:00	lapses	-		o
86	Philip_2004	86.22	107	RM		15:00	lapses	-		o
86	Philip_2004	86.23	107	RM		17:00	lapses	-		o
86	Philip_2004	86.24	107	RM		19:00	lapses	-		o
87	Powell_2001	87.2	890	2GC	32		lapses	-	table	PVT
91	Steyvers_1993	91.3	69	RM	34		lapses	-		
100	Lieberman_200	100.5	425	RM	77	18:00, 12:02	lapses	-	table	4CRT-lapses
100	Lieberman_200	100.6	425	RM	94	18:00, 05:02	lapses	-	table	
100	Lieberman_200	100.13	425	RM	77	18:00, 12:06	lapses	-	table	Gram lapse
100	Lieberman_200	100.14	425	RM	94	18:00, 05:06	lapses	-	table	
105	Jewett_1999	105.3	175	2GC	26	10:00	lapses	-	read from	# of lapses

Table 95: Number of Lapses Raw Data Part 2b

Study Id #	N Control Assigned	N Control Observed	N Test Assigned	N Test Observed	Mean Control	Mean Test	Standard Deviation Control	Standard Deviation Test	Standard Error Control	Standard Error Test	Diff Mean T-C	Poooled Stdev	B Stdev
54	11	11	11	11	F-stat								
58	7	7	13	13	1.53	2.5	0.920	103.000			0.97	84.101	103.004
58	7	7	13	13	1.5	2.9	0.910	2.200			1.4	1.872	2.381
86	10	10	10	10	1	7	4.048	12.333	1.28	3.9	6	9.178	12.980
86	10	10	10	10	1	2	4.902	15.558	1.55	4.92	1	11.534	16.312
86	10	10	10	10	1	3	5.629	12.681	1.78	4.01	2	9.810	13.874
86	10	10	10	10	2	5.5	3.036	18.310	0.96	5.79	3.5	13.124	18.560
86	10	10	10	10	1.5	4	4.838	17.108	1.53	5.41	2.5	12.572	17.779
86	10	10	10	10	1	3.5	6.894	8.918	2.18	2.82	2.5	7.970	11.272
86	10	10	10	10	5	7	21.788	22.927	6.89	7.25	2	22.365	31.628
86	10	10	10	10	12.5	12.5	21.946	23.844	6.94	7.54	0	22.915	32.406
86	10	10	10	10	15.5	12.5	20.681	30.864	6.54	9.76	-3	26.271	37.152
86	10	10	10	10	13.5	14.5	25.994	25.330	8.22	8.01	1	25.664	36.294
86	10	10	10	10	20	11.5	27.069	34.943	8.56	11.05	-8.5	31.255	44.201
86	10	10	10	10	23	17.5	27.607	40.699	8.73	12.87	-5.5	34.774	49.178
87	8	8	8	8	0.62	4.4	0.600	4.500			3.78	3.210	4.540
91	16	16	16	16							0	0.000	0.000
100	31	31	31	31	1.4	3.5	2.784	1.122	0.5	0.6	2.1	2.122	3.002
100	31	31	31	31	1.4	3.7	2.784	1.154	0.5	0.6	2.3	2.131	3.014
100	31	31	31	31	0.2	0.7	0.557	0.251	0.1	0.3	0.5	0.432	0.611
100	31	31	31	31	0.2	0.7	0.557	0.251	0.1	0.3	0.5	0.432	0.611
105	32	32	25	25	1.75	4.6	11.314	8.579	2	4	2.85	10.211	14.199
107	12	12	13	13		8					8	0.000	0.000
107	12	12	13	13		13					13	0.000	0.000
107	12	12	13	13		15					15	0.000	0.000
108	48	48	48	48		2.5		2.000			2.5	1.414	2.000
108	48	48	48	48		2		1.750			2	1.237	1.750
108	48	48	48	48		3.5		3.000			3.5	2.121	3.000
108	48	48	48	48		4		4.500			4	3.182	4.500
108	48	48	48	48		4.5		2.500			4.5	1.768	2.500
108	48	48	48	48		5		5.500			5	3.889	5.500
108	48	48	48	48		4.5		5.500			4.5	3.889	5.500
108	48	48	48	48		3.5		2.750			3.5	1.945	2.750
108	48	48	48	48		7.5		6.500			7.5	4.596	6.500
108	48	48	48	48		8		7.000			8	4.950	7.000
108	48	48	48	48		9		8.000			9	5.657	8.000
108	48	48	48	48		10		9.000			10	6.364	9.000
108	48	48	48	48		12		11.500			12	8.132	11.500
108	48	48	48	48		11		12.500			11	8.839	12.500
108	48	48	48	48		10		10.000			10	7.071	10.000
108	48	48	48	48		9		10.000			9	7.071	10.000
108	48	48	48	48		8		9.500			8	6.718	9.500
108	48	48	48	48		9		11.000			9	7.778	11.000
108	48	48	48	48		6		6.000			6	4.243	6.000
108	48	48	48	48		7		5.000			7	3.536	5.000
108	48	48	48	48		11		15.500			11	10.960	15.500
108	48	48	48	48		17		16.000			17	11.314	16.000
108	48	48	48	48		20		20.000			20	14.142	20.000
108	48	48	48	48		25		20.000			25	14.142	20.000
108	48	48	48	48		23		24.000			23	16.971	24.000
108	48	48	48	48		22		19.000			22	13.435	19.000
108	48	48	48	48		15		13.000			15	9.192	13.000
108	48	48	48	48		14		15.000			14	10.607	15.000
108	48	48	48	48		14		15.000			14	10.607	15.000
108	48	48	48	48		14		16.000			14	11.314	16.000
108	48	48	48	48		13		14.500			13	10.253	14.500
108	48	48	48	48		9		7.500			9	5.303	7.500
108	48	48	48	48		12		15.000			12	10.607	15.000
108	48	48	48	48		19		21.000			19	14.849	21.000
108	48	48	48	48		20		16.000			20	11.314	16.000
108	48	48	48	48		22		15.000			22	10.607	15.000
108	48	48	48	48		19		20.000			19	14.142	20.000
108	48	48	48	48		21		25.500			21	18.031	25.500
108	48	48	48	48		16		16.500			16	11.667	16.500
108	48	48	48	48		12		10.000			12	7.071	10.000
108	48	48	48	48		11		11.000			11	7.778	11.000
108	48	48	48	48		9		11.000			9	7.778	11.000

Table 96: Number of Lapses Raw Data Part 3

Study Id #	1st Author_year	Effect Size Id #	Page #	Type of Comparison	Hours of Wakefulness	Time of Measure	Performance Var	Task Info	Calc Procedure	Var/task Info
107	VanDongen_2003	B	120	RM	88	day1	lapses	-		PVT
107	VanDongen_2003	B	120	RM	88	day2	lapses	-		PVT
107	VanDongen_2003	B	120	RM	88	day3	lapses	-		PVT
108	Rajaraman_2007	108.1	465	RM	0	8:00	lapses		read from	PVT
108	Rajaraman_2007	108.2	465	RM	2	10:00	lapses			PVT
108	Rajaraman_2007	108.3	465	RM	4	12:00	lapses			PVT
108	Rajaraman_2007	108.4	465	RM	6	14:00	lapses			PVT
108	Rajaraman_2007	108.5	465	RM	8	16:00	lapses			PVT
108	Rajaraman_2007	108.6	465	RM	10	18:00	lapses			PVT
108	Rajaraman_2007	108.7	465	RM	12	20:00	lapses			PVT
108	Rajaraman_2007	108.8	465	RM	14	22:00	lapses			PVT
108	Rajaraman_2007	108.9	465	RM	16	24:00:00	lapses			PVT
108	Rajaraman_2007	108.1	465	RM	18	2:00	lapses			PVT
108	Rajaraman_2007	108.11	465	RM	20	4:00	lapses			PVT
108	Rajaraman_2007	108.12	465	RM	22	6:00	lapses			PVT
108	Rajaraman_2007	108.13	465	RM	24	8:00	lapses			PVT
108	Rajaraman_2007	108.14	465	RM	26	10:00	lapses			PVT
108	Rajaraman_2007	108.15	465	RM	28	12:00	lapses			PVT
108	Rajaraman_2007	108.16	465	RM	30	14:00	lapses			PVT
108	Rajaraman_2007	108.17	465	RM	32	16:00	lapses			PVT
108	Rajaraman_2007	108.18	465	RM	34	18:00	lapses			PVT
108	Rajaraman_2007	108.19	465	RM	36	20:00	lapses			PVT
108	Rajaraman_2007	108.2	465	RM	38	22:00	lapses			PVT
108	Rajaraman_2007	108.21	465	RM	40	24:00:00	lapses			PVT
108	Rajaraman_2007	108.22	465	RM	42	2:00	lapses			PVT
108	Rajaraman_2007	108.23	465	RM	44	4:00	lapses			PVT
108	Rajaraman_2007	108.24	465	RM	46	6:00	lapses			PVT
108	Rajaraman_2007	108.25	465	RM	48	8:00	lapses			PVT
108	Rajaraman_2007	108.26	465	RM	50	10:00	lapses			PVT
108	Rajaraman_2007	108.27	465	RM	52	12:00	lapses			PVT
108	Rajaraman_2007	108.28	465	RM	54	14:00	lapses			PVT
108	Rajaraman_2007	108.29	465	RM	56	16:00	lapses			PVT
108	Rajaraman_2007	108.3	465	RM	58	18:00	lapses			PVT
108	Rajaraman_2007	108.31	465	RM	60	20:00	lapses			PVT
108	Rajaraman_2007	108.32	465	RM	62	22:00	lapses			PVT
108	Rajaraman_2007	108.33	465	RM	64	24:00:00	lapses			PVT
108	Rajaraman_2007	108.34	465	RM	66	2:00	lapses			PVT
108	Rajaraman_2007	108.35	465	RM	68	4:00	lapses			PVT
108	Rajaraman_2007	108.36	465	RM	70	6:00	lapses			PVT
108	Rajaraman_2007	108.37	465	RM	72	8:00	lapses			PVT
108	Rajaraman_2007	108.38	465	RM	74	10:00	lapses			PVT
108	Rajaraman_2007	108.39	465	RM	76	12:00	lapses			PVT
108	Rajaraman_2007	108.4	465	RM	78	14:00	lapses			PVT
108	Rajaraman_2007	108.41	465	RM	80	16:00	lapses			PVT
108	Rajaraman_2007	108.42	465	RM	82	18:00	lapses			PVT

Table 97: Reaction Time Raw Data Part 1a

Study Id #	1st Author_year	Effect Size Id #	Page #	Type of Comparison	Hours of Wakefulness	Time of Measure	Performance Var	Task Info	Speed Units	Var/task Info
1	Nilsson_2005	1.1	4	2GC	31.5		Speed	serial reac	ms	
2	Thomas_2000	2.1	346	RM	24		Speed	responses/	x	serial addit
3	Choo_2005	3.1	581	RM	24.4		Speed	reaction ti	ms	SRT
3	Choo_2005	3.2	581	RM	24.4		Speed	reaction ti	ms	SRT
3	Choo_2005	3.3	581	RM	24.4		Speed	reaction ti	ms	SRT
3	Choo_2005	3.4	581	RM	24.4		Speed	reaction ti	ms	SRT
4	Chee_2004	4.1	4561	RM	24		Speed	reaction ti	ms	2 working
4	Chee_2004	4.2	4561	RM	24		Speed	reaction ti	ms	verbal wor
4	Chee_2004	4.3	4561	RM	24		Speed	reaction ti	ms	SRT
5	Williamson_2000	5.1	652	RM	2.27	8:00	Speed	RT	ms	Simple RT
5	Williamson_2000	5.1	652	RM	13.27	19:00	Speed	RT	ms	Simple RT
5	Williamson_2000	5.1	652	RM	14	19:44	Speed	RT	ms	Simple RT
5	Williamson_2000	5.1	652	RM	18	23:44	Speed	RT	ms	Simple RT
5	Williamson_2000	5.1	652	RM	22	27:44:00	Speed	RT	ms	Simple RT
5	Williamson_2000	5.1	652	RM	2.27	8:00	speed	RT	ms	Mackwort
5	Williamson_2000	5.1	652	RM	13.27	19:00	speed	RT	ms	Mackwort
5	Williamson_2000	5.1	652	RM	14	19:44	Speed	RT	ms	Mackwort
5	Williamson_2000	5.1	652	RM	18	23:44	Speed	RT	ms	Mackwort
5	Williamson_2000	5.1	652	RM	22	27:44:00	Speed	RT	ms	Mackwort
5	Williamson_2000	5.1	652	RM	2.27	8:00	Speed	RT	ms	gram reas
5	Williamson_2000	5.1	652	RM	13.27	19:00	Speed	RT	ms	gram reas
5	Williamson_2000	5.1	652	RM	14	19:44	Speed	RT	ms	gram reas
5	Williamson_2000	5.1	652	RM	18	23:44	Speed	RT	ms	gram reas
5	Williamson_2000	5.1	652	RM	22	27:44:00	Speed	RT	ms	gram reas
6	Kobbeltvedt_2005	6.1	4	2GC	52		Speed	F-test		
7	Robbins_1990	7.2	83	RM	35	sleep on-call	Speed	total test ti	?	
9	Babkoff_2005	9.1	12	RM	24		Speed	RT	ms	
10	Swann_2005	10.1	28	RM	2 nights restrict	tricted sleep	Speed	reaction ti	ms	PVT
11	Koslowsky_1992	11		MA				-		
12	Pilcher_1996	12		MA				-		
13	Belenky_2003	13.1	6	GC	3hrs	7:00	Speed	1/RT*100	ms	PVT
13	Belenky_2003	13.2	6	GC	day1	7:00	Speed	1/RT*100	ms	PVT
13	Belenky_2003	13.3	6	GC	day2	7:00	Speed	1/RT*100	ms	PVT
13	Belenky_2003	13.4	6	GC	day3	7:00	Speed	1/RT*100	ms	PVT
13	Belenky_2003	13.5	6	GC	day4	7:00	Speed	1/RT*100	ms	PVT
13	Belenky_2003	13.6	6	GC	day5	7:00	Speed	1/RT*100	ms	PVT
13	Belenky_2003	13.7	6	GC	day6	7:00	Speed	1/RT*100	ms	PVT
13	Belenky_2003	13.8	6	GC	day7	7:00	Speed	1/RT*100	ms	PVT
13	Belenky_2003	13.9	6	GC	5hrs	7:00	Speed	1/RT*100	ms	PVT
13	Belenky_2003	13.1	6	GC	day1	7:00	Speed	1/RT*100	ms	PVT
13	Belenky_2003	13.11	6	GC	day2	7:00	Speed	1/RT*100	ms	PVT
13	Belenky_2003	13.12	6	GC	day3	7:00	Speed	1/RT*100	ms	PVT
13	Belenky_2003	13.13	6	GC	day4	7:00	Speed	1/RT*100	ms	PVT
13	Belenky_2003	13.14	6	GC	day5	7:00	Speed	1/RT*100	ms	PVT
13	Belenky_2003	13.15	6	GC	day6	7:00	Speed	1/RT*100	ms	PVT
13	Belenky_2003	13.16	6	GC	day7	7:00	Speed	1/RT*100	ms	PVT
13	Belenky_2003	13.17	6	GC	7hr	7:00	Speed	1/RT*100	ms	PVT
13	Belenky_2003	13.18	6	GC	day1	7:00	Speed	1/RT*100	ms	PVT
13	Belenky_2003	13.19	6	GC	day2	7:00	Speed	1/RT*100	ms	PVT
13	Belenky_2003	13.2	6	GC	day3	7:00	Speed	1/RT*100	ms	PVT
13	Belenky_2003	13.21	6	GC	day4	7:00	Speed	1/RT*100	ms	PVT
13	Belenky_2003	13.22	6	GC	day5	7:00	Speed	1/RT*100	ms	PVT
13	Belenky_2003	13.23	6	GC	day6	7:00	Speed	1/RT*100	ms	PVT
13	Belenky_2003	13.24	6	GC	day7	7:00	Speed	1/RT*100	ms	PVT

Table 98: Reaction Time Raw Data Part 1b

	N				Statistical Data										
	Control		Test		Mean		Standard Deviation		Standard Error		Mean in ms		Diff	Poooled	
Study Id #	Assigned	Observed	Assigned	Observed	Control	Test	Control	Test	Control	Test	Control	Test	Means	Stdev	B Stdev
1	11	11	11	11	225	265	43.44	62.35			225	265	40	53.73	75.99
2	17	17	17	17	61.4	71	24.6	27.2			61.4	71	9.6	25.93	36.67
3	12	12	12	12	552	668	149	182			552	668	116	166.32	235.21
3	12	12	12	12	588	746	162	271			588	746	158	223.25	315.73
3	12	12	12	12	617	718	233	245			617	718	101	239.08	338.10
3	12	12	12	12	585.67	710.7	181.33	232.67			585.67	710.7	125.03	208.59	294.98
4	13	13	13	13	825	883	80	110			825	883	58	96.18	136.01
4	13	13	13	13	786	860	119	144			786	860	74	132.09	186.81
4	13	13	13	13	378	394	58	82			378	394	16	71.02	100.44
5	39	39	39	39	489	494	-	-			489	494	5		
5	39	39	39	39	489	495	-	-			489	495	6		
5	39	39	39	39	489	497	-	-			489	497	8		
5	39	39	39	39	489	521	-	-			489	521	32		
5	39	39	39	39	489	540	-	-			489	540	51		
5	39	39	39	39	958	1020	-	-			958	1020	62		
5	39	39	39	39	958	964	-	-			958	964	6		
5	39	39	39	39	958	1010	-	-			958	1010	52		
5	39	39	39	39	958	1225	-	-			958	1225	267		
5	39	39	39	39	958	1511	-	-			958	1511	553		
5	39	39	39	39	4286	4413	-	-			4286	4413	127		
5	39	39	39	39	4286	4054	-	-			4286	4054	-232		
5	39	39	39	39	4286	4128	-	-			4286	4128	-158		
5	39	39	39	39	4286	4255	-	-			4286	4255	-31		
5	39	39	39	39	4286	4182	-	-			4286	4182	-104		
6	21	21	69	69	-	-	-	-							
7	31	23	31	23	5000	4750	359.69	748.15			5000	4750	-250	586.99	830.12
9	18	12	18	12	57.61	73.93					57.61	73.93	16.32		
10	15	12	15	12	251.15	285.29	33.60179	41.91563	9.7	12.1	251.15	285.29	34.14	37.99	53.72
11													0		
12													0		
13	13	13	13	13	3.83	3.83	1.814313	1.814313	0.5032	0.5032	261.0966	261.0966	0		
13	13	13	13	13	3.83	3.5	1.814313	2.51379	0.5032	0.6972	261.0966	285.7143	24.61768	2.19	3.10
13	13	13	13	13	3.83	3.4	1.814313	2.672435	0.5032	0.7412	261.0966	294.1176	33.02104	2.28	3.23
13	13	13	13	13	3.83	3	1.814313	3.414818	0.5032	0.9471	261.0966	333.3333	72.23673	2.73	3.87
13	13	13	13	13	3.83	2.87	1.814313	3.839191	0.5032	1.0648	261.0966	348.4321	87.33545	3.00	4.25
13	13	13	13	13	3.83	2.75	1.814313	3.440778	0.5032	0.9543	261.0966	363.6364	102.5398	2.75	3.89
13	13	13	13	13	3.83	2.6	1.814313	3.31891	0.5032	0.9205	261.0966	384.6154	123.5188	2.67	3.78
13	13	13	13	13	3.83	2.3	1.814313	3.652784	0.5032	1.0131	261.0966	434.7826	173.686	2.88	4.08
13	13	13	13	13	3.95	3.95	2.586262	2.586262	0.7173	0.7173	253.1646	253.1646	0		
13	13	13	13	13	3.95	3.75	2.586262	3.124931	0.7173	0.8667	253.1646	266.6667	13.50211	2.87	4.06
13	13	13	13	13	3.95	3.72	2.586262	2.936361	0.7173	0.8144	253.1646	268.8172	15.65265	2.77	3.91
13	13	13	13	13	3.95	3.55	2.586262	3.217955	0.7173	0.8925	253.1646	281.6901	28.52558	2.92	4.13
13	13	13	13	13	3.95	3.45	2.586262	3.54606	0.7173	0.9835	253.1646	289.8551	36.69052	1.83	2.59
13	13	13	13	13	3.95	3.28	2.586262	3.974039	0.7173	1.1022	253.1646	304.878	51.71349	3.35	4.74
13	13	13	13	13	3.95	3.35	2.586262	3.863348	0.7173	1.0715	253.1646	298.5075	45.34291	3.29	4.65
13	13	13	13	13	3.95	3.3	2.586262	3.659274	0.7173	1.0149	253.1646	303.0303	49.86575	3.17	4.48
13	14	14	14	14	3.88	3.88	2.136861	2.136861	0.5711	0.5711	257.732	257.732	0		
13	14	14	14	14	3.88	3.88	2.136861	1.996174	0.5711	0.5335	257.732	257.732	0	2.07	2.92
13	14	14	14	14	3.88	3.8	2.136861	1.973724	0.5711	0.5275	257.732	263.1579	5.425936	2.06	2.91
13	14	14	14	14	3.88	3.78	2.136861	2.34789	0.5711	0.6275	257.732	264.5503	6.818306	2.24	3.17

Table 99: Reaction Time Raw Data Part 2a

Study Id #	1st Author_year	Effect Size Id #	Page #	Type of Comparison	Hours of Wakefulness	Time of Measure	Performance Var	Task info	Speed Units	Var/task info
13	Belenky_2003	13.25	6	GC	9hr	7:00	Speed	1/RT*1000	ms	PVT
13	Belenky_2003	13.26	6	GC	day1	7:00	Speed	1/RT*1000	ms	PVT
13	Belenky_2003	13.27	6	GC	day2	7:00	Speed	1/RT*1000	ms	PVT
13	Belenky_2003	13.28	6	GC	day3	7:00	Speed	1/RT*1000	ms	PVT
13	Belenky_2003	13.29	6	GC	day4	7:00	Speed	1/RT*1000	ms	PVT
13	Belenky_2003	13.3	6	GC	day5	7:00	Speed	1/RT*1000	ms	PVT
13	Belenky_2003	13.31	6	GC	day6	7:00	Speed	1/RT*1000	ms	PVT
13	Belenky_2003	13.32	6	GC	day7	7:00	Speed	1/RT*1000	ms	PVT
14	Buck_1972	14.1	50	RM	24	self paced	Speed	RT	ms	
14	Buck_1972	14.2	50	RM	24		Speed	RT	ms	
14	Buck_1972	14.3	50	RM	24		Speed	RT	ms	
14	Buck_1972	14.4	50	RM	24		Speed	RT	ms	
14	Buck_1972	14.5	50	RM	24	work paced	Speed	RT	ms	
14	Buck_1972	14.6	50	RM	24		Speed	RT	ms	
14	Buck_1972	14.7	50	RM	24		Speed	RT	ms	
14	Buck_1972	14.8	50	RM	24		Speed	RT	ms	
15	Killgore_2006	15.1	10	RM	49.5		Speed	F-test		
16	Marmuff_2005	16.1	26	RM	2	9:00	Speed	cohen's d	-	
16	Marmuff_2005	16.2	26	RM	4	11:00	Speed	cohen's d	-	
16	Marmuff_2005	16.3	26	RM	6	13:00	Speed	cohen's d	-	
16	Marmuff_2005	16.4	26	RM	8	15:00	Speed	cohen's d	-	
16	Marmuff_2005	16.5	26	RM	10	17:00	Speed	cohen's d	-	
16	Marmuff_2005	16.6	26	RM	12	19:00	Speed	cohen's d	-	
16	Marmuff_2005	16.7	26	RM	14	21:00	Speed	cohen's d	-	
16	Marmuff_2005	16.8	26	RM	16	23:00	Speed	cohen's d	-	
16	Marmuff_2005	16.9	26	RM	18	1:00	Speed	cohen's d	-	
16	Marmuff_2005	16.10'	26	RM	20	3:00	Speed	cohen's d	-	
16	Marmuff_2005	16.11	26	RM	22	5:00	Speed	cohen's d	-	
16	Marmuff_2005	16.12	26	RM	24	7:00	Speed	cohen's d	-	
16	Marmuff_2005	16.13	26	RM	26	9:00	Speed	cohen's d	-	
17	Yoo_2007	17.3	386	2GC	35		Speed	response t	ms	hits
17	Yoo_2007	17.4	386	2GC	35		Speed	response t	ms	misses
17	Yoo_2007	17.5	386	2GC	35		Speed	response t	ms	omits
17	Yoo_2007	17.6	386	2GC	35		Speed	response t	ms	hits
17	Yoo_2007	17.7	386	2GC	35		Speed	response t	ms	misses
17	Yoo_2007	17.8	386	2GC	35		Speed	response t	ms	correct rej
19	Williams_1967	19.1	315	RM	26		Speed	residual speed scores		percent ch
19	Williams_1967	19.2	315	RM	50		Speed	residual speed scores		
20	Williams_1959	20.1	5	RM	b4		Speed	RT	s	
20	Williams_1959	20.2	5	RM	30		Speed	RT	s	
20	Williams_1959	20.3	5	RM	54		Speed	RT	s	
20	Williams_1959	20.4	5	RM	69		Speed	RT	s	
20	Williams_1959	20.5	5	RM	78		Speed	RT	s	
21	Wilson_2007	21.6	228	RM	16.5	21:00	Speed	RT	ms	PVT - spe
21	Wilson_2007	21.7	228	RM	19.5	0:00	Speed	RT	ms	PVT - spe
21	Wilson_2007	21.8	228	RM	22.5	3:00	Speed	RT	ms	PVT - spe
21	Wilson_2007	21.9	228	RM	25.5	6:00	Speed	RT	ms	PVT - spe
21	Wilson_2007	21.10	228	RM	28.5	9:00	Speed	RT	ms	PVT - spe
21	Wilson_2007	21.16	229	RM	16.5	21:00	Speed	RT	ms	MATB
21	Wilson_2007	21.17	229	RM	19.5	0:00	Speed	RT	ms	MATB
21	Wilson_2007	21.18	229	RM	22.5	3:00	Speed	RT	ms	MATB
21	Wilson_2007	21.19	229	RM	25.5	6:00	Speed	RT	ms	MATB
21	Wilson_2007	21.20	229	RM	28.5	9:00	Speed	RT	ms	MATB
22	Gundel_2007	22.1	190	RM	day 3	21:30	Speed	response t	sec	

Table 100: Reaction Time Raw Data Part 2b

Study Id #	N				Statistical Data										
	Control		Test		Mean		Standard Deviation		Standard Error		Mean in ms		Diff	Poooled	
	Assigned	Observed	Assigned	Observed	Control	Test	Control	Test	Control	Test	Control	Test	Means	Stdev	B Stdev
13	16	16	16	16	3.95	3.95	2.112	2.0004	0.528	0.5001	253.1646	253.1646	0		
13	16	16	16	16	3.95	4	2.112	1.8528	0.528	0.4632	253.1646	250	-3.16456	1.99	2.81
13	16	16	16	16	3.95	4.05	2.112	2.0112	0.528	0.5028	253.1646	246.9136	-6.25098	2.06	2.92
13	16	16	16	16	3.95	4.06	2.112	1.8504	0.528	0.4626	253.1646	246.3054	-6.85914	1.99	2.81
13	16	16	16	16	3.95	4.05	2.112	1.7724	0.528	0.4431	253.1646	246.9136	-6.25098	1.95	2.76
13	16	16	16	16	3.95	4.07	2.112	1.6476	0.528	0.4119	253.1646	245.7002	-7.46431	1.89	2.68
13	16	16	16	16	3.95	4.06	2.112	1.8892	0.528	0.4723	253.1646	246.3054	-6.85914	2.00	2.83
13	16	16	16	16	3.95	4.07	2.112	1.8692	0.528	0.4673	253.1646	245.7002	-7.46431	1.99	2.82
14	14	14	14	14	-16	1 and day2						-16	-16		
14	14	14	14	14	9							9	9		
14	14	14	14	14	16							16	16		
14	14	14	14	14	30							30	30		
14	14	12	14	12	20							20	20		
14	14	12	14	12	21							21	21		
14	14	12	14	12	28							28	28		
14	14	12	14	12	45							45	45		
15	48	34	48	34											
16	34	34	34	34											
16	34	34	34	34											
16	34	34	34	34											
16	34	34	34	34											
16	34	34	34	34											
16	34	34	34	34											
16	34	34	34	34											
16	34	34	34	34											
16	34	34	34	34											
16	34	34	34	34											
16	34	34	34	34											
16	34	34	34	34											
16	34	34	34	34											
17	14	14	14	14	1155	1148	149	0.017			1155	1148	-7	105.36	149.00
17	14	14	14	14	1138	1158	188	222			1138	1158	20	205.70	290.91
17	14	14	14	14	0.83	1.57	0.36	215			0.83	1.57	0.74	152.03	215.00
17	14	14	14	14	790	853	92	0.69			790	853	63	65.06	92.00
17	14	14	14	14	944	921	255	126			944	921	-23	201.12	284.43
17	14	14	14	14	813	877	111	178			813	877	64	148.33	209.77
19	40	40	40	40		-1.89						-1.89	-1.89		
19	40	40	40	40		-9.33		4.65				-9.33	-9.33	3.29	4.65
20	8	8	8	8	0.41	0.41		8.87			410	410		6.27	8.87
20	8	8	8	8	0.41	0.41					410	410			
20	8	8	8	8	0.41	0.6					410	600	190		
20	8	8	8	8	0.41	0.78					410	780	370		
20	8	8	8	8	0.41	0.9					410	900	490		
21	9	9	9	9		245	-	-				**245**	245		
21	9	9	9	9		262	-	-				**262**	262		
21	9	9	9	9		275	-	-				**275**	275		
21	9	9	9	9		300	-	-				**300**	300		
21	9	9	9	9		263	-	-				**263**	263		
21	9	9	9	9		1.4	-	-				**1.4**	1.4		
21	9	9	9	9		1.6	-	-				**1.6**	1.6		
21	9	9	9	9		1.75	-	-				**1.75**	1.75		
21	9	9	9	9		2.5	-	-				**2.5**	2.5		
21	9	9	9	9		2.2	-	-				**2.2**	2.2		
22	22	22	22	22		1.4	-	0.16				**1400**	1400		
22	22	22	22	22		1.41	-	0.215				**1410**	1410		

Table 101: Reaction Time Raw Data Part 3a

Study Id #	1st Author_year	Effect Size Id #	Page #	Type of Comparison	Hours of Wakefulness	Time of Measure	Performance Var	Task Info	Calc Procedure	Var/task Info
22	Gundel_2007	22.3	190	RM	day 3	21:50	Speed	response t	sec	
22	Gundel_2007	22.4	190	RM	day 3	0:00	Speed	response t	sec	
22	Gundel_2007	22.5	190	RM	day 3	0:10	Speed	response t	sec	
22	Gundel_2007	22.6	190	RM	day 3	0:20	Speed	response t	sec	
22	Gundel_2007	22.7	190	RM	day 3	2:30	Speed	response t	sec	
22	Gundel_2007	22.8	190	RM	day 3	2:40	Speed	response t	sec	
22	Gundel_2007	22.9	190	RM	day 3	2:50	Speed	response t	sec	
22	Gundel_2007	22.1	190	RM	day 3	5:00	Speed	response t	sec	
22	Gundel_2007	22.11	190	RM	day 3	5:10	Speed	response t	sec	
22	Gundel_2007	22.12	190	RM	day 3	5:20	Speed	response t	sec	
22	Gundel_2007	22.13	190	RM	day 4	21:30	Speed	response t	sec	
22	Gundel_2007	22.14	190	RM	day 4	21:40	Speed	response t	sec	
22	Gundel_2007	22.15	190	RM	day 4	21:50	Speed	response t	sec	
22	Gundel_2007	22.16	190	RM	day 4	0:00	Speed	response t	sec	
22	Gundel_2007	22.17	190	RM	day 4	0:10	Speed	response t	sec	
22	Gundel_2007	22.18	190	RM	day 4	0:20	Speed	response t	sec	
22	Gundel_2007	22.19	190	RM	day 4	2:30	Speed	response t	sec	
22	Gundel_2007	22.2	190	RM	day 4	2:40	Speed	response t	sec	
22	Gundel_2007	22.21	190	RM	day 4	2:50	Speed	response t	sec	
22	Gundel_2007	22.22	190	RM	day 4	5:00	Speed	response t	sec	
22	Gundel_2007	22.23	190	RM	day 4	5:10	Speed	response t	sec	
22	Gundel_2007	22.24	190	RM	day 4	5:20	Speed	response t	sec	
23a - old	Webb_1985	23a.1	159	RM	17 to 23	400 to 0600	Speed			
23a - old	Webb_1985	23a.2	159	RM	17 to 23	400 to 0600	Speed			
23a - old	Webb_1985	23a.3	159	RM	17 to 23	400 to 0600	Speed			
23a - old	Webb_1985	23a.4	159	RM	17 to 23	400 to 0600	Speed			
23a - old	Webb_1985	23a.5	159	RM	17 to 23	400 to 0600	Speed			
23a - old	Webb_1985	23a.6	159	RM	17 to 23	400 to 0600	Speed			
23b- young	Webb_1985	23b.1	159	RM	17 to 23	400 to 0600	Speed			
23b- young	Webb_1985	23b.2	159	RM	17 to 23	400 to 0600	Speed			
23b- young	Webb_1985	23b.3	159	RM	17 to 23	400 to 0600	Speed			
23b- young	Webb_1985	23b.4	159	RM	17 to 23	400 to 0600	Speed			
23b- young	Webb_1985	23b.5	159	RM	17 to 23	400 to 0600	Speed			
23b- young	Webb_1985	23b.6	159	RM	17 to 23	400 to 0600	Speed			
25	Sanders_1982	25.1	153	RM	24		Speed	mean total	ms	
25	Sanders_1982	25.2	153	RM	24		Speed	mean total	ms	
25	Sanders_1982	25.3	153	RM	24		Speed	mean total	ms	
27	Porcu_1998	27.11	1198	RM		baseline	Speed	DBT com	ms	
27	Porcu_1998	27.12	1198	RM		23:00	Speed	DBT com	ms	
27	Porcu_1998	27.13	1198	RM		1:00	Speed	DBT com	ms	
27	Porcu_1998	27.14	1198	RM		3:00	Speed	DBT com	ms	
27	Porcu_1998	27.15	1198	RM		5:00	Speed	DBT com	ms	
27	Porcu_1998	27.21	1198	RM		baseline	Speed	completion	ms	
27	Porcu_1998	27.22	1198	RM		23:00	Speed	completion	ms	
27	Porcu_1998	27.23	1198	RM		1:00	Speed	completion	ms	
27	Porcu_1998	27.24	1198	RM		3:00	Speed	completion	ms	
27	Porcu_1998	27.25	1198	RM		5:00	Speed	completion	ms	
28	Wojtczak_jaroszowa_197	28.1	803	RM	Time on Task	6:00	Speed	task time	sec	
28	Wojtczak_jaroszowa_197	28.2	803	RM	Time on Task	10:00	Speed	task time	sec	
28	Wojtczak_jaroszowa_197	28.3	803	RM	Time on Task	14:00	Speed	task time	sec	
28	Wojtczak_jaroszowa_197	28.4	803	RM	Time on Task	14:00	Speed	task time	sec	
28	Wojtczak_jaroszowa_197	28.5	803	RM	Time on Task	18:00	Speed	task time	sec	
28	Wojtczak_jaroszowa_197	28.6	803	RM	Time on Task	22:00	Speed	task time	sec	
28	Wojtczak_jaroszowa_197	28.7	803	RM	Time on Task	22:00	Speed	task time	sec	

Table 102: Reaction Time Raw Data Part 3b

Study Id #	N: Control Assigned	N: Control Observed	N: Test Assigned	N: Test Observed	Mean: Control	Mean: Test	Standard Deviation: Control	Standard Deviation: Test	Standard Error: Control	Standard Error: Test	Mean in ms: Control	Mean in ms: Test	Diff Means	Poooled Stdev	B Stdev
22	22	22	22	22		1.43	-	0.3				1430	1430		
22	22	22	22	22		1.49	-	0.23				1490	1490		
22	22	22	22	22		1.52	-	0.325				1520	1520		
22	22	22	22	22		1.6	-	0.4				1600	1600		
22	22	22	22	22		1.6		0.32				1600	1600	0.23	0.32
22	22	22	22	22		1.7		-0.075				1700	1700	0.05	0.08
22	22	22	22	22		1.65		0.33				1650	1650	0.23	0.33
22	22	22	22	22		1.55		0.275				1550	1550	0.19	0.28
22	22	22	22	22		1.6		0.35				1600	1600	0.25	0.35
22	22	22	22	22		1.8		0.275				1800	1800	0.19	0.28
22	22	22	22	22		1.4	-	0.3				1400	1400		
22	22	22	22	22		1.49	-	0.1745				1490	1490		
22	22	22	22	22		1.3	-	0.275				1300	1300		
22	22	22	22	22		1.43	-	0.26				1430	1430		
22	22	22	22	22		1.44	-	0.3				1440	1440		
22	22	22	22	22		1.43	-	0.265				1430	1430		
22	22	22	22	22		1.4		0.27				1400	1400	0.19	0.27
22	22	22	22	22		1.49		0.4				1490	1490	0.28	0.40
22	22	22	22	22		1.48		0.295				1480	1480	0.21	0.30
22	22	22	22	22		1.51		0.305				1510	1510	0.22	0.31
22	22	22	22	22		1.52		0.4				1520	1520	0.28	0.40
22	22	22	22	22		1.48		0.19				1480	1480	0.13	0.19
23a - o	12	12	12	12	26.4	19.8	8.4	7.4			26.4	19.8	-6.6	7.92	11.19
23a - o	12	12	12	12	38.6	32.3	8.1	6.7			38.6	32.3	-6.3	7.43	10.51
23a - o	12	12	12	12	344	258	67.7	48.1			344	258	-86	58.72	83.05
23a - o	12	12	12	12	79.7	68.5	16.1	22.1			79.7	68.5	-11.2	19.33	27.34
23a - o	12	12	12	12	87.4	87.5	7.4	9.8			87.4	87.5	0.1	8.68	12.28
23a - o	12	12	12	12	96.4	89.5	3.4	9.8			96.4	89.5	-6.9	7.33	10.37
23b- yo	6	6	6	6	16.6	14.3	6.9	1.9			16.6	14.3	-2.3	5.06	7.16
23b- yo	6	6	6	6	51.3	39.3	11.1	13.2			51.3	39.3	-12	12.20	17.25
23b- yo	6	6	6	6	469	292	48.6	74.6			469	292	-177	62.96	89.03
23b- yo	6	6	6	6	85	83.8	9.1	10.2			85	83.8	-1.2	9.67	13.67
23b- yo	6	6	6	6	93.4	84.7	2.9	7.3			93.4	84.7	-8.7	5.55	7.85
23b- yo	6	6	6	6	98.3	92.2	1.5	5.7			98.3	92.2	-6.1	4.17	5.89
25	12	12	12	12	456	470	22.17025	24.24871	6.4	7	456	470	14	23.23	32.86
25	12	12	12	12	657	705	25.28794	30.13768	7.3	8.7	657	705	48	27.82	39.34
25	12	12	12	12	819	915	27.71281	22.86307	8	6.6	819	915	96	25.40	35.93
27	10	10	10	10	471.3	-	96.1	20.7			471.3	-			
27	10	10	10	10	471.3	441.8	96.1	85.8			471.3	441.8	-29.5	91.10	128.83
27	10	10	10	10	471.3	438.2	96.1	91.8			471.3	438.2	-33.1	93.97	132.90
27	10	10	10	10	471.3	479.2	96.1	93			471.3	479.2	7.9	94.56	133.73
27	10	10	10	10	471.3	466.5	96.1	57.1			471.3	466.5	-4.8	79.04	111.78
27	7	7	7	7	597.9	-	177.5	-			597.9	-			
27	7	7	7	7	597.9	531.4	177.5	118.9			597.9	531.4	-66.5	151.07	213.64
27	7	7	7	7	597.9	611.4	177.5	129.1			597.9	611.4	13.5	155.20	219.48
27	7	7	7	7	597.9	637.1	177.5	257.3			597.9	637.1	39.2	221.03	312.59
27	7	7	7	7	597.9	557.1	177.5	1.4			597.9	557.1	-40.8	125.52	177.51
28	10	10	10	10	-	104	-					104	104		
28	10	10	10	10	-	95	-					95	95		
28	10	10	10	10	-	95	-					95	95		
28	10	10	10	10	-	98	-					98	98		
28	10	10	10	10	-	97	-					97	97		
28	10	10	10	10	-	106	-					106	106		
28	10	10	10	10	-	105	-					105	105		

Table 103: Reaction Time Raw Data Part 4a

Study Id #	1st Author_year	Effect Size Id #	Page #	Type of Comparison	Hours of Wakefulness	Time of Measure	Performance Var	Task Info	Calc Procedure	Var/task Info
28	Wojtczak_jaroszowa_197	28.8	803	RM	Time on Task	2:00	Speed	task time	sec	
28	Wojtczak_jaroszowa_197	28.9	803	RM	Time on Task	6:00	Speed	task time	sec	
29	Dorrian_2007	29.1	163	RM	pretest	23:00-07:00	PVT			
29	Dorrian_2007	29.2	163	RM	posttest	23:00-07:00	PVT			
30	Maury_1993	30.1	294	RM		18:00	Speed	RT	ms	g task - dra
30	Maury_1993	30.2	294	RM		22:00	Speed	RT	ms	
30	Maury_1993	30.3	294	RM		2:00	Speed	RT	ms	
30	Maury_1993	30.4	294	RM		6:00	Speed	RT	ms	
30	Maury_1993	30.5	294	RM		18:00	Speed	RT	ms	pelling- wor
30	Maury_1993	30.6	294	RM		22:00	Speed	RT	ms	
30	Maury_1993	30.7	294	RM		2:00	Speed	RT	ms	
30	Maury_1993	30.8	294	RM		6:00	Speed	RT	ms	
30	Maury_1993	30.9	294	RM		18:00	Speed	RT	ms	arision - dra
30	Maury_1993	30.10	294	RM		22:00	Speed	RT	ms	
30	Maury_1993	30.11	294	RM		2:00	Speed	RT	ms	
30	Maury_1993	30.12	294	RM		6:00	Speed	RT	ms	
30	Maury_1993	30.13	294	RM		18:00	Speed	RT	ms	parison - w
30	Maury_1993	30.14	294	RM		22:00	Speed	RT	ms	
30	Maury_1993	30.15	294	RM		2:00	Speed	RT	ms	
30	Maury_1993	30.16	294	RM		6:00	Speed	RT	ms	
33	Roach_2006	33.1	1384	RM	1	9:00	Speed	RT	ms	10 min PV
33	Roach_2006	33.2	1384	RM	3	11:00	Speed	RT	ms	10 min PV
33	Roach_2006	33.3	1384	RM	5	13:00	Speed	RT	ms	10 min PV
33	Roach_2006	33.4	1384	RM	7	15:00	Speed	RT	ms	10 min PV
33	Roach_2006	33.5	1384	RM	9	17:00	Speed	RT	ms	10 min PV
33	Roach_2006	33.6	1384	RM	11	19:00	Speed	RT	ms	10 min PV
33	Roach_2006	33.7	1384	RM	13	21:00	Speed	RT	ms	10 min PV
33	Roach_2006	33.8	1384	RM	15	23:00	Speed	RT	ms	10 min PV
33	Roach_2006	33.9	1384	RM	17	1:00	Speed	RT	ms	10 min PV
33	Roach_2006	33.10	1384	RM	19	3:00	Speed	RT	ms	10 min PV
33	Roach_2006	33.11	1384	RM	21	5:00	Speed	RT	ms	10 min PV
33	Roach_2006	33.12	1384	RM	23	7:00	Speed	RT	ms	10 min PV
33	Roach_2006	33.13	1384	RM	25	9:00	Speed	RT	ms	10 min PV
33	Roach_2006	33.14	1384	RM	27	11:00	Speed	RT	ms	10 min PV
34	Reznick_1987	34.2	523	RM	< 3hrs in 25	tricted sleep	Speed and accuracy			
34	Reznick_1987	34.3	523	RM	< 3hrs in 26	tricted sleep	Speed and accuracy			
35	Daniel_1989	35.1	691	RM	-	7:00	Speed	RT	sec	
35	Daniel_1989	35.2	691	RM		11:00	Speed	RT	sec	
35	Daniel_1989	35.3	691	RM		15:00	Speed	RT	sec	
35	Daniel_1989	35.4	691	RM		19:00	Speed	RT	sec	
35	Daniel_1989	35.5	691	RM		23:00	Speed	RT	sec	
35	Daniel_1989	35.6	691	RM		3:00	Speed	RT	sec	
35	Daniel_1989	35.7	691	RM		7:00	Speed	RT	sec	
35	Daniel_1989	35.8	692	RM		7:00	Speed	RT	sec	
35	Daniel_1989	35.9	692	RM		11:00	Speed	RT	sec	
35	Daniel_1989	35.10	692	RM		15:00	Speed	RT	sec	
35	Daniel_1989	35.11	692	RM		19:00	Speed	RT	sec	
35	Daniel_1989	35.12	692	RM		23:00	Speed	RT	sec	
35	Daniel_1989	35.13	692	RM		3:00	Speed	RT	sec	
35	Daniel_1989	35.14	692	RM		7:00	Speed	RT	sec	
36	Buck_1975	36.1	419	RM		day1	Speed	RT	ms	
36	Buck_1975	36.2	419	RM		day2	Speed	RT	sec	
36	Buck_1975	36.3	419	RM		day1	Speed	RT	sec	
36	Buck_1975	36.4	419	RM		day3	Speed	RT	sec	

Table 104: Reaction Time Raw Data Part 4b

Study Id #	N				Statistical Data										
	Control		Test		Mean		Standard Deviation		Standard Error		Mean in ms		Diff Means	Poooled Stdev	B Stdev
	Assigned	Observed	Assigned	Observed	Control	Test	Control	Test	Control	Test	Control	Test			
28	10	10	10	10	-	113	-					113	113		
28	10	10	10	10	-	109	-					109	109		
29	20	20	20	20											
29	20	20	20	20											
30	15	15	15	15	540	540	37.5	37.5			540	540	0	37.50	53.03
30	15	15	15	15	540	600	37.5	65			540	600	60	53.06	75.04
30	15	15	15	15	540	490	37.5	30			540	490	-50	33.96	48.02
30	15	15	15	15	540	560	37.5	45			540	560	20	41.42	58.58
30	14	14	14	14	480	480	25	25			480	480	0	25.00	35.36
30	14	14	14	14	480	500	25	22.5			480	500	20	23.78	33.63
30	14	14	14	14	480	495	25	27.5			480	495	15	26.28	37.17
30	14	14	14	14	480	460	25	25			480	460	-20	25.00	35.36
30	15	15	15	15	210	210	20	20			210	210	0	20.00	28.28
30	15	15	15	15	210	200	20	20			210	200	-10	20.00	28.28
30	15	15	15	15	210	205	20	20			210	205	-5	20.00	28.28
30	15	15	15	15	210	212	20	17.5			210	212	2	18.79	26.58
30	14	14	14	14	150	150	10	10			150	150	0	10.00	14.14
30	14	14	14	14	150	140	10	12.5			150	140	-10	11.32	16.01
30	14	14	14	14	150	170	10	17.5			150	170	20	14.25	20.16
30	14	14	14	14	150	160	10	20			150	160	10	15.81	22.36
33	16	16	16	16	229	216	44	36	11	9	229	216	-13	40.20	56.85
33	16	16	16	16	229	218	44	52	11	13	229	218	-11	48.17	68.12
33	16	16	16	16	229	220	44	44	11	11	229	220	-9	44.00	62.23
33	16	16	16	16	229	230	44	60	11	15	229	230	1	52.61	74.40
33	16	16	16	16	229	229	44	44	11	11	229	229	0	44.00	62.23
33	16	16	16	16	229	227	44	52	11	13	229	227	-2	48.17	68.12
33	16	16	16	16	229	230	44	60	11	15	229	230	1	52.61	74.40
33	16	16	16	16	229	250	44	88	11	22	229	250	21	69.57	98.39
33	16	16	16	16	229	265	44	76	11	19	229	265	36	62.10	87.82
33	16	16	16	16	229	272	44	72	11	18	229	272	43	59.67	84.38
33	16	16	16	16	229	278	44	72	11	18	229	278	49	59.67	84.38
33	16	16	16	16	229	308	44	72	11	18	229	308	79	59.67	84.38
33	16	16	16	16	229	288	44	64	11	16	229	288	59	54.92	77.67
33	16	16	16	16	229	285	44	72	11	18	229	285	56	59.67	84.38
34	21	12	21	12				-							
34	21	12	21	12											
35	18	18	18	18		3.8						3.8	3.8		
35	18	18	18	18		3.6						3.6	3.6		
35	18	18	18	18		3.3						3.3	3.3		
35	18	18	18	18		3.45						3.45	3.45		
35	18	18	18	18		3.34						3.34	3.34		
35	18	18	18	18		3.38						3.38	3.38		
35	18	18	18	18		3.8						3.8	3.8		
35	16	16	16	16		3.45						3.45	3.45		
35	16	16	16	16		2.95						2.95	2.95		
35	16	16	16	16		2.95						2.95	2.95		
35	16	16	16	16		2.6						2.6	2.6		
35	16	16	16	16		2.9						2.9	2.9		
35	16	16	16	16		2.9						2.9	2.9		
35	16	16	16	16		3.65						3.65	3.65		
36	20	20	20	20	241	244	-	-			241	244	3		
36	20	20	20	20	229	233	-	-			229	233	4		
36	8	8	8	8	207	214	-	-			207	214	7		
36	8	8	8	8	202	228	-	-			202	228	26		

Table 105: Reaction Time Raw Data Part 5a

Study Id #	1st Author_year	Effect Size Id #	Page #	Type of Comparison	Hours of Wakefulness	Time of Measure	Performance Var	Task Info	Calc Procedure	Var/task Info
36	Buck_1975	36.5	419	RM		day1	Speed	RT	sec	
36	Buck_1975	36.6	419	RM		day2	Speed	RT	sec	
36	Buck_1975	36.7	419	RM		day1	Speed	RT	sec	
36	Buck_1975	36.8	419	RM		day3	Speed	RT	sec	
37	Lenne_1997	37.1	434	RM		6:00	Speed	RT	sec	
37	Lenne_1997	37.2	434	RM		10:00	Speed	RT	sec	
37	Lenne_1997	37.3	434	RM		14:00	Speed	RT	sec	
37	Lenne_1997	37.4	434	RM		18:00	Speed	RT	sec	
37	Lenne_1997	37.5	434	RM		22:00	Speed	RT	sec	
37	Lenne_1997	37.6	434	RM		2:00	Speed	RT	sec	
41	Monk_1997	41.19	15	RM	2	9:00	Speed	residuals	sec	Vigilance S
41	Monk_1997	41.2	15	RM	4	11:00	Speed	residuals	sec	Vigilance S
41	Monk_1997	41.21	15	RM	6	13:00	Speed	residuals	sec	Vigilance S
41	Monk_1997	41.22	15	RM	8	15:00	Speed	residuals	sec	Vigilance S
41	Monk_1997	41.23	15	RM	10	17:00	Speed	residuals	sec	Vigilance S
41	Monk_1997	41.24	15	RM	12	19:00	Speed	residuals	sec	Vigilance S
41	Monk_1997	41.25	15	RM	14	21:00	Speed	residuals	sec	Vigilance S
41	Monk_1997	41.26	15	RM	16	23:00	Speed	residuals	sec	Vigilance S
41	Monk_1997	41.27	15	RM	18	1:00	Speed	residuals	sec	Vigilance S
41	Monk_1997	41.28	15	RM	20	3:00	Speed	residuals	sec	Vigilance S
41	Monk_1997	41.29	15	RM	22	5:00	Speed	residuals	sec	Vigilance S
41	Monk_1997	41.3	15	RM	24	7:00	Speed	residuals	sec	Vigilance S
41	Monk_1997	41.31	15	RM	26	9:00	Speed	residuals	sec	Vigilance S
41	Monk_1997	41.32	15	RM	28	11:00	Speed	residuals	sec	Vigilance S
41	Monk_1997	41.33	15	RM	30	13:00	Speed	residuals	sec	Vigilance S
41	Monk_1997	41.34	15	RM	32	15:00	Speed	residuals	sec	Vigilance S
41	Monk_1997	41.35	15	RM	34	17:00	Speed	residuals	sec	Vigilance S
41	Monk_1997	41.36	15	RM	36	19:00	Speed	residuals	sec	Vigilance S
41	Monk_1997	41.37	14	RM	2	9:00	Speed	residuals	sec	Search Spe
41	Monk_1997	41.38	14	RM	4	11:00	Speed	residuals	sec	Search Spe
41	Monk_1997	41.39	14	RM	6	13:00	Speed	residuals	sec	Search Spe
41	Monk_1997	41.4	14	RM	8	15:00	Speed	residuals	sec	Search Spe
41	Monk_1997	41.41	14	RM	10	17:00	Speed	residuals	sec	Search Spe
41	Monk_1997	41.42	14	RM	12	19:00	Speed	residuals	sec	Search Spe
41	Monk_1997	41.43	14	RM	14	21:00	Speed	residuals	sec	Search Spe
41	Monk_1997	41.44	14	RM	16	23:00	Speed	residuals	sec	Search Spe
41	Monk_1997	41.45	14	RM	18	1:00	Speed	residuals	sec	Search Spe
41	Monk_1997	41.46	14	RM	20	3:00	Speed	residuals	sec	Search Spe
41	Monk_1997	41.47	14	RM	22	5:00	Speed	residuals	sec	Search Spe
41	Monk_1997	41.48	14	RM	24	7:00	Speed	residuals	sec	Search Spe
41	Monk_1997	41.49	14	RM	26	9:00	Speed	residuals	sec	Search Spe
41	Monk_1997	41.5	14	RM	28	11:00	Speed	residuals	sec	Search Spe
41	Monk_1997	41.51	14	RM	30	13:00	Speed	residuals	sec	Search Spe
41	Monk_1997	41.52	14	RM	32	15:00	Speed	residuals	sec	Search Spe
41	Monk_1997	41.53	14	RM	34	17:00	Speed	residuals	sec	Search Spe
41	Monk_1997	41.54	14	RM	36	19:00	Speed	residuals	sec	Search Spe
41	Monk_1997	41.55	14	RM	2	9:00	Speed	residuals	sec	Reasoning
41	Monk_1997	41.56	14	RM	4	11:00	Speed	residuals	sec	Reasoning
41	Monk_1997	41.57	14	RM	6	13:00	Speed	residuals	sec	Reasoning
41	Monk_1997	41.58	14	RM	8	15:00	Speed	residuals	sec	Reasoning
41	Monk_1997	41.59	14	RM	10	17:00	Speed	residuals	sec	Reasoning
41	Monk_1997	41.6	14	RM	12	19:00	Speed	residuals	sec	Reasoning
41	Monk_1997	41.61	14	RM	14	21:00	Speed	residuals	sec	Reasoning
41	Monk_1997	41.62	14	RM	16	23:00	Speed	residuals	sec	Reasoning

Table 106: Reaction Time Raw Data Part 5b

Study Id #	N				Statistical Data										
	Control		Test		Mean		Standard Deviation		Standard Error		Mean in ms		Diff Means	Poooled Stdev	B Stdev
	Assigned	Observed	Assigned	Observed	Control	Test	Control	Test	Control	Test	Control	Test			
36	20	20	20	20	374	369	-	-			374	369	-5		
36	20	20	20	20	354	379	-	-			354	379	25		
36	8	8	8	8	304	305	-	-			304	305	1		
36	8	8	8	8	277	343	-	-			277	343	66		
37	11	11	11	11		0.88		0.15754		0.0475		880	880	0.11	0.16
37	11	11	11	11		0.8		0.132665		0.04		800	800	0.09	0.13
37	11	11	11	11		0.925		0.505785		0.1525		925	925	0.36	0.51
37	11	11	11	11		0.81		0.140957		0.0425		810	810	0.10	0.14
37	11	11	11	11		0.78		0.116082		0.035		780	780	0.08	0.12
37	11	11	11	11		0.92		0.140957		0.0425		920	920	0.10	0.14
41	17	17	17	17		0				1.8					
41	17	17	17	17		-1				2.15					
41	17	17	17	17		-0.6				1.5					
41	17	17	17	17		3				1.8					
41	17	17	17	17		1				1.5					
41	17	17	17	17		3				1.5					
41	17	17	17	17		3.3				2.1					
41	17	17	17	17		0.5				1.5					
41	17	17	17	17		-4.5				2.3					
41	17	17	17	17		-2				1.5					
41	17	17	17	17		-3.8				1.75					
41	17	17	17	17		-3.7				2.5					
41	17	17	17	17		-0.4				1.6					
41	17	17	17	17		-3.8				1.8					
41	17	17	17	17		2.8				2.3					
41	17	17	17	17		0				1.5					
41	17	17	17	17		2				1.5					
41	17	17	17	17		3.9				2.3					
41	17	17	17	17		0				0.275					
41	17	17	17	17		0.35				0.45					
41	17	17	17	17		-0.4				0.275					
41	17	17	17	17		-0.8				0.275					
41	17	17	17	17		0.5				0.275					
41	17	17	17	17		1				0.275					
41	17	17	17	17		0.15				0.45					
41	17	17	17	17		0.9				0.45					
41	17	17	17	17		0.5				0.45					
41	17	17	17	17		-0.5				0.45					
41	17	17	17	17		-1.2				0.825					
41	17	17	17	17		-1.3				0.82					
41	17	17	17	17		-0.6				0.45					
41	17	17	17	17		0				0.5					
41	17	17	17	17		-0.15				0.275					
41	17	17	17	17		0.1				0.5					
41	17	17	17	17		0.3				0.2					
41	17	17	17	17		1				0.45					
41	17	17	17	17		-1.5				0.6					
41	17	17	17	17		-0.5				0.4					
41	17	17	17	17		0.2				0.6					
41	17	17	17	17		0.8				0.4					
41	17	17	17	17		0.2				0.5					
41	17	17	17	17		1.8				0.6					
41	17	17	17	17		1.15				0.6					
41	17	17	17	17		1				0.5					

Table 107: Reaction Time Raw Data Part 6a

Study Id #	1st Author_year	Effect Size Id #	Page #	Type of Comparison	Hours of Wakefulness	Time of Measure	Performance Var	Task Info	Calc Procedure	Var/task Info
41	Monk_1997	41.63	14	RM	18	1:00	Speed	residuals	sec	Reasoning Speed (VR
41	Monk_1997	41.64	14	RM	20	3:00	Speed	residuals	sec	Reasoning Speed (VR
41	Monk_1997	41.65	14	RM	22	5:00	Speed	residuals	sec	Reasoning Speed (VR
41	Monk_1997	41.66	14	RM	24	7:00	Speed	residuals	sec	Reasoning Speed (VR
41	Monk_1997	41.67	14	RM	26	9:00	Speed	residuals	sec	Reasoning Speed (VR
41	Monk_1997	41.68	14	RM	28	11:00	Speed	residuals	sec	Reasoning Speed (VR
41	Monk_1997	41.69	14	RM	30	13:00	Speed	residuals	sec	Reasoning Speed (VR
41	Monk_1997	41.7	14	RM	32	15:00	Speed	residuals	sec	Reasoning Speed (VR
41	Monk_1997	41.71	14	RM	34	17:00	Speed	residuals	sec	Reasoning Speed (VR
41	Monk_1997	41.72	14	RM	36	19:00	Speed	residuals	sec	Reasoning Speed (VR
42	Jones_2006	42.1	1259	RM	2	9:00	Speed	1/RT	ms	
42	Jones_2006	42.1	1259	RM	4	11:00	Speed	1/RT	ms	
42	Jones_2006	42.1	1259	RM	6	13:00	Speed	1/RT	ms	
42	Jones_2006	42.1	1259	RM	8	15:00	Speed	1/RT	ms	
42	Jones_2006	42.1	1259	RM	10	17:00	Speed	1/RT	ms	
42	Jones_2006	42.1	1259	RM	12	19:00	Speed	1/RT	ms	
42	Jones_2006	42.1	1259	RM	14	21:00	Speed	1/RT	ms	
42	Jones_2006	42.1	1259	RM	16	23:00	Speed	1/RT	ms	
42	Jones_2006	42.1	1259	RM	18	1:00	Speed	1/RT	ms	
42	Jones_2006	42.1	1259	RM	20	3:00	Speed	1/RT	ms	
42	Jones_2006	42.1	1259	RM	22	5:00	Speed	1/RT	ms	
42	Jones_2006	42.1	1259	RM	24	7:00	Speed	1/RT	ms	
42	Jones_2006	42.1	1259	RM	26	9:00	Speed	1/RT	ms	
42	Jones_2006	42.1	1259	RM	28	11:00	Speed	1/RT	ms	
42	Jones_2006	42.1	1259	RM	30	13:00	Speed	1/RT	ms	
42	Jones_2006	42.1	1259	RM	32	15:00	Speed	1/RT	ms	
42	Jones_2006	42.1	1259	RM	34	17:00	Speed	1/RT	ms	
42	Jones_2006	42.1	1259	RM	36	19:00	Speed	1/RT	ms	
42	Jones_2006	42.1	1259	RM	38	21:00	Speed	1/RT	ms	
42	Jones_2006	42.1	1259	RM	40	23:00	Speed	1/RT	ms	
45	Halbach_2003	45.1	1200	RM	one night on ca	ricted sleep	Speed	groove peg	sec	peg board - dominant
45	Halbach_2003	45.2	1200	RM	one night on call		Speed	groove peg	sec	peg board - non-domin
47	Lamond_2007	47.1		RM	24	9:00	Speed	1/RT	ms	PVT
48	Drummond_2006	48.9	263	RM	7		Speed	hit RT	ms	PVT
48	Drummond_2006	48.10	263	RM	23		Speed	hit RT	ms	PVT
48	Drummond_2006	48.11	263	RM	31		Speed	hit RT	ms	PVT
48	Drummond_2006	48.12	263	RM	55		Speed	hit RT	ms	PVT
49	Eastridge_2003	49.2	172	RM	-		Speed	mean RT	sec	
50	Engle_Friedman	50.1	115	RM	1 night	8:00 to16:00	Speed	mean RT	sec	
50	Engle_Friedman	50.3	121	2GC	1 night	):00 to 10:30	Speed	mean RT	sec	
50	Engle_Friedman	50.4	121	2GC	2 night	):00 to 10:31	Speed	mean RT	sec	
50	Engle_Friedman	50.6	121	2GC	4 night	):00 to 10:33	Speed	mean RT	sec	
51	Caldwell_2003	51.1	27	RM	4	18:45	Speed	1/RT	ms	reaction time
51	Caldwell_2003	51.2	27	RM	8	22:45	Speed	1/RT	ms	
51	Caldwell_2003	51.3	27	RM	12	2:45	Speed	1/RT	ms	
51	Caldwell_2003	51.4	27	RM	20	10:45	Speed	1/RT	ms	
51	Caldwell_2003	51.5	27	RM	24	14:45	Speed	1/RT	ms	
51	Caldwell_2003	51.6	27	RM	28	18:45	Speed	1/RT	ms	
52	Rosa_1983	52	156	RM	32	23:30	Speed	1/RT	sec	
52	Rosa_1983	52.1	156	RM	34	1:30	Speed	1/RT	sec	
52	Rosa_1983	52.2	156	RM	36.5	4:00	Speed	1/RT	sec	
52	Rosa_1983	52.3	156	RM	38.25	6:15	Speed	1/RT	sec	
52	Rosa_1983	52.3	156	RM	40	8:30	Speed	1/RT	sec	
52	Rosa_1983	52.4	156	RM	56	23:30	Speed	1/RT	sec	

Table 108: Reaction Time Raw Data Part 6b

Study Id #	N Control Assigned	N Control Observed	N Test Assigned	N Test Observed	Mean Control	Mean Test	Standard Deviation Control	Standard Deviation Test	Standard Error Control	Standard Error Test	Mean in ms Control	Mean in ms Test	Diff Means	Poooled Stdev	B Stdev
41	17	17	17	17		0.4				0.25					
41	17	17	17	17		-1.1				1.1					
41	17	17	17	17		-1.3				1.1					
41	17	17	17	17		-2.4				1					
41	17	17	17	17		-1				0.6					
41	17	17	17	17		-0.8				0.75					
41	17	17	17	17		-0.6				0.75					
41	17	17	17	17		2.2				1					
41	17	17	17	17		-0.6				0.75					
41	17	17	17	17		1		**0.6**					0	0.42	0.60
42	32	32	32	32	4.6	4.63	0.622254	0.565685	0.11	0.1	217.3913	215.98272	-1.40858	0.59	0.84
42	32	32	32	32	4.6	4.62	0.622254	0.622254	0.11	0.11	217.3913	216.45022	-0.94109	0.62	0.88
42	32	32	32	32	4.6	4.58	0.622254	0.565685	0.11	0.1	217.3913	218.34061	0.949307	0.59	0.84
42	32	32	32	32	4.6	4.6	0.622254	0.622254	0.11	0.11	217.3913	217.3913	0	0.62	0.88
42	32	32	32	32	4.6	4.58	0.622254	0.565685	0.11	0.1	217.3913	218.34061	0.949307	0.59	0.84
42	32	32	32	32	4.6	4.56	0.622254	0.622254	0.11	0.11	217.3913	219.29825	1.906941	0.62	0.88
42	32	32	32	32	4.6	4.57	0.622254	0.622254	0.11	0.11	217.3913	218.81838	1.427076	0.62	0.88
42	32	32	32	32	4.6	4.56	0.622254	0.622254	0.11	0.11	217.3913	219.29825	1.906941	0.62	0.88
42	32	32	32	32	4.6	4.34	0.622254	0.622254	0.11	0.11	217.3913	230.41475	13.02344	0.62	0.88
42	32	32	32	32	4.6	4.18	0.622254	0.622254	0.11	0.11	217.3913	239.23445	21.84315	0.62	0.88
42	32	32	32	32	4.6	4.1	0.622254	0.678823	0.11	0.12	217.3913	243.90244	26.51113	0.65	0.92
42	32	32	32	32	4.6	3.85	0.622254	0.622254	0.11	0.11	217.3913	259.74026	42.34896	0.62	0.88
42	32	32	32	32	4.6	3.63	0.622254	0.622254	0.11	0.11	217.3913	275.48209	58.09079	0.62	0.88
42	32	32	32	32	4.6	3.8	0.622254	0.565685	0.11	0.1	217.3913	263.15789	45.76659	0.59	0.84
42	32	32	32	32	4.6	3.72	0.622254	0.565685	0.11	0.1	217.3913	268.8172	51.4259	0.59	0.84
42	32	32	32	32	4.6	3.73	0.622254	0.678823	0.11	0.12	217.3913	268.09651	50.70521	0.65	0.92
42	32	32	32	32	4.6	4	0.622254	0.678823	0.11	0.12	217.3913	250	32.6087	0.65	0.92
42	32	32	32	32	4.6	3.8	0.622254	0.735391	0.11	0.13	217.3913	263.15789	45.76659	0.68	0.96
42	32	32	32	32	4.6	3.92	0.622254	0.622254	0.11	0.11	217.3913	255.10204	37.71074	0.62	0.88
42	32	32	32	32	4.6	3.98	0.622254	0.565685	0.11	0.1	217.3913	251.25628	33.86498	0.59	0.84
45	30	30	30	30	fter on-call	2.3		6.4					0	4.53	6.40
45	30	30	30	30		-3.1		6.6					0	4.67	6.60
47	30	30	30	30	4.6	2.95	1.095445	1.369306	0.2	0.25	217.3913	338.98305	121.5917	1.24	1.75
48	32	32	32	32	612	612	57.9827561	57.98			612	612	0	57.98	82.00
48	32	32	32	32	612	635	57.9827561	67.882251			612	635	23	63.13	89.27
48	32	32	32	32	612	640	57.9827561	73.5391052			612	640	28	66.22	93.65
48	32	32	32	32	612	645	57.9827561	79.1959595			612	645	33	69.40	98.15
49	35	35	35	35	65	75	29.5804	29.5804	5	5	**65000**	**75000**	10000	29.58	41.83
50	50	50	50	50	0.58	0.68	0.27	0.4			580	680	100	0.34	0.48
50b	29	24	29	24	0.339	0.371	0.046	0.052			339	371	32	0.05	0.07
50b	24	24	24	24											
50b	24	24	24	24											
51	16	15	16	15		4.8	-	0.09				208.33333	208.3333		
51	16	15	16	15		4.7	-	0.1				212.76596	212.766		
51	16	15	16	15		4.3	-	0.125				232.55814	232.5581		
51	16	15	16	15		4.15	-	0.14				240.96386	240.9639		
51	16	15	16	15		3.98	-	0.16				251.25628	251.2563		
51	16	15	16	15		4.05	-	0.175				246.91358	246.9136		
52	12	12	12	12	4.95	5	-				202.0202	200	-2.0202		
52	12	12	12	12	3.75	4.7	-				266.66667	212.76596	-53.9007		
52	12	12	12	12	3.65	4.9	-				273.9726	204.08163	-69.891		
52	12	12	12	12	3.9	4.4	-				256.41026	227.27273	-29.1375		
52	12	12	12	12	4.25	4.3	-				235.29412	232.55814	-2.73598		
52	12	12	12	12	4.8	4.6	-				208.33333	217.3913	9.057971		

Table 109: Reaction Time Raw Data Part 7a

Study Id #	1st Author_year	Effect Size Id #	Page #	Type of Comparison	Hours of Wakefulness	Time of Measure	Performance Var	Task Info	Calc Procedure	Var/task Info
52	Rosa_1983	52.5	156	RM	58	1:30	Speed	1/RT	sec	
52	Rosa_1983	52.6	156	RM	60.5	4:00	Speed	1/RT	sec	
52	Rosa_1983	52.7	156	RM	62.75	6:15	Speed	1/RT	sec	
52	Rosa_1983	52.8	156	RM	64	8:30	Speed	1/RT	sec	
53	Frey_2004	53.2	308	RM	43		Speed	1/RT	ms	PVT
53	Frey_2004	53.5	308	RM	43		Speed	RT	ms	Wilkinson
53	Frey_2004	53.7	308	RM	43		Speed	1/RT	ms	
53	Frey_2004	53.9	308	RM	43		Speed	1/RT	ms	Math ORT
53	Frey_2004	53.11	308	RM	43		Speed	DNR	sec	2ADD
53	Frey_2004	53.13	308	RM	43		Speed	DNR	sec	Dual
53	Frey_2004	53.15	308	RM	43		Speed	DNR	sec	RCT
53	Frey_2004	53.18	308	RM	43		Speed	DNR	sec	DR
54	Glenville_1979	54.1	930	RM	shiftwork		Speed	RT	ms	
54	Glenville_1979	54.2	930	RM	ToT		Speed	RT	ms	
54	Glenville_1979	54.3	931	RM	ToT		Speed	RT	ms	
54	Glenville_1979	54.5	931	RM	ToT		Speed	RT	ms	
58	Saxena_2005	58.1	1388	2GC	on call vs not o	ricted sleep	Speed	RT media	ms	PVT
59	Richardon_1996	59.1	724	RM	36 hrs on call	tricted sleep	Speed	-		
59	Richardon_1996	59.2	724	RM	36 hrs on call w	ricted sleep	Speed	-		
61	Rosa_1988	61.1	312	RM		rest day	Speed	SRT Aud	ms	
61	Rosa_1988	61.2	312	RM		day1	Speed	SRT Aud	ms	
61	Rosa_1988	61.3	312	RM		day2	Speed	SRT Aud	ms	
61	Rosa_1988	61.4	312	RM		day3	Speed	SRT Aud	ms	
61	Rosa_1988	61.5	312	RM		day4	Speed	SRT Aud	ms	
61	Rosa_1988	61.6	312	RM		day5	Speed	SRT Aud	ms	
61	Rosa_1988	61.7	312	RM		rest day	Speed	SRT Aud	ms	
62	Hart_1987	62.1	942	GC	2.7 hrs in 24 fo	:00 to 15:00	Speed	% change	in RT	
68	Deaconson_1988	68.2	1723	RM	< 4hrs in past 2	ricted sleep	? Accuracy or RT			Trail-maki
70	Storer_1989	70.2	31	RM	24		Speed	task time	sec	intub
70	Storer_1989	70.3	31	RM	24		Speed	task time	sec	vein cann
70	Storer_1989	70.4	31	RM	24		Speed	task time	sec	catheter
70	Storer_1989	70.6	31	RM	34		Speed	task time	sec	
70	Storer_1989	70.7	31	RM	34		Speed	task time	sec	
70	Storer_1989	70.8	31	RM	34		Speed	task time	sec	
71	Lichtor_1989	71.1	S164	RM	24	6:30	Speed	VRT	sec	Visual rea
71	Lichtor_1989	71.2	S164	RM	24	ricted sleep	Speed	Aud RT	sec	aud reacti
72	Linde_1999	72.1	704	2GC		16:00	Speed	# solved/3	sec	
72	Linde_1999	72.2	704	2GC		22:00	Speed	# solved/3	sec	
72	Linde_1999	72.3	704	2GC		4:00	Speed	# solved/3	sec	
72	Linde_1999	72.4	704	2GC		10:00	Speed	# solved/3	sec	
72	Linde_1999	72.5	704	2GC		16:00	Speed	# solved/3	sec	
72	Linde_1999	72.6	704	2GC		22:00	Speed	# solved/3	sec	
72	Linde_1999	72.7	704	2GC		4:00	Speed	# solved/3	sec	
72	Linde_1999	72.8	704	2GC		10:00	Speed	# solved/3	sec	
72	Linde_1999	72.9	704	2GC		16:00	Speed	# solved/3	sec	
75	Tilley_1982	75.1	635	RM	Morning shift	day1	Speed	SRT	ms	
75	Tilley_1982	75.2	635	RM	06:00-14:00	day2	Speed	SRT	ms	
75	Tilley_1982	75.3	635	RM	06:00-14:00	day3	Speed	SRT	ms	
75	Tilley_1982	75.4	635	RM	06:00-14:00	day4	Speed	SRT	ms	
75	Tilley_1982	75.5	635	RM	06:00-14:00	day5	Speed	SRT	ms	
75	Tilley_1982	75.6	635	RM	Afternoon	day1	Speed	SRT	ms	
75	Tilley_1982	75.7	635	RM	14:00-22:00	day2	Speed	SRT	ms	
75	Tilley_1982	75.8	635	RM	14:00-22:00	day3	Speed	SRT	ms	
22	Gundel_2007	22.2	190	RM	day 3	21:40	Speed	response t	sec	

Table 110: Reaction Time Raw Data Part 7b

Study Id #	N				Statistical Data											
	Control		Test		Mean		Standard Deviation		Standard Error		Mean in ms			Poooled	
	Assigned	Observed	Assigned	Observed	Control	Test	Control	Test	Control	Test	Control	Test	Diff Means	Stdev	B Stdev
52	12	12	12	12	3.7	4.45	-				270.27027	224.7191	-45.55117		
52	12	12	12	12	3.6	4.1	-				277.77778	243.90244	-33.87534		
52	12	12	12	12	3.7	3.8	-				270.27027	263.15789	-7.112376		
52	12	12	12	12	4	4	-				250	250	0		
53	25	25	25	25	3.3	2.7	0.35	0.2	0.00007	0.00004	303.0303	370.37037	67.34007	0.29	0.40
53	25	25	25	25	181.7	151.9	21.5	26	4.3	5.2	181.7	151.9	-29.8	23.86	33.74
53	25	25	25	25	0.000493	0.000483	0.075	0.055	0.015	0.011	2028.3976	2070.3934	41.99581	0.07	0.09
53	25	25	25	25	0.000429	0.000399	0.07	0.05	0.014	0.01	2331.0023	2506.2657	175.2633	0.06	0.09
53	25	25	25	25	3.4	3.2	0.9	0.85	0.18	0.17	3400	3200	-200	0.88	1.24
53	25	25	25	25	92.5	74.8	19	15.5	3.8	3.1	92500	74800	-17700	17.34	24.52
53	25	25	25	25	89.6	73.6	12.5	9.5	2.5	1.9	89600	73600	-16000	11.10	15.70
53	25	25	25	25	13.2	13.3	3.5	5	0.7	1	13200	13300	100	4.32	6.10
54	18	10	18	10											
54	18	10	18	10											
54	18	11	18	11											
54	18	11	18	11											
58	7	7		13	239	264	26	16.9			239	264	25	20.39	31.01
59	26	26		z-score	-0.17	-0.02	0.66	3.2							3.27
59	26	26			0.09	0.01	0.66	0.74					0	0.66	0.99
61	11	11		11	158	158	66	66			158	158	0	66.00	93.34
61	11	11		11	158	192	66	68			158	192	34	67.01	94.76
61	11	11		11	158	210	66	90			158	210	52	78.92	111.61
61	11	11		11	158	214	66	104			158	214	56	87.10	123.17
61	11	11		11	158	215	66	95			158	215	57	81.80	115.68
61	11	11		11	158	210	66	109			158	210	52	90.10	127.42
61	11	11		11	176	176	67	67			176	176		67.00	94.75
62	14	14		16											
A	49	42													
68	26	26	26	26	40.17	41.43	16.41	17.16			40.17	41.43	1.26	16.79	23.74
70	26	26	26	26	81.35	89.8	8.45				81.35	89.8	8.45	5.98	8.45
70	26	26	26	26	154.16	140.7	-13.46				154.16	140.7	-13.46	9.52	13.46
70	26	26	26	26	231.81	1822.14	1590.33				231.81	1822.14	1590.33	1124.53	1590.33
70	26	26	26	26	81.35	83.07	1.72				81.35	83.07	1.72	1.22	1.72
70	26	26	26	26	154.16	209.06	54.9				154.16	209.06	54.9	38.82	54.90
70	26	26	26	26	231.81	258.85	27.04				231.81	258.85	27.04	19.12	27.04
71	6	6	6	6	0.31	0.36	0.03	0.06			310	360	50	0.05	0.07
71	6	6	6	6	0.27	0.3	0.03	0.04			270	300	30	0.04	0.05
72	12	12	12	12	0.4	0.52	0.12	0.18			400	520	120	0.11	0.22
72	12	12	12	12	0.54	0.71	0.17	0.17			540	710	170	0.17	0.24
72	12	12	12	12	0.57	0.78	0.19	0.21			570	780	210	0.19	0.28
72	12	12	12	12	0.65	0.86	0.21	0.14			650	860	210	0.22	0.25
72	12	12	12	12	0.67	0.91	0.18	0.13			670	910	240	0.18	0.22
72	12	12	12	12	0.142	0.19	0.116	0.142			142	190	48	0.11	0.18
72	12	12	12	12	0.175	0.266	0.109	0.105			175	266	91	0.11	0.15
72	12	12	12	12	0.252	0.341	0.146	0.176			252	341	89	0.14	0.23
72	12	12	12	12	0.271	0.398	0.134	0.18			271	398	127	0.13	0.22
75	12	12	12	12		422						422	422		
75	12	12	12	12		422						422	422		
75	12	12	12	12		415						415	415		
75	12	12	12	12		402						402	402		
75	12	12	12	12		410						410	410		
75	12	12	12	12		426						426	426		
75	12	12	12	12		422						422	422		
75	12	12	12	12		416						416	416		

Table 111: Reaction Time Raw Data Part 8a

Study Id #	1st Author_year	Effect Size Id #	Page #	Type of Comparison	Hours of Wakefulness	Time of Measure	Performance Var	Task Info	Calc Procedure	Var/task Info
75	Tilley_1982	75.9	635	RM	14:00-22:00	day4	Speed	SRT	ms	
75	Tilley_1982	75.1	635	RM	14:00-22:00	day5	Speed	SRT	ms	
75	Tilley_1982	75.1	635	RM	Evening	day1	Speed	SRT	ms	
75	Tilley_1982	75.1	635	RM	22:00-06:00	day2	Speed	SRT	ms	
75	Tilley_1982	75.1	635	RM	22:00-06:00	day3	Speed	SRT	ms	
75	Tilley_1982	75.1	635	RM	22:00-06:00	day4	Speed	SRT	ms	
75	Tilley_1982	75.1	635	RM	22:00-06:00	day5	Speed	SRT	ms	
75	Tilley_1982	75.1	634	RM	Morning shift	day1	Speed	SRT	ms	
75	Tilley_1982	75.1	634	RM	06:00-14:00	day2	Speed	SRT	ms	
75	Tilley_1982	75.1	634	RM	06:00-14:00	day3	Speed	SRT	ms	
75	Tilley_1982	75.1	634	RM	06:00-14:00	day4	Speed	SRT	ms	
75	Tilley_1982	75.1	634	RM	06:00-14:00	day5	Speed	SRT	ms	
75	Tilley_1982	75.1	634	RM	Afternoon	day1	Speed	SRT	ms	
75	Tilley_1982	75.1	634	RM	14:00-22:00	day2	Speed	SRT	ms	
75	Tilley_1982	75.1	634	RM	14:00-22:00	day3	Speed	SRT	ms	
75	Tilley_1982	75.1	634	RM	14:00-22:00	day4	Speed	SRT	ms	
75	Tilley_1982	75.1	634	RM	14:00-22:00	day5	Speed	SRT	ms	
75	Tilley_1982	75.1	634	RM	Evening	day1	Speed	SRT	ms	
75	Tilley_1982	75.1	634	RM	22:00-06:00	day2	Speed	SRT	ms	
75	Tilley_1982	75.1	634	RM	22:00-06:00	day3	Speed	SRT	ms	
75	Tilley_1982	75.1	634	RM	22:00-06:00	day4	Speed	SRT	ms	
75	Tilley_1982	75.1	634	RM	22:00-06:00	day5	Speed	SRT	ms	
76	Rosa_1993	76.1	1185	RM	8hr	day	Speed			
76	Rosa_1993	76.2	1185	RM	8hr	evening	Speed			
76	Rosa_1993	76.2	1185	RM	8hr	night	Speed			
76	Rosa_1993	76.2	1185	RM	12 -hr	day	Speed			
76	Rosa_1993	76.2	1185	RM	12 -hr	night	Speed			
83	Taffinder_1998	83.4	1191	RM	normal sleep		Speed	task time		
83	Taffinder_1998	83.5	1191	RM	on call - disturbed sleep		Speed	task time		
83	Taffinder_1998	83.6	1191	RM	no sleep		Speed	task time		
86	Philip_2004	86.1	107	RM		9:00	Speed	RT	ms	young
86	Philip_2004	86.2	107	RM		11:00	Speed	RT	ms	young
86	Philip_2004	86.3	107	RM		13:00	Speed	RT	ms	young
86	Philip_2004	86.4	107	RM		15:00	Speed	RT	ms	young
86	Philip_2004	86.5	107	RM		17:00	Speed	RT	ms	young
86	Philip_2004	86.6	107	RM		19:00	Speed	RT	ms	young
86	Philip_2004	86	107	RM		9:00	Speed	RT	ms	old
86	Philip_2004	86	107	RM		11:00	Speed	RT	ms	old
86	Philip_2004	86	107	RM		13:00	Speed	RT	ms	old
86	Philip_2004	86	107	RM		15:00	Speed	RT	ms	old
86	Philip_2004	86	107	RM		17:00	Speed	RT	ms	old
86	Philip_2004	86	107	RM		19:00	Speed	RT	ms	old
87	Powell_2001	87.1	890	2GC	24	s for 7 days	Speed	RT	ms	data given
90	Sharp_1988	90.1	509	RM	on call	3:30	Speed	task time	ms	read from
90	Sharp_1988	90.2	509	RM	on call	9:30	Speed	task time	ms	SST
90	Sharp_1988	90.3	509	RM	on call	15:30	Speed	task time	ms	SST
90	Sharp_1988	90.4	509	RM	on call	21:30	Speed	task time	ms	SST
90	Sharp_1988	90.5	509	RM	on call	3:30	Speed	task time	ms	VRT
90	Sharp_1988	90.6	509	RM	on call	9:30	Speed	task time	ms	VRT
90	Sharp_1988	90.7	509	RM	on call	15:30	Speed	task time	ms	VRT
90	Sharp_1988	90.8	509	RM	on call	21:30	Speed	task time	ms	VRT
90	Sharp_1988	90.9	509	RM	on call	3:30	Speed	task time	ms	USRT
90	Sharp_1988	90.1	509	RM	on call	9:30	Speed	task time	ms	USRT
90	Sharp_1988	90.11	509	RM	on call	15:30	Speed	task time	ms	USRT

Table 112: Reaction Time Raw Data Part 8b

Study Id #	N				Statistical Data										
	Control		Test		Mean		Standard Deviation		Standard Error		Mean in ms		Diff Means	Poooled Stdev	B Stdev
	Assigned	Observed	Assigned	Observed	Control	Test	Control	Test	Control	Test	Control	Test			
75	12	12	12	12		411						411	411		
75	12	12	12	12		411						411	411		
75	12	12	12	12		445						445	445		
75	12	12	12	12		438						438	438		
75	12	12	12	12		440						440	440		
75	12	12	12	12		444						444	444		
75	12	12	12	12		442						442	442		
75	12	12	12	12		255						255	255		
75	12	12	12	12		250						250	250		
75	12	12	12	12		257						257	257		
75	12	12	12	12		261						261	261		
75	12	12	12	12		260						260	260		
75	12	12	12	12		250						250	250		
75	12	12	12	12		248						248	248		
75	12	12	12	12		247						247	247		
75	12	12	12	12		246						246	246		
75	12	12	12	12		249						249	249		
75	12	12	12	12		263						263	263		
75	12	12	12	12		262						262	262		
75	12	12	12	12		272						272	272		
75	12	12	12	12		280						280	280		
75	12	12	12	12		285									
76	15	15	15	15		4.63		0.31				285	285	0.22	0.31
76	15	15	15	15		4.06		0.69				285	285	0.49	0.69
76	15	15	15	15		4.46		0.5				285	285	0.35	0.50
76	15	15	15	15		3.77		0.49				285	285	0.35	0.49
76	15	15	15	15		4.01		0.45				285	285	0.32	0.45
83	15	15	15	15	-1	-	1.161895	1.161895	0.3	0.3	**-1**	-		1.16	1.64
83	15	15	15	15	-1	-0.5	1.161895	1.161895	0.3	0.3	**-1**	**-0.5**	0.5	1.16	1.64
83	15	15	15	15	-1	0.5	1.161895	1.549193	0.3	0.4	**-1**	**0.5**	1.5	1.37	1.94
86	10	10	10	10	266.5	279	35.29102	74.53488	11.16	23.57	266.5	279	12.5	58.31	82.47
86	10	10	10	10	254	271	53.09464	93.19232	16.79	29.47	254	271	17	75.84	107.26
86	10	10	10	10	246	259	45.47355	71.81533	14.38	22.71	246	259	13	60.11	85.00
86	10	10	10	10	257	277.5	35.86023	152.6431	11.34	48.27	257	277.5	20.5	110.87	156.80
86	10	10	10	10	267	266	41.45746	88.5754	13.11	28.01	267	266	-1	69.15	97.80
86	10	10	10	10	259.5	274.5	51.67162	62.202	16.34	19.67	259.5	274.5	15	57.18	80.86
86	10	10	10	10	335	339	87.59509	103.3116	27.7	32.67	335	339	4	95.78	135.45
86	10	10	10	10	358.5	353	92.84447	126.9971	29.36	40.16	358.5	353	-5.5	111.24	157.32
86	10	10	10	10	363.5	347	98.03061	155.4892	31	49.17	363.5	347	-16.5	129.97	183.81
86	10	10	10	10	383	391	97.0503	120.3563	30.69	38.06	383	391	8	109.33	154.61
86	10	10	10	10	412.5	366	99.5485	146.034	31.48	46.18	412.5	366	-46.5	124.97	176.74
86	10	10	10	10	405	400.5	107.3593	193.4365	33.95	61.17	405	400.5	-4.5	156.43	221.23
87	8	8	8	8	60.7	60.4	77	56			60.7	60.4	-0.3	67.32	95.21
90	7	7	7	7	3450	3650	300	550			**3450**	**3650**	200	443.00	626.50
90	7	7	7	7	3200	3450	350	250			**3200**	**3450**	250	304.14	430.12
90	7	7	7	7	3250	3250	300	300			**3250**	**3250**	0	300.00	424.26
90	7	7	7	7	3050	3200	450	335			**3050**	**3200**	150	396.69	561.00
90	7	7	7	7	4300	4700	400	600			**4300**	**4700**	400	509.90	721.11
90	7	7	7	7	4150	4000	250	400			**4150**	**4000**	-150	333.54	471.70
90	7	7	7	7	3950	3950	150	450			**3950**	**3950**	0	335.41	474.34
90	7	7	7	7	3900	3950	250	500			**3900**	**3950**	50	395.28	559.02
90	7	7	7	7	352	388	18	27			352	388	36	22.95	32.45
90	7	7	7	7	325	352	7	13			325	352	27	10.44	14.76
90	7	7	7	7	325	363	10	17			325	363	38	13.95	19.72

Table 113: Reaction Time Raw Data Part 9a

Study Id #	1st Author_year	Effect Size Id #	Page #	Type of Comparison	Hours of Wakefulness	Time of Measure	Performance Var	Task Info	Calc Procedure	Var/task Info
90	Sharp_1988	90.12	509	RM	on call	21:30	Speed	task time	ms	USRT
91	Steyvers_1993	91.1	67	RM	32		Speed	reaction ti	x	
95	Sagaspe_2006	95.31	80	RM	0.5	8:00	Speed	reaction ti	sec	motor RT
95	Sagaspe_2006	95.32	80	RM	4.5	12:00	Speed	reaction ti	sec	motor RT
95	Sagaspe_2006	95.33	80	RM	8.5	16:00	Speed	reaction ti	sec	motor RT
95	Sagaspe_2006	95.34	80	RM	12.5	20:00	Speed	reaction ti	sec	motor RT
95	Sagaspe_2006	95.35	80	RM	16.5	24:00:00	Speed	reaction ti	sec	motor RT
95	Sagaspe_2006	95.36	80	RM	20.5	4:00	Speed	reaction ti	sec	motor RT
95	Sagaspe_2006	95.37	80	RM	24.5	8:00	Speed	reaction ti	sec	motor RT
95	Sagaspe_2006	95.38	80	RM	28.5	12:00	Speed	reaction ti	sec	motor RT
95	Sagaspe_2006	95.39	80	RM	32.5	16:00	Speed	reaction ti	sec	motor RT
95	Sagaspe_2006	95.4	80	RM	12	8:00	Speed	reaction ti	sec	motor RT
95	Sagaspe_2006	95.41	80	RM	12	12:00	Speed	reaction ti	sec	motor RT
95	Sagaspe_2006	95.42	80	RM	12	16:00	Speed	reaction ti	sec	motor RT
96	Scott_2006	96.1	400	RM	2	30 hrs total	Speed	RT	ms	SRT
96	Scott_2006	96.2	400	RM	6		Speed	RT	ms	SRT
96	Scott_2006	96.3	400	RM	10		Speed	RT	ms	SRT
96	Scott_2006	96.4	400	RM	14		Speed	RT	ms	SRT
96	Scott_2006	96.5	400	RM	18		Speed	RT	ms	SRT
96	Scott_2006	96.6	400	RM	22		Speed	RT	ms	SRT
96	Scott_2006	96.7	400	RM	26		Speed	RT	ms	SRT
96	Scott_2006	96.8	400	RM	30		Speed	RT	ms	SRT
96	Scott_2006	96.9	400	RM	2		Speed	RT	ms	2-CRT
96	Scott_2006	96.1	400	RM	6		Speed	RT	ms	2-CRT
96	Scott_2006	96.11	400	RM	10		Speed	RT	ms	2-CRT
96	Scott_2006	96.12	400	RM	14		Speed	RT	ms	2-CRT
96	Scott_2006	96.13	400	RM	18		Speed	RT	ms	2-CRT
96	Scott_2006	96.14	400	RM	22		Speed	RT	ms	2-CRT
96	Scott_2006	96.15	400	RM	26		Speed	RT	ms	2-CRT
96	Scott_2006	96.16	400	RM	30		Speed	RT	ms	2-CRT
96	Scott_2006	96.17	400	RM	2		Speed	RT	ms	NCT
96	Scott_2006	96.18	400	RM	6		Speed	RT	ms	NCT
96	Scott_2006	96.19	400	RM	10		Speed	RT	ms	NCT
96	Scott_2006	96.2	400	RM	14		Speed	RT	ms	NCT
96	Scott_2006	96.21	400	RM	18		Speed	RT	ms	NCT
96	Scott_2006	96.22	400	RM	22		Speed	RT	ms	NCT
96	Scott_2006	96.23	400	RM	26		Speed	RT	ms	NCT
96	Scott_2006	96.24	400	RM	30		Speed	RT	ms	NCT
97	Venkatraman_2007	97.1	606	RM	24		Speed	RT	ms	certain/low
97	Venkatraman_2007	97.2	606	RM	24		Speed	RT	ms	certain/low
97	Venkatraman_2007	97.3	606	RM	24		Speed	RT	ms	low/high
97	Venkatraman_2007	97.4	606	RM	24		Speed	RT	ms	low/high
98	Dinges_1988	98.1	366	RM	baseline		Speed	VRT	ms	VRT
98	Dinges_1988	98.2	366	RM	baseline		Speed	VRT	ms	VRT
98	Dinges_1988	98.3	366	RM	5.5	22:30	Speed	VRT	ms	VRT
98	Dinges_1988	98.4	366	RM	8	1:00	Speed	VRT	ms	VRT
98	Dinges_1988	98.5	366	RM	10.5	3:30	Speed	VRT	ms	VRT
98	Dinges_1988	98.6	366	RM	13	6:00	Speed	VRT	ms	VRT
98	Dinges_1988	98.7	366	RM	15.5	8:30	Speed	VRT	ms	VRT
98	Dinges_1988	98.8	366	RM	18	11:00	Speed	VRT	ms	VRT
98	Dinges_1988	98.9	366	RM	20.5	13:30	Speed	VRT	ms	VRT
98	Dinges_1988	98.10	366	RM	23	16:00	Speed	VRT	ms	VRT
98	Dinges_1988	98.11	366	RM	25.5	18:30	Speed	VRT	ms	VRT
98	Dinges_1988	98.12	366	RM	28	21:00	Speed	VRT	ms	VRT

Table 114: Reaction Time Raw Data Part 9b

Study	N				Statistical Data										
	Control		Test		Mean		Standard Deviation		Standard Error		Mean in ms		Diff	Poooled	
Id #	Assigned	Observed	Assigned	Observed	Control	Test	Control	Test	Control	Test	Control	Test	Means	Stdev	B Stdev
90	7	7	7	7	329	353	11	17			329	353	24	14.32	20.25
91	16	16	16	16									0		
95	12	12	12	12		300		30				300	300	21.21	30.00
95	12	12	12	12		290		30				290	290	21.21	30.00
95	12	12	12	12		300		30				300	300	21.21	30.00
95	12	12	12	12		280		35				280	280	24.75	35.00
95	12	12	12	12		310		55				310	310	38.89	55.00
95	12	12	12	12		385		115				385	385	81.32	115.00
95	12	12	12	12		475		150				475	475	106.07	150.00
95	12	12	12	12		430		140				430	430	98.99	140.00
95	12	12	12	12		395		85				395	395	60.10	85.00
95	12	12	12	12	290.2	394.7					290.2	394.7	104.5	0.00	0.00
95	12	12	12	12	285.8	369.5					285.8	369.5	83.7	0.00	0.00
95	12	12	12	12	298.4	355.4					298.4	355.4	57	0.00	0.00
96	6	6	3	3	260	258	19.8	27.4			260	258	-2	22.24	33.81
96	6	6	3	3	251	258	17.9	22.1			251	258	7	19.19	28.44
96	6	6	3	3	257	268	19.3	36.4			257	268	11	25.39	41.20
96	6	6	3	3	265	262	21.1	25.1			265	262	-3	22.32	32.79
96	6	6	3	3		258		14.7				258	258	7.86	14.70
96	6	6	3	3		266		20.5				266	266	10.96	20.50
96	6	6	3	3		287		54.9				287	287	29.35	54.90
96	6	6	3	3		290		51.5				290	290	27.53	51.50
96	6	6	3	3	381	359	39.8	32.6			381	359	-22	37.88	51.45
96	6	6	3	3	383	372	31.5	37.4			383	372	-11	33.29	48.90
96	6	6	3	3	375	377	29	39.8			375	377	2	32.45	49.24
96	6	6	3	3	380	365	32.4	40			380	365	-15	34.74	51.48
96	6	6	3	3		371		35.8				371	371	19.14	35.80
96	6	6	3	3		375		34.5				375	375	18.44	34.50
96	6	6	3	3		397		38.3				397	397	20.47	38.30
96	6	6	3	3		375		27.6				375	375	14.75	27.60
96	6	6	3	3	8.5	6.4	2.4	1.6			8.5	6.4	-2.1	2.20	2.88
96	6	6	3	3	8.2	6.4	2.9	2.1			8.2	6.4	-1.8	2.70	3.58
96	6	6	3	3	7.8	6.5	1.7	2.3			7.8	6.5	-1.3	1.89	2.86
96	6	6	3	3	7.8	6.6	2.1	1.8			7.8	6.6	-1.2	2.02	2.77
96	6	6	3	3		5.7		1.8				5.7	5.7	0.96	1.80
96	6	6	3	3		6.2		1.9				6.2	6.2	1.02	1.90
96	6	6	3	3		6.2		2.1				6.2	6.2	1.12	2.10
96	6	6	3	3		6.3		2.4				6.3	6.3	1.28	2.40
97	26	26	26	26	1660	1827	1845.845	1988.618	362	390	1660	1827	167	1918.56	2713.25
97	26	26	26	26	1509	1636	1947.825	2314.955	382	454	1509	1636	127	2139.28	3025.40
97	26	26	26	26	1745	1777	2248.668	2304.757	441	452	1745	1777	32	2276.88	3220.00
97	26	26	26	26	1821	1946	2641.292	2896.243	518	568	1821	1946	125	2771.70	3919.78
98	17	17	17	17	185	-	4	-			185	185	0		
98	17	17	17	17	187	-	3	-			187	187	0		
98	17	17	17	17	186	189	3.5	3.5			186	189	3	3.50	4.95
98	17	17	17	17	186	190	3.5	5			186	190	4	4.32	6.10
98	17	17	17	17	186	190.5	3.5	4			186	190.5	4.5	3.76	5.32
98	17	17	17	17	186	195	3.5	3			186	195	9	3.26	4.61
98	17	17	17	17	186	204	3.5	5			186	204	18	4.32	6.10
98	17	17	17	17	186	206	3.5	4.5			186	206	20	4.03	5.70
98	17	17	17	17	186	203	3.5	4			186	203	17	3.76	5.32
98	17	17	17	17	186	200.5	3.5	4			186	200.5	14.5	3.76	5.32
98	17	17	17	17	186	197	3.5	4			186	197	11	3.76	5.32
98	17	17	17	17	186	196	3.5	4.5			186	196	10	4.03	5.70

Table 115: Reaction Time Raw Data Part 10a

Study Id #	1st Author_year	Effect Size Id #	Page #	Type of Comparison	Hours of Wakefulness	Time of Measure	Performance Var	Task Info	Calc Procedure	Var/task Info
98	Dinges_1988	98.13	366	RM	30.5	23:30	Speed	VRT	ms	VRT
98	Dinges_1988	98.14	366	RM	33	2:00	Speed	VRT	ms	VRT
98	Dinges_1988	98.15	366	RM	42	11:00	Speed	VRT	ms	VRT
98	Dinges_1988	98.16	366	RM	48	17:00	Speed	VRT	ms	VRT
98	Dinges_1988	98.17	366	RM	54	23:00	Speed	VRT	ms	VRT
98	Dinges_1988	98.18	366	RM	baseline		Speed	ART	ms	ART
98	Dinges_1988	98.19	366	RM	baseline		Speed	ART	ms	ART
98	Dinges_1988	98.20	366	RM	5.5	22:30	Speed	ART	ms	ART
98	Dinges_1988	98.21	366	RM	8	1:00	Speed	ART	ms	ART
98	Dinges_1988	98.22	366	RM	10.5	3:30	Speed	ART	ms	ART
98	Dinges_1988	98.23	366	RM	13	6:00	Speed	ART	ms	ART
98	Dinges_1988	98.24	366	RM	15.5	8:30	Speed	ART	ms	ART
98	Dinges_1988	98.25	366	RM	18	11:00	Speed	ART	ms	ART
98	Dinges_1988	98.26	366	RM	20.5	13:30	Speed	ART	ms	ART
98	Dinges_1988	98.27	366	RM	23	16:00	Speed	ART	ms	ART
98	Dinges_1988	98.28	366	RM	25.5	18:30	Speed	ART	ms	ART
98	Dinges_1988	98.29	366	RM	28	21:00	Speed	ART	ms	ART
98	Dinges_1988	98.30	366	RM	30.5	23:30	Speed	ART	ms	ART
98	Dinges_1988	98.31	366	RM	33	2:00	Speed	ART	ms	ART
98	Dinges_1988	98.32	366	RM	42	11:00	Speed	ART	ms	ART
98	Dinges_1988	98.33	366	RM	48	17:00	Speed	ART	ms	ART
98	Dinges_1988	98.34	366	RM	54	23:00	Speed	ART	ms	ART
100	Lieberman_2005	100.1	425	RM	77	18:00, 12:00	Speed	RT	ms	4CRT -RT
100	Lieberman_2005	100.1	425	RM	94	18:00, 05:00	Speed	RT	ms	4CRT -RT
100	Lieberman_2005	100.7	425	RM	77	18:00, 12:03	Speed	RT	sec	Vis Vig - I
100	Lieberman_2005	100.8	425	RM	94	18:00, 05:03	Speed	RT	sec	Vis Vig - I
100	Lieberman_2005	100.11	425	RM	77	18:00, 12:05	Speed	RT	sec	Gram Reas
100	Lieberman_2005	100.12	425	RM	94	18:00, 05:05	Speed	RT	sec	Gram Reas
101	Lamond_1999	101.1	260	RM	3	10:00	Speed	mean relative performan		gram reaso
101	Lamond_1999	101.2	260	RM	5	12:00	Speed	mean relative performan		gram reaso
101	Lamond_1999	101.3	260	RM	7	14:00	Speed	mean relative performan		gram reaso
101	Lamond_1999	101.4	260	RM	9	16:00	Speed	mean relative performan		gram reaso
101	Lamond_1999	101.5	260	RM	11	18:00	Speed	mean relative performan		gram reaso
101	Lamond_1999	101.6	260	RM	13	20:00	Speed	mean relative performan		gram reaso
101	Lamond_1999	101.7	260	RM	15	22:00	Speed	mean relative performan		gram reaso
101	Lamond_1999	101.8	260	RM	17	24:00:00	Speed	mean relative performan		gram reaso
101	Lamond_1999	101.9	260	RM	19	2:00	Speed	mean relative performan		gram reaso
101	Lamond_1999	101.10	260	RM	21	4:00	Speed	mean relative performan		gram reaso
101	Lamond_1999	101.11	260	RM	23	6:00	Speed	mean relative performan		gram reaso
101	Lamond_1999	101.12	260	RM	25	8:00	Speed	mean relative performan		gram reaso
101	Lamond_1999	101.13	260	RM	27	10:00	Speed	mean relative performan		gram reaso
101	Lamond_1999	101.14	260	RM	29	12:00	Speed	mean relative performan		gram accu
101	Lamond_1999	101.15	260	RM	3	10:00	Speed	mean relative performan		Vig -latenc
101	Lamond_1999	101.16	260	RM	5	12:00	Speed	mean relative performan		Vig -latenc
101	Lamond_1999	101.17	260	RM	7	14:00	Speed	mean relative performan		Vig -latenc
101	Lamond_1999	101.18	260	RM	9	16:00	Speed	mean relative performan		Vig -latenc
101	Lamond_1999	101.19	260	RM	11	18:00	Speed	mean relative performan		Vig -latenc
101	Lamond_1999	101.20	260	RM	13	20:00	Speed	mean relative performan		Vig -latenc
101	Lamond_1999	101.21	260	RM	15	22:00	Speed	mean relative performan		Vig -latenc
101	Lamond_1999	101.22	260	RM	17	24:00:00	Speed	mean relative performan		Vig -latenc
101	Lamond_1999	101.23	260	RM	19	2:00	Speed	mean relative performan		Vig -latenc
101	Lamond_1999	101.24	260	RM	21	4:00	Speed	mean relative performan		Vig -latenc
101	Lamond_1999	101.25	260	RM	23	6:00	Speed	mean relative performan		Vig -latenc
101	Lamond_1999	101.26	260	RM	25	8:00	Speed	mean relative performan		Vig -latenc

Table 116: Reaction Time Raw Data Part 10b

Study Id #	N				Statistical Data										
	Control		Test		Mean		Standard Deviation		Standard Error		Mean in ms		Diff Means	Poooled Stdev	B Stdev
	Assigned	Observed	Assigned	Observed	Control	Test	Control	Test	Control	Test	Control	Test			
98	17	17	17	17	186	205	3.5	0.25			186	205	19	2.48	3.51
98	17	17	17	17	186	222	3.5	3.5			186	222	36	3.50	4.95
98	17	17	17	17	186	225	3.5	5.5			186	225	39	4.61	6.52
98	17	17	17	17	186	215.5	3.5	5			186	215.5	29.5	4.32	6.10
98	17	17	17	17	186	210	3.5	4.5			186	210	24	4.03	5.70
98	17	17	17	17	151	-	5.5	-			151	151			
98	17	17	17	17	149	-	4	-			149	149			
98	17	17	17	17	150	150.5	4.75	5			150	150.5	0.5	4.88	6.90
98	17	17	17	17	150	148	4.75	5			150	148	-2	4.88	6.90
98	17	17	17	17	150	152	4.75	3			150	152	2	3.97	5.62
98	17	17	17	17	150	156	4.75	4			150	156	6	4.39	6.21
98	17	17	17	17	150	159	4.75	6			150	159	9	5.41	7.65
98	17	17	17	17	150	155	4.75	4			150	155	5	4.39	6.21
98	17	17	17	17	150	156	4.75	4.5			150	156	6	4.63	6.54
98	17	17	17	17	150	156.5	4.75	3.5			150	156.5	6.5	4.17	5.90
98	17	17	17	17	150	154.5	4.75	3.5			150	154.5	4.5	4.17	5.90
98	17	17	17	17	150	154.5	4.75	5			150	154.5	4.5	4.88	6.90
98	17	17	17	17	150	167.5	4.75	3.5			150	167.5	17.5	4.17	5.90
98	17	17	17	17	150	170.5	4.75	6			150	170.5	20.5	5.41	7.65
98	17	17	17	17	150	172	4.75	6.5			150	172	22	5.69	8.05
98	17	17	17	17											
98	17	17	17	17											
100	31	31	31	31	522.7	580.4	83.51647	146.989	15	26.4	522.7	580.4	57.7	119.54	169.06
100	31	31	31	31	522.7	624.8	83.51647	93.53844	15	16.8	522.7	624.8	102.1	88.67	125.40
100	31	31	31	31	0.9	1.1	0.556776	0.556776	0.1	0.1	0.9	1.1	0.2	0.56	0.79
100	31	31	31	31	0.9	1.1	0.556776	0.556776	0.1	0.1	0.9	1.1	0.2	0.56	0.79
100	31	31	31	31	3.9	4.1	1.113553	1.113553	0.2	0.2	3.9	4.1	0.2	1.11	1.57
100	31	31	31	31	3.9	3.5	1.113553	1.670329	0.2	0.3	3.9	3.5	-0.4	1.42	2.01
101	22	22	22	22		0		3.25				0	0	2.30	3.25
101	22	22	22	22		-0.75		4.5				-0.75	-0.75	3.18	4.50
101	22	22	22	22		1		3.25				1	1	2.30	3.25
101	22	22	22	22		1		3.5				1	1	2.47	3.50
101	22	22	22	22		2		3				2	2	2.12	3.00
101	22	22	22	22		3.5		3.25				3.5	3.5	2.30	3.25
101	22	22	22	22		-0.2		3.5				-0.2	-0.2	2.47	3.50
101	22	22	22	22		-0.2		4.5				-0.2	-0.2	3.18	4.50
101	22	22	22	22		-7		2.75				-7	-7	1.94	2.75
101	22	22	22	22		-10		3				-10	-10	2.12	3.00
101	22	22	22	22		-14.9		5				-14.9	-14.9	3.54	5.00
101	22	22	22	22		-25		6.5				-25	-25	4.60	6.50
101	22	22	22	22		-25		7.25				-25	-25	5.13	7.25
101	22	22	22	22		-13.5		-4.25				-13.5	-13.5	3.01	4.25
101	22	22	22	22		0		0.75				0	0	0.53	0.75
101	22	22	22	22		-0.5		1				-0.5	-0.5	0.71	1.00
101	22	22	22	22		-1		1.5				-1	-1	1.06	1.50
101	22	22	22	22		-2.2		1				-2.2	-2.2	0.71	1.00
101	22	22	22	22		-2.2		1				-2.2	-2.2	0.71	1.00
101	22	22	22	22		-2.4		1				-2.4	-2.4	0.71	1.00
101	22	22	22	22		-1.75		1.7				-1.75	-1.75	1.20	1.70
101	22	22	22	22		-2.5		1				-2.5	-2.5	0.71	1.00
101	22	22	22	22		-7.2		1.5				-7.2	-7.2	1.06	1.50
101	22	22	22	22		-11		1.625				-11	-11	1.15	1.63
101	22	22	22	22		-15		-2.5				-15	-15	1.77	2.50
101	22	22	22	22		-21.5		1.875				-21.5	-21.5	1.33	1.88

Table 117: Reaction Time Raw Data Part 11a

Study Id #	1st Author_year	Effect Size Id #	Page #	Type of Comparison	Hours of Wakefulness	Time of Measure	Performance Var	Task Info	Calc Procedure	Var/task Info
101	Lamond_1999	101.27	260	RM	27	10:00	Speed	mean relative performance		Vig -latenc
101	Lamond_1999	101.28	260	RM	29	12:00	Speed	mean relative performance		Vig -latenc
102	Thorne_2005	102.1	116	RM	1.67	9:00	Speed	% relative Speed		
102	Thorne_2005	102.2	116	RM	4	11:20	Speed	% relative Speed		
102	Thorne_2005	102.3	116	RM	5.67	13:00	Speed	% relative Speed		
102	Thorne_2005	102.4	116	RM	8	15:20	Speed	% relative Speed		
102	Thorne_2005	102.5	116	RM	9.67	17:00	Speed	% relative Speed		
102	Thorne_2005	102.6	116	RM	12	19:20	Speed	% relative Speed		
102	Thorne_2005	102.7	116	RM	13.67	21:00	Speed	% relative Speed		
102	Thorne_2005	102.8	116	RM	16	23:20	Speed	% relative Speed		
102	Thorne_2005	102.9	116	RM	17.67	1:00	Speed	% relative Speed		
102	Thorne_2005	102.10	116	RM	20	3:20	Speed	% relative Speed		
102	Thorne_2005	102.11	116	RM	21.67	5:00	Speed	% relative Speed		
102	Thorne_2005	102.12	116	RM	24	7:20	Speed	% relative Speed		
102	Thorne_2005	102.13	116	RM	25.67	9:00	Speed	% relative Speed		
102	Thorne_2005	102.14	116	RM	28	11:20	Speed	% relative Speed		
102	Thorne_2005	102.15	116	RM	29.67	13:00	Speed	% relative Speed		
102	Thorne_2005	102.16	116	RM	32	15:20	Speed	% relative Speed		
102	Thorne_2005	102.17	116	RM	33.67	17:00	Speed	% relative Speed		
102	Thorne_2005	102.18	116	RM	36	19:20	Speed	% relative Speed		
102	Thorne_2005	102.19	116	RM	37.33	21:00	Speed	% relative Speed		
102	Thorne_2005	102.20	116	RM	40	23:20	Speed	% relative Speed		
103	Doran_2001	103.1	257	baseline co	0	8:00	Speed	RT	ms	
103	Doran_2001	103.2	257	baseline co	2	10:00	Speed	RT	ms	
103	Doran_2001	103.3	257	baseline co	4	12:00	Speed	RT	ms	
103	Doran_2001	103.4	257	baseline co	6	14:00	Speed	RT	ms	
103	Doran_2001	103.5	257	baseline co	8	16:00	Speed	RT	ms	
103	Doran_2001	103.6	257	baseline co	10	18:00	Speed	RT	ms	
103	Doran_2001	103.7	257	baseline co	12	20:00	Speed	RT	ms	
103	Doran_2001	103.8	257	baseline co	14	22:00	Speed	RT	ms	
103	Doran_2001	103.9	257	baseline co	16	24:00:00	Speed	RT	ms	
103	Doran_2001	103.10	257	baseline co	18	2:00	Speed	RT	ms	
103	Doran_2001	103.11	257	baseline co	20	4:00	Speed	RT	ms	
103	Doran_2001	103.12	257	baseline co	22	6:00	Speed	RT	ms	
103	Doran_2001	103.13	257	baseline co	24	8:00	Speed	RT	ms	
103	Doran_2001	103.14	257	baseline co	26	10:00	Speed	RT	ms	
103	Doran_2001	103.15	257	baseline co	28	12:00	Speed	RT	ms	
103	Doran_2001	103.16	257	baseline co	30	14:00	Speed	RT	ms	
103	Doran_2001	103.17	257	baseline co	32	16:00	Speed	RT	ms	
103	Doran_2001	103.18	257	baseline co	34	18:00	Speed	RT	ms	
103	Doran_2001	103.19	257	baseline co	36	20:00	Speed	RT	ms	
103	Doran_2001	103.20	257	baseline co	38	22:00	Speed	RT	ms	
103	Doran_2001	103.21	257	baseline co	40	24:00:00	Speed	RT	ms	
103	Doran_2001	103.22	257	baseline co	42	2:00	Speed	RT	ms	
103	Doran_2001	103.23	257	baseline co	44	4:00	Speed	RT	ms	
103	Doran_2001	103.24	257	baseline co	46	6:00	Speed	RT	ms	
103	Doran_2001	103.25	257	baseline co	48	8:00	Speed	RT	ms	
103	Doran_2001	103.26	257	baseline co	50	10:00	Speed	RT	ms	
103	Doran_2001	103.27	257	baseline co	52	12:00	Speed	RT	ms	
103	Doran_2001	103.28	257	baseline co	54	14:00	Speed	RT	ms	
103	Doran_2001	103.29	257	baseline co	56	16:00	Speed	RT	ms	
103	Doran_2001	103.30	257	baseline co	58	18:00	Speed	RT	ms	
103	Doran_2001	103.31	257	baseline co	60	20:00	Speed	RT	ms	
103	Doran_2001	103.32	257	baseline co	62	22:00	Speed	RT	ms	

Table 118: Reaction Time Raw Data Part 11b

Study	N				Statistical Data										
	Control		Test		Mean		Standard Deviation		Standard Error		Mean in ms			Poooled	
Id #	Assigned	Observed	Assigned	Observed	Control	Test	Control	Test	Control	Test	Control	Test	Diff Means	Stdev	B Stdev
101	22	22	22	22		-21		2.5				-21	-21	1.77	2.50
101	22	22	22	22		-10.5		-0.5				-10.5	-10.5	0.35	0.50
102	12	12	12	12	3.472	3.747208					288.045		-288.045		
102	12	12	12	12	3.472	3.475729					288.045		-288.045		
102	12	12	12	12	3.472	3.599742					288.045		-288.045		
102	12	12	12	12	3.472	3.23474									
102	12	12	12	12	3.472	3.418952									
102	12	12	12	12	3.472	3.507176									
102	12	12	12	12	3.472	3.588339									
102	12	12	12	12	3.472	3.04147									
102	12	12	12	12	3.472	3.306906									
102	12	12	12	12	3.472	2.231129									
102	12	12	12	12	3.472	2.589535									
102	12	12	12	12	3.472	1.221086									
102	12	12	12	12	3.472	2.656454									
102	12	12	12	12	3.472	2.215323									
102	12	12	12	12	3.472	3.01407									
102	12	12	12	12	3.472	2.661258									
102	12	12	12	12	3.472	3.095616									
102	12	12	12	12	3.472	3.049183									
102	12	12	12	12	3.472	3.296757									
102	12	12	12	12	3.472	2.750367									
103	15	15	13	13	315	315	450.7	450.7	125	125	315	315	0	450.69	637.38
103	15	15	13	13	315	375	450.7	450.7	125	125	315	375	60	450.69	637.38
103	15	15	13	13	315	310	450.7	450.7	125	125	315	310	-5	450.69	637.38
103	15	15	13	13	315	495	450.7	901.4	125	250	315	495	180	695.97	1007.78
103	15	15	13	13	315	315	450.7	450.7	125	125	315	315	0	450.69	637.38
103	15	15	13	13	315	300	450.7	450.7	125	125	315	300	-15	450.69	637.38
103	15	15	13	13	315	290	450.7	450.7	125	125	315	290	-25	450.69	637.38
103	15	15	13	13	315	300	450.7	450.7	125	125	315	300	-15	450.69	637.38
103	15	15	13	13	315	330	450.7	450.7	125	125	315	330	15	450.69	637.38
103	15	15	13	13	315	440	450.7	811.2	125	225	315	440	125	642.75	928.04
103	15	15	13	13	315	600	450.7	811.2	125	225	315	600	285	642.75	928.04
103	15	15	13	13	315	1125	450.7	2704.2	125	750	315	1125	810	1866.65	2741.46
103	15	15	13	13	315	1450	450.7	2704.2	125	750	315	1450	1135	1866.65	2741.46
103	15	15	13	13	315	1500	450.7	3605.6	125	1000	315	1500	1185	2471.71	3633.61
103	15	15	13	13	315	640	450.7	1153.8	125	320	315	640	325	850.75	1238.68
103	15	15	13	13	315	940	450.7	2523.9	125	700	315	940	625	1746.25	2563.81
103	15	15	13	13	315	825	450.7	2704.2	125	750	315	825	510	1866.65	2741.46
103	15	15	13	13	315	550	450.7	721.1	125	200	315	550	235	591.08	850.37
103	15	15	13	13	315	390	450.7	2794.3	125	775	315	390	75	1926.95	2830.42
103	15	15	13	13	315	875	450.7	2884.4	125	800	315	875	560	1987.30	2919.44
103	15	15	13	13	315	575	450.7	1153.8	125	320	315	575	260	850.75	1238.68
103	15	15	13	13	315	1375	450.7	2794.3	125	775	315	1375	1060	1926.95	2830.42
103	15	15	13	13	315	1550	450.7	2884.4	125	800	315	1550	1235	1987.30	2919.44
103	15	15	13	13	315	1875	450.7	4957.6	125	1375	315	1875	1560	3384.25	4978.08
103	15	15	13	13	315	1250	450.7	2451.8	125	680	315	1250	935	1698.17	2492.85
103	15	15	13	13	315	1450	450.7	3154.9	125	875	315	1450	1135	2168.67	3186.89
103	15	15	13	13	315	1400	450.7	1983.1	125	550	315	1400	1085	1387.22	2033.62
103	15	15	13	13	315	1050	450.7	1802.8	125	500	315	1050	735	1268.61	1858.26
103	15	15	13	13	315	1425	450.7	3785.8	125	1050	315	1425	1110	2593.14	3812.56
103	15	15	13	13	315	1125	450.7	2704.2	125	750	315	1125	810	1866.65	2741.46
103	15	15	13	13	315	875	450.7	1532.4	125	425	315	875	560	1092.30	1597.26
103	15	15	13	13	315	1125	450.7	3335.1	125	925	315	1125	810	2289.79	3365.45

Table 119: Reaction Time Raw Data Part 12a

Study Id #	1st Author_year	Effect Size Id #	Page #	Type of Comparison	Hours of Wakefulness	Time of Measure	Performance Var	Task Info	Calc Procedure	Var/task Info
103	Doran_2001	103.32	257	baseline co	64	24:00:00	Speed	RT	ms	
103	Doran_2001	103.33	257	baseline co	66	2:00	Speed	RT	ms	
103	Doran_2001	103.34	257	baseline co	68	4:00	Speed	RT	ms	
103	Doran_2001	103.35	257	baseline co	70	6:00	Speed	RT	ms	
103	Doran_2001	103.36	257	baseline co	72	8:00	Speed	RT	ms	
103	Doran_2001	103.37	257	baseline co	74	10:00	Speed	RT	ms	
103	Doran_2001	103.38	257	baseline co	76	12:00	Speed	RT	ms	
103	Doran_2001	103.39	257	baseline co	78	14:00	Speed	RT	ms	
103	Doran_2001	103.40	257	baseline co	80	16:00	Speed	RT	ms	
103	Doran_2001	103.41	257	baseline co	82	18:00	Speed	RT	ms	
103	Doran_2001	103.42	257	baseline co	84	20:00	Speed	RT	ms	
103	Doran_2001	103.43	257	baseline co	86	22:00	Speed	RT	ms	
104	Wesenten_2005	104.1	260	baseline to	41		Speed	1/RT* 1000	ms	PVT
104	Wesenten_2005	104.2	260	baseline to	43		Speed	1/RT* 1000	ms	PVT
104	Wesenten_2005	104.3	260	baseline to	45		Speed	1/RT* 1000	ms	PVT
104	Wesenten_2005	104.4	260	baseline to	47	24:00:00	Speed	1/RT* 1000	ms	PVT
104	Wesenten_2005	104.5	260	baseline to	49	2:00	Speed	1/RT* 1000	ms	PVT
104	Wesenten_2005	104.6	260	baseline to	51	4:00	Speed	1/RT* 1000	ms	PVT
104	Wesenten_2005	104.7	260	baseline to	53	6:00	Speed	1/RT* 1000	ms	PVT
104	Wesenten_2005	104.8	260	baseline to	55	8:00	Speed	1/RT* 1000	ms	PVT
104	Wesenten_2005	104.9	260	baseline to	57	10:00	Speed	1/RT* 1000	ms	PVT
104	Wesenten_2005	104.10	260	baseline to	59	12:00	Speed	1/RT* 1000	ms	PVT
104	Wesenten_2005	104.11	260	baseline to	61	14:00	Speed	1/RT* 1000	ms	PVT
104	Wesenten_2005	104.12	260	baseline to	63	16:00	Speed	1/RT* 1000	ms	PVT
104	Wesenten_2005	104.13	260	baseline to	65	18:00	Speed	1/RT* 1000	ms	PVT
104	Wesenten_2005	104.14	260	baseline to	67	20:00	Speed	1/RT* 1000	ms	PVT
104	Wesenten_2005	104.15	260	baseline to	69	22:00	Speed	1/RT* 1000	ms	PVT
104	Wesenten_2005	104.16	260	baseline to	71	24:00:00	Speed	1/RT* 1000	ms	PVT
104	Wesenten_2005	104.17	260	baseline to	73	2:00	Speed	1/RT* 1000	ms	PVT
104	Wesenten_2005	104.18	260	baseline to	75	4:00	Speed	1/RT* 1000	ms	PVT
104	Wesenten_2005	104.19	260	baseline to	77	6:00	Speed	1/RT* 1000	ms	PVT
104	Wesenten_2005	104.20	260	baseline to	79	8:00	Speed	1/RT* 1000	ms	PVT
104	Wesenten_2005	104.21	260	baseline to	81	10:00	Speed	1/RT* 1000	ms	PVT
104	Wesenten_2006	104.22	260	baseline to	83	12:00	Speed	1/RT* 1000	ms	PVT
105	Jewett_1999	105.1	175	2GC	26	14:00	Speed	1/RT* 1000	ms	median rea
105	Jewett_1999	105.2	175	2GC	26	16:00	Speed	1/RT* 1000	ms	optimum re
105	Jewett_1999	105.3	175	2GC	26	17:00	Speed	1/RT* 1001	ms	slowest rea
106	Drake_2001	106.1	982	RM	36	10:00	Speed	median RT	ms	PVT

Table 120: Reaction Time Raw Data Part 12b

Study Id #	N				Statistical Data										
	Control		Test		Mean		Standard Deviation		Standard Error		Mean in ms			Poooled	
	Assigned	Observed	Assigned	Observed	Control	Test	Control	Test	Control	Test	Control	Test	Diff Mean	Stdev	B Stdev
103	15	15	13	13	315	1380	450.7	4506.9	125	1250	315	1380	1065	3079.67	4529.42
103	15	15	13	13	315	1500	450.7	4723.3	125	1310	315	1500	1185	3225.83	4744.73
103	15	15	13	13	315	2300	450.7	4506.9	125	1250	315	2300	1985	3079.67	4529.42
103	15	15	13	13	315	2125	450.7	4056.2	125	1125	315	2125	1810	2775.45	4081.21
103	15	15	13	13	315	2125	450.7	5408.3	125	1500	315	2125	1810	3689.09	5427.07
103	15	15	13	13	315	1400	450.7	2704.2	125	750	315	1400	1085	1866.65	2741.46
103	15	15	13	13	315	1450	450.7	2704.2	125	750	315	1450	1135	1866.65	2741.46
103	15	15	13	13	315	1250	450.7	2704.2	125	750	315	1250	935	1866.65	2741.46
103	15	15	13	13	315	1300	450.7	2433.7	125	675	315	1300	985	1686.16	2475.13
103	15	15	13	13	315	1000	450.7	1892.9	125	525	315	1000	685	1327.83	1945.83
103	15	15	13	13	315	1600	450.7	2884.4	125	800	315	1600	1285	1987.30	2919.44
103	15	15	13	13	315	1125	450.7	2091.2	125	580	315	1125	810	1458.69	2139.23
104	12	12	12	12		*2.6*		0.6928203		*0.2*		384.61538	384.61538	0.49	0.69
104	12	12	12	12		*2.3*		0.6928203		*0.2*		434.78261	434.78261	0.49	0.69
104	12	12	12	12		*2*		1.0392305		*0.3*		500	500	0.73	1.04
104	12	12	12	12		*1.7*		1.0392305		*0.3*		588.23529	588.23529	0.73	1.04
104	12	12	12	12		*1.9*		1.0392305		*0.3*		526.31579	526.31579	0.73	1.04
104	12	12	12	12		*1.85*		1.0392305		*0.3*		540.54054	540.54054	0.73	1.04
104	12	12	12	12		*2.4*		0.6928203		*0.2*		416.66667	416.66667	0.49	0.69
104	12	12	12	12		*2.5*		0.6928203		*0.2*		400	400	0.49	0.69
104	12	12	12	12		*2.4*		0.6928203		*0.2*		416.66667	416.66667	0.49	0.69
104	12	12	12	12		*2.5*		1.0392305		*0.3*		400	400	0.73	1.04
104	12	12	12	12		*2.6*		1.0392305		*0.3*		384.61538	384.61538	0.73	1.04
104	12	12	12	12		*2.8*		0.6928203		*0.2*		357.14286	357.14286	0.49	0.69
104	12	12	12	12		*2.7*		0.6928203		*0.2*		370.37037	370.37037	0.49	0.69
104	12	12	12	12		*2.3*		1.0392305		*0.3*		434.78261	434.78261	0.73	1.04
104	12	12	12	12		*1.8*		1.0392305		*0.3*		555.55556	555.55556	0.73	1.04
104	12	12	12	12		*1.7*		1.0392305		*0.3*		588.23529	588.23529	0.73	1.04
104	12	12	12	12		*2.1*		1.3856406		*0.4*		476.19048	476.19048	0.98	1.39
104	12	12	12	12		*2.1*		1.3856406		*0.4*		476.19048	476.19048	0.98	1.39
104	12	12	12	12		*1.85*		1.0392305		*0.3*		540.54054	540.54054	0.73	1.04
104	12	12	12	12		*2.5*		0.6928203		*0.2*		400	400	0.49	0.69
104	12	12	12	12		*2.6*		0.6928203		*0.2*		384.61538	384.61538	0.49	0.69
104	12	12	12	12		*2.85*		1.0392305		*0.3*		350.87719	350.87719	0.73	1.04
105	32	32	25	25	235	305	62.225397	90	11	*18*	235	305	70	75.61	109.42
105	32	32	25	25	192	215	11.313708	15	*2*	3	192	215	23	13.05	18.79
105	32	32	25	25	*2.9*	1.6	5.6568542	7.5	*1*	1.5	344.83	**625**	280.17241	6.53	9.39
106	28	12	28	12	266.3	310.07	54.01	68.9			266.3	310.07	43.77	61.90	87.55

Table 121: Percentage of Error Raw Data Part 1a

Study Id #	1st Author_year	Effect Size Id #	Page #	Type of Comparison	Hours of Wakefulness	Time of Measure	Performance Var	Task Info	Calc Procedure	Var/task Info
14	Buck_1972	14.9	50	RM	24	self paced	Accuracy	% error rate	table	
14	Buck_1972	14.10'	50	RM	24	self paced	Accuracy	% error rate	table	
14	Buck_1972	14.11	50	RM	24	self paced	Accuracy	% error rate	table	
14	Buck_1972	14.12	50	RM	24	self paced	Accuracy	% error rate	table	
14	Buck_1972	14.13	50	RM	24	work pace	Accuracy	% error rate	table	
14	Buck_1972	14.14	50	RM	24	work pace	Accuracy	% error rate	table	
14	Buck_1972	14.15	50	RM	24	work pace	Accuracy	% error rate	table	
14	Buck_1972	14.16	50	RM	24	work pace	Accuracy	% error rate	table	
26	Collins_1977	26.1	569	2GC	2	9:00	Accuracy	% changes in	read from graph	
26	Collins_1977	26.2	569	2GC	6	13:00	Accuracy	% changes in	read from g	dynamic
26	Collins_1977	26.3	569	2GC	10	17:00	Accuracy	% changes in	read from graph	
26	Collins_1977	26.4	569	2GC	14	21:00	Accuracy	% changes in	read from graph	
26	Collins_1977	26.5	569	2GC	26	9:00	Accuracy	% changes in	read from graph	
26	Collins_1977	26.6	569	2GC	30	13:00	Accuracy	% changes in	read from graph	
26	Collins_1977	26.7	569	2GC	34	17:00	Accuracy	% changes in	read from graph	
26	Collins_1977	26.8	569	2GC	2	9:00	Accuracy	% changes in	read from graph	
26	Collins_1977	26.9	569	2GC	6	13:00	Accuracy	% changes in	read from g	static
26	Collins_1977	26.1	569	2GC	10	17:00	Accuracy	% changes in	read from graph	
26	Collins_1977	26.11	569	2GC	14	21:00	Accuracy	% changes in	read from graph	
26	Collins_1977	26.12	569	2GC	26	9:00	Accuracy	% changes in	read from graph	
26	Collins_1977	26.13	569	2GC	30	13:00	Accuracy	% changes in	read from graph	
26	Collins_1977	26.14	569	2GC	34	17:00	Accuracy	% changes in	read from graph	
26	Collins_1977	26.15	569	2GC	2	9:00	Accuracy	% changes in	read from graph	
26	Collins_1977	26.16	569	2GC	6	13:00	Accuracy	% changes in	read from g	dynamic
26	Collins_1977	26.17	569	2GC	10	17:00	Accuracy	% changes in	read from graph	
26	Collins_1977	26.18	569	2GC	14	21:00	Accuracy	% changes in	read from graph	
26	Collins_1977	26.19	569	2GC	26	9:00	Accuracy	% changes in	read from graph	
26	Collins_1977	26.2	569	2GC	30	13:00	Accuracy	% changes in	read from graph	
26	Collins_1977	26.21	569	2GC	34	17:00	Accuracy	% changes in	read from graph	
26	Collins_1977	26.22	569	2GC	50	9:00	Accuracy	% changes in	read from graph	
26	Collins_1977	26.23	569	2GC	2	9:00	Accuracy	% changes in	read from g	static
26	Collins_1977	26.24	569	2GC	6	13:00	Accuracy	% changes in	read from graph	
26	Collins_1977	26.25	569	2GC	10	17:00	Accuracy	% changes in	read from graph	
26	Collins_1977	26.26	569	2GC	14	21:00	Accuracy	% changes in	read from graph	
26	Collins_1977	26.27	569	2GC	26	9:00	Accuracy	% changes in	read from graph	
26	Collins_1977	26.28	569	2GC	30	13:00	Accuracy	% changes in	read from graph	
26	Collins_1977	26.29	569	2GC	34	17:00	Accuracy	% changes in	read from graph	
26	Collins_1977	26.30	569	2GC	50	9:00	Accuracy	% changes in	read from graph	
31	Borland_1986	31.1	247	RM		-	Accuracy	% of missed	table	mean of 3
31	Borland_1986	31.2	247	RM		17:00	Accuracy	% of missed	table	mean of 3
31	Borland_1986	31.3	247	RM		20:00	Accuracy	% of missed	table	mean of 3
31	Borland_1986	31.4	247	RM		23:00	Accuracy	% of missed	table	mean of bo
31	Borland_1986	31.5	247	RM		2:00	Accuracy	% of missed	table	mean of bo
31	Borland_1986	31.6	247	RM		5:00	Accuracy	% of missed	table	mean of bo
32	Dawson_1997	32.1	235	RM	12	8:00 to 12:	Accuracy	% of perform	read from graph	
32	Dawson_1997	32.2	235	RM	1	9:00	Accuracy	% of perform	read from g	unpredicta
32	Dawson_1997	32.3	235	RM	3	11:00	Accuracy	% of perform	read from graph	

Table 122: Percentage of Error Raw Data Part 1b

	N				Statistical Data							
	Control		Test		Mean		Stdev		Standard Error		Diff Mean	Poooled
Study Id #	Assigned	Observed	Assigned	Observed	Control	Test	Control	Test	Control	Test	C-T	Stdev
14	14	14	14	14	-0.1						-0.1	
14	14	14	14	14	0.6						0.6	
14	14	14	14	14	-0.6						-0.6	
14	14	14	14	14	6.2						6.2	
14	14	12	14	12	-0.6						-0.6	
14	14	12	14	12	0.8						0.8	
14	14	12	14	12	1.4						1.4	
14	14	12	14	12	1.4						1.4	
26	20	20	20	20	0	0					0	
26	20	20	20	20	15	4					11	
26	20	20	20	20	5	-2					7	
26	20	20	20	20	-10	-4					-6	
26	20	20	20	20	-2	60					-62	
26	20	20	20	20	-18	30					-48	
26	20	20	20	20	-20	22					-42	
26	20	20	20	20	0	0					0	
26	20	20	20	20	20	4					16	
26	20	20	20	20	18	2					16	
26	20	20	20	20	36	-1					37	
26	20	20	20	20	15	62					-47	0.000
26	20	20	20	20	16	20					-4	0.000
26	20	20	20	20	4	20					-16	0.000
26	20	20	20	20	0	0					0	0.000
26	20	20	20	20	-16	-4					-12	0.000
26	20	20	20	20	-20	-2					-18	0.000
26	20	20	20	20	-16	45					-61	0.000
26	20	20	20	20	-30	70					-100	0.000
26	20	20	20	20	-4	60					-64	0.000
26	20	20	20	20	-38	120					-158	0.000
26	20	20	20	20	0	0					0	0.000
26	20	20	20	20	-18	-16					-2	0.000
26	20	20	20	20	-20	0					-20	
26	20	20	20	20	-22	30					-52	
26	20	20	20	20	-30	42					-72	
26	20	20	20	20	-8	28					-36	
26	20	20	20	20	-42	115					-157	
26												
26												
31	4	4	4	4	21.5	-					21.5	
31	4	4	4	4	21.5	16.1					5.4	
31	4	4	4	4	21.5	22					-0.5	
31	4	4	4	4	21.5	53.3					-31.8	
31	4	4	4	4	21.5	52.3					-30.8	
31	4	4	4	4	21.5	51					-29.5	
32	20	20	20	20								
32	40	40	40	40		1.001		0.1581139		0.025	-1.001	0.112
32	40	40	40	40		1.01		0.1770875		0.028	-1.01	0.125

Table 123: Percentage of Error Raw Data Part 2a

Study Id #	1st Author_year	Effect Size Id #	Page #	Type of Comparison	Hours of Wakefulness	Time of Measure	Performance Var	Task Info	Calc Procedure	Var/task Info
32	Dawson_1997	32.4	235	RM	5	13:00	Accuracy	% of perf	read from graph	
32	Dawson_1997	32.5	235	RM	7	15:00	Accuracy	% of perf	read from graph	
32	Dawson_1997	32.6	235	RM	9	17:00	Accuracy	% of perf	read from graph	
32	Dawson_1997	32.7	235	RM	11	19:00	Accuracy	% of perf	read from graph	
32	Dawson_1997	32.8	235	RM	13	21:00	Accuracy	% of perf	read from graph	
32	Dawson_1997	32.9	235	RM	15	23:00	Accuracy	% of perf	read from graph	
32	Dawson_1997	32.1	235	RM	17	1:00	Accuracy	% of perf	read from graph	
32	Dawson_1997	32.11	235	RM	19	3:00	Accuracy	% of perf	read from graph	
32	Dawson_1997	32.12	235	RM	21	5:00	Accuracy	% of perf	read from graph	
32	Dawson_1997	32.13	235	RM	23	7:00	Accuracy	% of perf	read from graph	
32	Dawson_1997	32.14	235	RM	25	9:00	Accuracy	% of perf	read from graph	
32	Dawson_1997	32.15	235	RM	27	11:00	Accuracy	% of perf	read from graph	
32	Dawson_1997	32.16	235	RM	29	13:00	Accuracy	% of perf	read from graph	
43	Hull_2003	43.1	333	RM	2		Accuracy	deviation f	iation from mean	
43	Hull_2003	43.2	333	RM	4		Accuracy	deviation f	iation from mean	
43	Hull_2003	43.3	333	RM	6		Accuracy	deviation f	iation from mean	
43	Hull_2003	43.4	333	RM	8		Accuracy	deviation f	iation from mean	
43	Hull_2003	43.5	333	RM	10		Accuracy	deviation f	iation from mean	
43	Hull_2003	43.6	333	RM	12		Accuracy	deviation f	iation from mean	
43	Hull_2003	43.7	333	RM	14		Accuracy	deviation f	iation from mean	
43	Hull_2003	43.8	333	RM	16		Accuracy	deviation f	iation from mean	
56	Poulton_1978	56.1	286	RM	10		Accuracy	avg chang	read from gra	average ch
56	Poulton_1978	56.2	286	RM	12		Accuracy	avg chang	read from graph	
56	Poulton_1978	56.3	286	RM	14		Accuracy	avg chang	read from graph	
56	Poulton_1978	56.4	286	RM	16		Accuracy	avg chang	read from graph	
56	Poulton_1978	56.5	286	RM	18		Accuracy	avg chang	read from graph	
56	Poulton_1978	56.6	286	RM	20		Accuracy	avg chang	read from graph	
56	Poulton_1978	56.7	286	RM (subjects	22		Accuracy	avg chang	read from graph	
56	Poulton_1978	56.8	286	RM (subjects	10		Accuracy	avg chang	read from graph	
56	Poulton_1978	56.9	286	RM (subjects	12		Accuracy	avg chang	read from graph	
56	Poulton_1978	56.10	286	RM (subjects	14		Accuracy	avg chang	read from graph	
56	Poulton_1978	56.11	286	RM (subjects	16		Accuracy	avg chang	read from graph	
56	Poulton_1978	56.12	286	RM (subjects	18		Accuracy	avg chang	read from graph	
91	Steyvers_1993	91.2	68	RM	33		Accuracy	% of errors		
95	Sagaspe_2006_	95.1	81	RM	0.5	8:00	Accuracy	% of errors		Classical s
95	Sagaspe_2006_	95.2	81	RM	4.5	12:00	Accuracy	% of errors		
95	Sagaspe_2006_	95.3	81	RM	8.5	16:00	Accuracy	% of errors		
95	Sagaspe_2006_	95.4	81	RM	12.5	20:00	Accuracy	% of errors		
95	Sagaspe_2006_	95.5	81	RM	16.5	24:00:00	Accuracy	% of errors		
95	Sagaspe_2006_	95.6	81	RM	20.5	4:00	Accuracy	% of errors		
95	Sagaspe_2006_	95.7	81	RM	24.5	8:00	Accuracy	% of errors		
95	Sagaspe_2006_	95.8	81	RM	28.5	12:00	Accuracy	% of errors		
95	Sagaspe_2006_	95.9	81	RM	32.5	16:00	Accuracy	% of errors		
95	Sagaspe_2006_	95.10	81	RM	36.5	20:00	Accuracy	% of errors		
95	Sagaspe_2006_	95.11	81	RM	0.5	8:00	Accuracy	% of errors		emotional s
95	Sagaspe_2006_	95.12	81	RM	4.5	12:00	Accuracy	% of errors		
95	Sagaspe_2006_	95.13	81	RM	8.5	16:00	Accuracy	% of errors		
95	Sagaspe_2006_	95.14	81	RM	12.5	20:00	Accuracy	% of errors		
95	Sagaspe_2006_	94.15	81	RM	16.5	24:00:00	Accuracy	% of errors		
95	Sagaspe_2006_	94.16	81	RM	20.5	4:00	Accuracy	% of errors		
95	Sagaspe_2006_	95.17	81	RM	24.5	8:00	Accuracy	% of errors		
95	Sagaspe_2006_	95.18	81	RM	28.5	12:00	Accuracy	% of errors		
95	Sagaspe_2006_	95.19	81	RM	32.5	16:00	Accuracy	% of errors		
95	Sagaspe_2006_	95.20	81	RM	36.5	20:00	Accuracy	% of errors		
95	Sagaspe_2006_	95.21	81	RM	0.5	8:00	Accuracy	% of errors		specific str
95	Sagaspe_2006_	95.22	81	RM	4.5	12:00	Accuracy	% of errors		

Table 124: Percentage of Error Raw Data Part 2b

Study Id #	N				Statistical Data							
	Control		Test		Mean		Stdev		Standard Error		Diff Mean	Poooled
	Assigned	Observed	Assigned	Observed	Control	Test	Control	Test	Control	Test	C-T	Stdev
32	40	40	40	40		1.009		0.1897367		0.03	-1.009	0.134
32	40	40	40	40		1.02		0.1581139		0.025	-1.02	0.112
32	40	40	40	40		1.01		0.1960612		0.031	-1.01	0.139
32	40	40	40	40		1.01		0.1834121		0.029	-1.01	0.130
32	40	40	40	40		1.015		0.1644384		0.026	-1.015	0.116
32	40	40	40	40		1.007		0.1897367		0.03	-1.007	0.134
32	40	40	40	40		0.995		0.1770875		0.028	-0.995	0.125
32	40	40	40	40		0.968		0.2213594		0.035	-0.968	0.157
32	40	40	40	40		0.96		0.1897367		0.03	-0.96	0.134
32	40	40	40	40		0.942		0.2023858		0.032	-0.942	0.143
32	40	40	40	40		0.945		0.2213594		0.035	-0.945	0.157
32	40	40	40	40		0.97		0.1960612		0.031	-0.97	0.139
32	40	40	40	40		0.995		0.1897367		0.03	-0.995	0.134
43	15	15	15	15		71	0.71	7.7459667	0.07746	2	-71	5.500
43	15	15	15	15		70.75	0.7075	1.9364917	0.019365	0.5	-70.75	1.458
43	15	15	15	15		70.5	0.705	1.5491933	0.015492	0.4	-70.5	1.204
43	15	15	15	15		69	0.69	1.9364917	0.019365	0.5	-69	1.454
43	15	15	15	15		69.75	0.6975	5.809475	0.058095	1.5	-69.75	4.137
43	15	15	15	15		69.75	0.6975	3.8729833	0.03873	1	-69.75	2.783
43	15	15	15	15		69	0.69	3.8729833	0.03873	1	-69	2.782
43	15	15	15	15		68	0.68	3.8729833	0.03873	1	-68	2.781
56	7	7	7	7								
56	10	10	10	10								
56	11	11	11	11								
56	12	12	12	12								
56	3	3	3	3								
56	1	1	1	1								
56	1	1	1	1								
56	14	14	14	14								
56	10	10	10	10								
56	12	12	12	12								
56	10	10	10	10								
56	9	9	9	9								
91	16	16	16	16								
95	12	12	12	12	1	3.5	1.5	2.4			-2.5	2.001
95	12	12	12	12	0.5	2.3	0.9	2			-1.8	1.551
95	12	12	12	12	0.5	1.3	0.9	0.9			-0.8	0.900
95	12	12	12	12	0.6	1.1	0.9	1.9			-0.5	1.487
95	12	12	12	12	0.5	2.5	0.9	2.7			-2	2.012
95	12	12	12	12	0.6	1.5	1.7	2.4			-0.9	2.080
95	12	12	12	12	0.8	1.6	1.8	1.8			-0.8	1.800
95	12	12	12	12	0.8	2	1.5	2.2			-1.2	1.883
95	12	12	12	12	1.6	1.5	1.8	1.5			0.1	1.657
95	12	12	12	12	1.1	1.8	1.3	2.1			-0.7	1.746
95	12	12	12	12	0.5	0.6	0.9	1.3			-0.1	1.118
95	12	12	12	12	0.8	1	1	1.3			-0.2	1.160
95	12	12	12	12	0.3	0.5	0.7	0.9			-0.2	0.806
95	12	12	12	12	1	1	1.8	1.3			0	1.570
95	12	12	12	12	0.5	0.3	0.9	0.7			0.2	0.806
95	12	12	12	12	0.8	0.3	1.3	0.7			0.5	1.044
95	12	12	12	12	1.3	1	1.5	1.3			0.3	1.404
95	12	12	12	12	0.8	0.3	1.5	0.7			0.5	1.170
95	12	12	12	12	0.8	0	1.3	0			0.8	0.919
95	12	12	12	12	1	0.3	1.5	0.7			0.7	1.170
95	12	12	12	12	1	0.5	1.5	1.2			0.5	1.358
95	12	12	12	12	0.3	0.1	1.1	0.5			0.2	0.854
95	12	12	12	12	1	1.5	1.8	1.2			-0.5	1.530
95	12	12	12	12	1	0.6	1.5	1.3			0.4	1.404
95	12	12	12	12	0.6	0.8	0.9	1.3			-0.2	1.118
95	12	12	12	12	0.6	0.1	1.3	0.5			0.5	0.985
95	12	12	12	12	0.6	0.5	0.9	0.9			0.1	0.900
95	12	12	12	12	0.1	0.6	0.5	0.9			-0.5	0.728
95	12	12	12	12	1.1	2	2.3	2.4			-0.9	2.351
95	12	12	12	12	2.3	1.5	2.8	2.2			0.8	2.518

Table 125: False Positive Raw Data Part 1a

Study Id #	1st Author_year	Effect Size Id #	Page #	Type of Comparison	Hours of Sleep Deprivati	Time of Measure	Performance Var	Task Info	Calc Procedure	Var/task Info
5	Williamson_2000	5.21	652	RM	2.27	8:00	Accuracy	false +	table	Mackworth a
5	Williamson_2000	5.22	652	RM	13.27	19:00	Accuracy	false +	table	Mackworth a
5	Williamson_2000	5.23	652	RM	14	19:44	Accuracy	false +	table	Mackworth a
5	Williamson_2000	5.24	652	RM	18	23:44	Accuracy	false +	table	Mackworth a
5	Williamson_2000	5.25	652	RM	22	27:44:00	Accuracy	false +	table	Mackworth a
27	Porcu_1998	27.26	1198	RM		baseline	Accuracy	false +		DBT
27	Porcu_1998	27.27	1198	RM		23:00	Accuracy	false +		DBT
27	Porcu_1998	27.28	1198	RM		1:00	Accuracy	false +		DBT
27	Porcu_1998	27.29	1198	RM		3:00	Accuracy	false +		DBT
27	Porcu_1998	27.30	1198	RM		5:00	Accuracy	false +		DBT
27	Porcu_1998	27.31	1198	RM		baseline	Accuracy	false +		LCT
27	Porcu_1998	27.32	1198	RM		23:00	Accuracy	false +		LCT
27	Porcu_1998	37.33	1198	RM		1:00	Accuracy	false +		LCT
27	Porcu_1998	27.34	1198	RM		3:00	Accuracy	false +		LCT
27	Porcu_1998	27.35	1198	RM		5:00	Accuracy	false +		LCT
48	Drummond_2006	48.5	263	RM	7		Accuracy	false +		PVT
48	Drummond_2006	48.6	263	RM	22.15		Accuracy	false +		PVT
48	Drummond_2006	48.7	263	RM	30.75		Accuracy	false +		PVT
48	Drummond_2006	48.8	263	RM	57.75		Accuracy	false +		PVT
53	Frey_2004	53.1	308	RM	43	02:00 to 08	Accuracy	false start		PVT
55	Webb_1982	55.5	274	RM			Accuracy	false +	table	AVI f +
55	Webb_1982	55.6	274	RM			Accuracy	false +	table	AVI f +
100	Lieberman_2005	100.9	425	RM	77	18:00, 12:0	Accuracy	false +	table	Vis Vig - fals
100	Lieberman_2005	100.1	425	RM	94	18:00, 05:0	Accuracy	false +	table	Vis Vig - fals

Table 126: False Positive Raw Data Part 1b

	N				Statistical Data								
	Control		Test		Mean		Standard Deviation		Standard Error		Diff Means	Poooled Stdev	B Stdev
Study Id #	Assigned	Observed	Assigned	Observed	Control	Test	Control	Test	Control	Test	C-T		
5	39	39	39	39	1.05	2.15					-1.1		
5	39	39	39	39	1.05	1.28					-0.23		
5	39	39	39	39	1.05	1.48					-0.43		
5	39	39	39	39	1.05	2.85					-1.8		
5	39	39	39	39	1.05	4.24					-3.19		
27	10	10	10	10									
27	10	10	10	10	0.78	0.46	1.03	1.092			0.32	1.061	1.501
27	10	10	10	10	0.78	0.46	1.03	0.96			0.32	0.996	1.408
27	10	10	10	10	0.78	0.78	1.03	0.69			0	0.877	1.240
27	10	10	10	10	0.78	0.56	1.03	1.13			0.22	1.081	1.529
27	7	7	7	7									
27	7	7	7	7	0.43	0.29	0.79	0.68			0.14	0.737	1.042
27	7	7	7	7	0.43	0.71	0.79	0.49			-0.28	0.657	0.930
27	7	7	7	7	0.43	1	0.79	1.1			-0.57	0.958	1.354
27	7	7	7	7	0.43	1	0.79	1			-0.57	0.901	1.274
48	36	36	36	36	0.14	0.14	0.045	0.045	0.0075	0.0075	0	0.045	0.064
48	36	36	36	36	0.14	0.195	0.045	0.06	0.0075	0.01	-0.055	0.053	0.075
48	36	36	36	36	0.14	0.2	0.045	0.105	0.0075	0.0175	-0.06	0.081	0.114
48	36	36	36	36	0.14	0.19	0.045	0.18	0.0075	0.03	-0.05	0.131	0.186
53	25	25	25	25	0.14	2.7	0.04	0.44			-2.56	0.312	0.442
55					13.5	14.8	10	8.2			-1.3	9.144	12.932
55					11.3	11.8	20	24.7			-0.5	22.473	31.782
100	31	31	31	31	1.1	5.1	1.6703293	8.3516465	0.3	1.5	-4	6.022	8.517
100	31	31	31	31	1.1	2.9	1.6703293	3.8974351	0.3	0.7	-1.8	2.998	4.240

Table 127: Percentage Correct Raw Data Part 1a

Study Id #	1st Author_year	Effect Size Id #	Page #	Type of Comparison	Hours of Sleep Deprivati	Time of Measure	Performance Var	Task Info	Performance Direction	CalcPprocedure	Var/task Info
2	Thomas_2000	2.2	346	RM	24		Accuracy	% correct	worse	directly	serial addit
3	Choo_2005	3.5	581	RM	24.4		Accuracy	% correct	worse	directly	SRT
3	Choo_2005	3.6	581	RM	24.4		Accuracy	% correct	worse	directly	SRT
3	Choo_2005	3.7	581	RM	24.4		Accuracy	% correct	worse	directly	SRT
3	Choo_2005	3.8	581	RM	24.4		Accuracy	% correct	worse	directly	SRT
4	Chee_2004	4.4		RM	24		Accuracy	% correct	worse	directly	
4	Chee_2004	4.5		RM	24		Accuracy	% correct	worse	directly	
7	Robbins_1990	7.1	83	RM	35	end of bei	Accuracy	% correct	worse	read from graph	
7	Robbins_1990	7.3	83	RM	35		Accuracy	% correct	worse	read from graph	
7	Robbins_1990	7.4	83	RM	35		Accuracy	% correct	worse	read from graph	
7	Robbins_1990	7.5	83	RM	35		Accuracy	% correct	better?	read from graph	
9	Babkoff_2005	9.2	11	RM	8.5	0.354167	Accuracy	% of correct respons		read from graph	
9	Babkoff_2005	9.3	11	RM	10.5	0.4375	Accuracy	% of correct respons		read from graph	
9	Babkoff_2005	9.4	11	RM	12.75	0.53125	Accuracy	% of correct respons		read from graph	
9	Babkoff_2005	9.5	11	RM	15.5	0.645833	Accuracy	% of correct respons		read from graph	
9	Babkoff_2005	9.6	11	RM	18.5	0.770833	Accuracy	% of correct respons		read from graph	
17	Yoo_2007	17.1	386	2GC	35	0.75	Accuracy	proportion	worse	read from	proportion
17	Yoo_2007	17.2	386	2GC	35	0.75	Accuracy	proportion of correct rejections			proportion
18	Babkoff_1985	18.2	616	RM	72		Accuracy	% correct	worse	in text	
50	Engle_Friedmar	50.2	115	RM	1night		Accuracy	% correct	worse	in text	
50	Engle_Friedmar	50.5	121	2GC	3 night	09:00 to 1(	Accuracy	% correct		table	
50	Engle_Friedmar	50.7	121	2GC	5 night	09:00 to 1(	Accuracy	% correct		table	
53	Frey_2004	53.4	308	RM	43		Accuracy	% correct			Wilkinson
53	Frey_2004	53.6	308	RM	43		Accuracy	% correct			Manikin
53	Frey_2004	53.8	308	RM	43		Accuracy	% correct			Math accu
53	Frey_2004	53.10	308	RM	43		Accuracy	% correct			2ADD
53	Frey_2004	53.12	308	RM	43		Accuracy	% correct			Dual
53	Frey_2004	53.14	308	RM	43		Accuracy	% correct			RCT
53	Frey_2004	53.17	308	RM	43		Accuracy	% correct			DR
55	Webb_1982	53.27	274	RM			Accuracy	% correct		table	REA - %
55	Webb_1982	55.1	274	RM			Accuracy	% correct		table	
57	Englund_1985	57.1	81	RM	2	0.375	Accuracy	% correct		table	4CRT
57	Englund_1985	57.2	81	RM	5.5	0.520833	Accuracy	% correct		table	4CRT
57	Englund_1985	57.3	81	RM	8.5	0.645833	Accuracy	% correct		table	4CRT
57	Englund_1985	57.4	81	RM	12.25	0.802083	Accuracy	% correct		table	4CRT
57	Englund_1985	57.5	81	RM	15.75	0.947917	Accuracy	% correct		table	4CRT
57	Englund_1985	57.6	81	RM	19	0.083333	Accuracy	% correct		table	4CRT
57	Englund_1985	57.7	81	RM	1	0.333333	Accuracy	% recall		table	word mem
57	Englund_1985	57.8	81	RM	7.5	0.604167	Accuracy	% recall		table	word mem
57	Englund_1985	57.9	81	RM	15.75	0.947917	Accuracy	% recall		table	word mem
57	Englund_1985	57.10	81	RM	19	0.083333	Accuracy	% recall		table	word mem
57	Englund_1985	57.15	81	RM	1	0.333333	Accuracy	% correct		table	logical rea:
57	Englund_1985	57.16	81	RM	4	0.458333	Accuracy	% correct		table	logical rea:
57	Englund_1985	57.17	81	RM	7.5	0.604167	Accuracy	% correct		table	logical rea:
57	Englund_1985	57.18	81	RM	11.25	0.760417	Accuracy	% correct		table	logical rea:
57	Englund_1985	57.19	81	RM	14.75	0.90625	Accuracy	% correct		table	logical rea:
57	Englund_1985	57.20	81	RM	18	0.041667	Accuracy	% correct		table	logical rea:
57	Englund_1985	57.21	81	RM	19	0.083333	Accuracy	% correct		table	logical rea:

Table 128: Percentage Correct Raw Data Part 1b

Study Id #	N				Statistical Data								
	Control		Test		Mean		Stdev		Standard Error		Diff Means	Poooled	
	Assigned	Observed	Assigned	Observed	Control	Test	Control	Test	Control	Test	T-C	Stdev	B Stdev
2	-	17	-	17	0.955	0.923	0.052	0.064			-0.032	0.05831	0.082462
3	14	12	-		0.988	0.941	0.013	0.05			-0.047	#NUM!	0.051662
3	14	12	-		0.968	0.927	0.05	0.074			-0.041	0.04693	0.089308
3	14	12	-		0.943	0.911	0.052	0.086			-0.032	0.047274	0.100499
3	14	12	-		0.966	0.926	0.038	0.07			-0.04	0.033142	0.079649
4	13	13	13	13	0.959	0.902	0.049	0.097			-0.057	0.076844	0.108674
4	13	13	13	13	0.957	0.926	0.055	0.086			-0.031	0.072184	0.102083
7	31	23	31	23	0.65	0.605	0.0575	0.0815			-0.045	0.070528	0.099742
7	31	23	31	23	0.75	0.67	0.0911	0.2254			-0.08	0.171907	0.243114
7	31	23	31	23	23.95	22.25	4.1723	4.556			-1.7	4.368365	6.177801
7	31	23	31	23	0.54	0.58	0.1247	0.1103			0.04	0.11772	0.166482
9	20	18	20	18	0.764	0.735					-0.029		
9	20	18	20	18	0.76	0.73					-0.03		
9	20	18	20	18	0.745	0.715					-0.03		
9	20	18	20	18	0.743	0.719					-0.024		
9	20	18	20	18	0.768	0.729					-0.039		
17	14	14	14	14	0.86	0.74	0.019	0.044			-0.12	0.03389	0.047927
17	14	14	14	14	0.91	0.92	0.021	0.044			0.01	0.034475	0.048754
18	10	6	10	6	0.827	0.646					-0.181		
50	50	50	50	50	0.6998	0.6408	0.1448	0.1817			-0.059	0.164289	0.23234
50	50	50	50	50									
50	50	50	50	50									
53	25	25	25	25	0.977	0.908	0.02	0.085	0.004	0.017	-0.069	0.061745	0.087321
53	25	25	25	25	0.916	0.822	0.1	0.145	0.02	0.029	-0.094	0.124549	0.176139
53	25	25	25	25	0.909	0.775	0.085	0.12	0.017	0.024	-0.134	0.103983	0.147054
53	25	25	25	25	0.855	0.709	0.115	0.185	0.023	0.037	-0.146	0.154029	0.21783
53	25	25	25	25	0.98	0.911	0.035	0.095	0.007	0.019	-0.069	0.071589	0.101242
53	25	25	25	25	0.913	0.839	0.085	0.125	0.017	0.025	-0.074	0.106888	0.151162
53	25	25	25	25	0.571	0.458	0.15	0.16	0.03	0.032	-0.113	0.155081	0.219317
55					0.76	0.843	0.362	0.206			0.083	0.294517	0.416509
55					0.422	0.399	0.086	0.093			-0.023	0.089568	0.126669
57	22	22	22	22	1	0.877					-0.123	0	0
57	22	22	22	22	1	0.852		0.173			-0.148		0.173
57	22	22	22	22	1	0.858		0.203			-0.142		0.203
57	22	22	22	22	1	0.867		0.168			-0.133		0.168
57	22	22	22	22	1	0.876		0.176			-0.124		0.176
57	22	22	22	22	1	0.795		0.189			-0.205		0.189
57	22	22	22	22	1	0.547		0.235			-0.453		0.235
57	22	22	22	22	1	0.588		0.192			-0.412		0.192
57	22	22	22	22	1	0.58		0.167			-0.42		0.167
57	22	22	22	22	1	0.787		0.16			-0.213		0.16
57	22	22	22	22	1	0.758		0.144			-0.242		0.144
57	22	22	22	22	1	0.781		0.148			-0.219		0.148

Table 129: Percentage Correct Raw Data Part 2a

Study Id #	1st Author_year	Effect Size Id #	Page #	Type of Comparison	Hours of Sleep Deprivation	Time of Measure	Performance Var	Task Info	Calc Procedure	Var/task Info
60	Christensen_1977	60.2	105	RM	worked at least 15hr		accuracy	% detecte	table	logical reasoning
63	Horne_1983	63.1	352	RM	60	1	accuracy	% hits	read from g	logical reasoning
63	Horne_1983	63.2	352	RM	60	0.166667	accuracy	% hits	read from g	logical reasoning
63	Horne_1983	63.3	352	RM	60	0.375	accuracy	% hits	read from g	logical reasoning
63	Horne_1983	63.4	352	RM	60	0.583333	accuracy	% hits	read from g	logical reasoning
63	Horne_1983	63.5	352	RM	60	0.791667	accuracy	% hits	read from g	logical reasoning
63	Horne_1983	63.6	352	RM	60	1	accuracy	% hits	read from g	logical reasoning
63	Horne_1983	63.7	352	RM	60	0.166667	accuracy	% hits	read from g	logical reasoning
63	Horne_1983	63.8	352	RM	60	0.375	accuracy	% hits	read from g	logical reasoning
63	Horne_1983	63.9	352	RM	60	0.583333	accuracy	% hits	read from g	logical reasoning
63	Horne_1983	63.1	352	RM	60	0.791667	accuracy	% hits	read from g	logical reasoning
67	Binks_1999	67.1	331	2GC	35	0.75	accuracy	% of corre	table	PASAT % - Aud serial add
72	Linde_1999	72.2	704	2GC		0.916667	accuracy	% correct	table	
72	Linde_1999	72.21	704	2GC		0.166667	accuracy	% correct	table	
72	Linde_1999	72.22	704	2GC		0.416667	accuracy	% correct	table	
72	Linde_1999	72.23	704	2GC		0.666667	accuracy	% correct	table	
72	Linde_1999	72.24	704	2GC		0.916667	accuracy	% correct	table	
72	Linde_1999	72.25	704	2GC		0.166667	accuracy	% correct	table	
72	Linde_1999	72.26	704	2GC		0.416667	accuracy	% correct	table	
72	Linde_1999	72.27	704	2GC		0.666667	accuracy	% correct	table	
92	Elkin_1974	92.1	194	2GC	55	0.625	accuracy	% correct - immediate recognition		
92	Elkin_1974	92.2	195	2GC	12	0.875	accuracy	% correct - immediate recognition		
92	Elkin_1974	92.3	195	2GC	25	0.375	accuracy	% correct - immediate recognition		
92	Elkin_1974	92.4	195	2GC	31	0.625	accuracy	% correct - immediate recognition		
92	Elkin_1974	92.5	195	2GC	37	0.875	accuracy	% correct - immediate recognition		
92	Elkin_1974	92.6	195	2GC	49	0.375	accuracy	% correct - immediate recognition		
92	Elkin_1974	92.7	195	2GC	55	0.625	accuracy	% correct - immediate recognition		
92	Elkin_1974	92.8	195	2GC	12	0.875	accuracy	% correct - recognition after 20 sec		
92	Elkin_1974	92.9	195	2GC	25	0.375	accuracy	% correct - recognition after 20 sec		
92	Elkin_1974	92.1	195	2GC	31	0.625	accuracy	% correct - recognition after 20 sec		
92	Elkin_1974	92.11	195	2GC	37	0.875	accuracy	% correct - recognition after 20 sec		
92	Elkin_1974	92.12	195	2GC	49	0.375	accuracy	% correct - recognition after 20 sec		
92	Elkin_1974	92.13	195	2GC	55	0.625	accuracy	% correct - recognition after 20 sec		
93	Webb_1986	93.1	171	RM	64	0.208333	accuracy	% correct	table	
93	Webb_1986	93.2	171	RM	64		accuracy	% correct	table	
93	Webb_1986	93.3	171	RM	64		accuracy	% correct	table	
93	Webb_1986	93.4	171	RM	64		accuracy	% correct	table	
93	Webb_1986	93.5	171	RM	64	0.208333	accuracy	reading ra	table	task 1a
93	Webb_1986	93.6	171	RM	64		accuracy	reading ra	table	task 1b
93	Webb_1986	93.7	171	RM	64		accuracy	reading ra	table	task 2
93	Webb_1986	93.8	171	RM	64		accuracy	reading ra	table	task 3
101	Lamond_1999	101.1	260	RM	3	0.416667	accuracy	mean rela	read from g	simple sensory
101	Lamond_1999	101.2	260	RM	5	0.5	accuracy	mean rela	read from g	simple sensory
101	Lamond_1999	101.3	260	RM	7	0.583333	accuracy	mean rela	read from g	simple sensory
101	Lamond_1999	101.4	260	RM	9	0.666667	accuracy	mean rela	read from g	simple sensory
101	Lamond_1999	101.5	260	RM	11	0.75	accuracy	mean rela	read from g	simple sensory
101	Lamond_1999	101.6	260	RM	13	0.833333	accuracy	mean rela	read from g	simple sensory
101	Lamond_1999	101.7	260	RM	15	0.916667	accuracy	mean rela	read from g	simple sensory
101	Lamond_1999	101.8	260	RM	17	1	accuracy	mean rela	read from g	simple sensory
101	Lamond_1999	101.9	260	RM	19	0.083333	accuracy	mean rela	read from g	simple sensory
101	Lamond_1999	101.1	260	RM	21	0.166667	accuracy	mean rela	read from g	simple sensory
101	Lamond_1999	101.11	260	RM	23	0.25	accuracy	mean rela	read from g	simple sensory
101	Lamond_1999	101.12	260	RM	25	0.333333	accuracy	mean rela	read from g	simple sensory
101	Lamond_1999	101.13	260	RM	27	0.416667	accuracy	mean rela	read from g	simple sensory
101	Lamond_1999	101.14	260	RM	29	0.5	accuracy	mean rela	read from g	simple sensory
101	Lamond_1999	101.29	259	RM	3	0.416667	accuracy	mean rela	read from g	gram accuracy
101	Lamond_1999	101.3	259	RM	5	0.5	accuracy	mean rela	read from g	gram accuracy
101	Lamond_1999	101.31	259	RM	7	0.583333	accuracy	mean rela	read from g	gram accuracy
101	Lamond_1999	101.32	259	RM	9	0.666667	accuracy	mean rela	read from g	gram accuracy
101	Lamond_1999	101.34	259	RM	11	0.75	accuracy	mean rela	read from g	gram accuracy
101	Lamond_1999	101.35	259	RM	13	0.833333	accuracy	mean rela	read from g	gram accuracy
101	Lamond_1999	101.36	259	RM	15	0.916667	accuracy	mean rela	read from g	gram accuracy
101	Lamond_1999	101.37	259	RM	17	1	accuracy	mean rela	read from g	gram accuracy
101	Lamond_1999	101.38	259	RM	19	0.083333	accuracy	mean rela	read from g	gram accuracy
101	Lamond_1999	101.39	259	RM	21	0.166667	accuracy	mean rela	read from g	gram accuracy
101	Lamond_1999	101.4	259	RM	23	0.25	accuracy	mean rela	read from g	gram accuracy

Table 130: Percentage Correct Raw Data Part 2b

Study Id #	N				Statistical Data								
	Control		Test		Mean		Stdev		Standard Error		Diff Means	Poooled	
	Assigned	Observed	Assigned	Observed	Control	Test	Control	Test	Control	Test	T-C	Stdev	B Stdev
60	14	14	14	14		0.614		0.607			0.614	0.429214	0.607
63	8	8	8	8		0.92					0.92	0	0
63	8	8	8	8		0.86					0.86	0	0
63	8	8	8	8	0.88	0.82					-0.06	0	0
63	8	8	8	8	0.83	0.83					0	0	0
63	8	8	8	8	0.87	0.82					-0.05	0	0
63	8	8	8	8		0.76					0.76	0	0
63	8	8	8	8		0.61					0.61	0	0
63	8	8	8	8	0.89	0.57					-0.32	0	0
63	8	8	8	8	0.91	0.61					-0.3	0	0
63	8	8	8	8	0.9	0.605					-0.295	0	0
67	32	32	32	29	0.573	0.561	0.153	0.147			-0.012	0.150182	0.212174
72	11	11	11	11	0.965	0.948	0.07	0.092			-0.017	0.067112	0.115603
72	11	11	11	11	0.956	0.929	0.044	0.119			-0.027	0.024035	0.126874
72	11	11	11	11	0.0954	0.92	0.075	0.131			0.8246	0.065903	0.15095
72	11	11	11	11	0.983	0.93	0.012	0.128			-0.053	#NUM!	0.128561
72	10	10	10	10	0.009	0.005	0.026	0.044			-0.004	0.022771	0.051108
72	9	9	9	9	0.014	-0.013	0.031	0.078			-0.027	0.015137	0.083934
72	10	10	10	10	0.002	-0.023	0.08	0.117			-0.025	0.074087	0.141736
72	10	10	10	10	0.031	-0.012	0.057	0.139			-0.043	0.035214	0.150233
92	20	20	20	20							0	0	0
92	20	20	20	20	0.76	0.79					0.03	0	0
92	20	20	20	20	0.79	0.8					0.01	0	0
92	20	20	20	20	0.785	0.8					0.015	0	0
92	20	20	20	20	0.76	0.78					0.02	0	0
92	20	20	20	20	0.74	0.79					0.05	0	0
92	20	20	20	20	0.75	0.79					0.04	0	0
92	20	20	20	20	0.75	0.77					0.02	0	0
92	20	20	20	20	0.685	0.75					0.065	0	0
92	20	20	20	20	0.685	0.76					0.075	0	0
92	20	20	20	20	0.7	0.73					0.03	0	0
92	20	20	20	20	0.65	0.78					0.13	0	0
92	20	20	20	20	0.66	0.75					0.09	0	0
93	10	8	10	8	0.69	0.73					0.04	0	0
93	10	6	10	6	0.67	0.73					0.06	0	0
93	10	6	10	6	0.94	0.86					-0.08	0	0
93	10	6	10	6	0.68	0.63					-0.05	0	0
93	10	8	10	8		0.906977					0.906977	0	0
93	10	6	10	6		0.835938					0.835938	0	0
93	10	6	10	6		0.8					0.8	0	0
93	10	6	10	6		0.7					0.7	0	0
101	22	22	22	22	1	0.99		0.0775		7.75	-0.01	0.054801	0.0775
101	22	22	22	22	1	0.995		0.025		2.5	-0.005	0.017678	0.025
101	22	22	22	22	1	0.981		0.025		2.5	-0.019	0.017678	0.025
101	22	22	22	22	1	0.9875		0.025		2.5	-0.0125	0.017678	0.025
101	22	22	22	22	1	0.991		0.0325		3.25	-0.009	0.022981	0.0325
101	22	22	22	22	1	1		0.036		3.6	0	0.025456	0.036
101	22	22	22	22	1	0.97		0.037		3.7	-0.03	0.026163	0.037
101	22	22	22	22	1	0.989		0.04		4	-0.011	0.028284	0.04
101	22	22	22	22	1	1		0.0355		3.55	0	0.025102	0.0355
101	22	22	22	22	1	0.99		0.04		4	-0.01	0.028284	0.04
101	22	22	22	22	1	0.971		0.043		4.3	-0.029	0.030406	0.043
101	22	22	22	22	1	0.99		0.0375		3.75	-0.01	0.026517	0.0375
101	22	22	22	22	1	0.95		0.035		3.5	-0.05	0.024749	0.035
101	22	22	22	22	1	0.97		0.045		4.5	-0.03	0.03182	0.045
101	22	22	22	22	1	0.995		0.0175		1.75	-0.005	0.012374	0.0175
101	22	22	22	22	1	0.985		0.02		2	-0.015	0.014142	0.02
101	22	22	22	22	1	0.99		0.023		2.3	-0.01	0.016263	0.023
101	22	22	22	22	1	0.99		0.025		2.5	-0.01	0.017678	0.025
101	22	22	22	22	1	0.991		0.022		2.2	-0.009	0.015556	0.022
101	22	22	22	22	1	0.975		0.0225		2.25	-0.025	0.01591	0.0225
101	22	22	22	22	1	0.975		0.0125		1.25	-0.025	0.008839	0.0125
101	22	22	22	22	1	0.975		0.0115		1.15	-0.025	0.008132	0.0115
101	22	22	22	22	1	0.977		0.015		1.5	-0.023	0.010607	0.015
101	22	22	22	22	1	0.978		0.015		1.5	-0.022	0.010607	0.015
101	22	22	22	22	1	0.975		0.0225		2.25	-0.025	0.01591	0.0225
101	22	22	22	22	1	0.965		0.022		2.2	-0.035	0.015556	0.022

Table 131: Percentage Correct Raw Data Part 3a

Study Id #	1st Author_year	Effect Size Id #	Page #	Type of Comparison	Hours of Sleep Deprivati	Time of Measure	Performance Var	Task Info	Calc Procedure	Var/task Info
101	Lamond_1999	101.42	259	RM	27	0.416667	accuracy	mean relative pe	read from g	gram accuracy
101	Lamond_1999	101.43	259	RM	29	0.5	accuracy	mean relative pe	read from g	gram accuracy
101	Lamond_1999	101.44	259	RM	3	0.416667	accuracy	mean relative pe	read from g	Vig- accuracy
101	Lamond_1999	101.15	259	RM	5	0.5	accuracy	mean relative pe	read from g	Vig- accuracy
101	Lamond_1999	101.46	259	RM	7	0.583333	accuracy	mean relative pe	read from g	Vig- accuracy
101	Lamond_1999	101.47	259	RM	9	0.666667	accuracy	mean relative pe	read from g	Vig- accuracy
101	Lamond_1999	101.48	259	RM	11	0.75	accuracy	mean relative pe	read from g	Vig- accuracy
101	Lamond_1999	101.49	259	RM	13	0.833333	accuracy	mean relative pe	read from g	Vig- accuracy
101	Lamond_1999	101.5	259	RM	15	0.916667	accuracy	mean relative pe	read from g	Vig- accuracy
101	Lamond_1999	101.51	259	RM	17	1	accuracy	mean relative pe	read from g	Vig- accuracy
101	Lamond_1999	101.52	259	RM	19	0.083333	accuracy	mean relative pe	read from g	Vig- accuracy
101	Lamond_1999	101.53	259	RM	21	0.166667	accuracy	mean relative pe	read from g	Vig- accuracy
101	Lamond_1999	101.54	259	RM	23	0.25	accuracy	mean relative pe	read from g	Vig- accuracy
101	Lamond_1999	101.55	259	RM	25	0.333333	accuracy	mean relative pe	read from g	Vig- accuracy
101	Lamond_1999	101.56	259	RM	27	0.416667	accuracy	mean relative pe	read from g	Vig- accuracy
101	Lamond_1999	101.57	259	RM	29	0.5	accuracy	mean relative pe	read from g	Vig- accuracy

Table 132: Percentage Correct Raw Data Part 3b

	N				Statistical Data								
	Control		Test		Mean		Stdev		Standard Error		Diff Means	Poooled	
Study Id #	Assigned	Observed	Assigned	Observed	Control	Test	Control	Test	Control	Test	T-C	Stdev	B Stdev
101	22	22	22	22	1	0.97		0.015		1.5	-0.03	0.010607	0.015
101	22	22	22	22	1	0.98		0.0125		1.25	-0.02	0.008839	0.0125
101	22	22	22	22	1	1		0.003		0.3	0	0.002121	0.003
101	22	22	22	22	1	0.999		0.002		0.2	-0.001	0.001414	0.002
101	22	22	22	22	1	0.998		0.005		0.5	-0.002	0.003536	0.005
101	22	22	22	22	1	0.995		0.007		0.7	-0.005	0.00495	0.007
101	22	22	22	22	1	0.99		0.007		0.7	-0.01	0.00495	0.007
101	22	22	22	22	1	0.99		0.01		1	-0.01	0.007071	0.01
101	22	22	22	22	1	0.992		0.0075		0.75	-0.008	0.005303	0.0075
101	22	22	22	22	1	0.9935		0.005		0.5	-0.0065	0.003536	0.005
101	22	22	22	22	1	0.985		0.015		1.5	-0.015	0.010607	0.015
101	22	22	22	22	1	0.981		0.0185		1.85	-0.019	0.013081	0.0185
101	22	22	22	22	1	0.968		0.024		2.4	-0.032	0.016971	0.024
101	22	22	22	22	1	0.947		0.032		3.2	-0.053	0.022627	0.032
101	22	22	22	22	1	0.935		0.03		3	-0.065	0.021213	0.03
101	22	22	22	22	1	0.975		0.013		1.3	-0.025	0.009192	0.013

Table 133: Number of Errors Raw Data Part 1a

Study Id #	1st Author_year	Effect Size Id #	Page #	Type of Comparison	Hours of Wakefulness	Time of Measure	Performance Var	Task Info	Calc Procedure	Var/task Info
5	Williamson_2000	5.6	652	RM	2.27	8:00	Accuracy	misses	table	RT accura
5	Williamson_2000	5.7	652	RM	13.27	19:00	Accuracy	misses	table	RT accura
5	Williamson_2000	5.8	652	RM	14	19:44	Accuracy	misses	table	RT accura
5	Williamson_2000	5.9	652	RM	18	23:44	Accuracy	misses	table	RT accura
5	Williamson_2000	5.1	652	RM	22	27:44:00	Accuracy	misses	table	RT accura
10	Swann_2006	10.2	28	RM	19.2		Accuracy	total errors	directly	PVT
20	Williams_1959	20.11	13	RM	b4		Accuracy	# of errors	read from graph	
20	Williams_1959	20.12	13	RM	28		Accuracy	# of errors	read from graph	
20	Williams_1959	20.13	13	RM	52		Accuracy	# of errors	read from graph	
20	Williams_1959	20.14	13	RM	76		Accuracy	# of errors	read from graph	
20	Williams_1959	20.15	13	RM	b4		Accuracy	# of errors	read from graph	
20	Williams_1959	20.16	13	RM	30		Accuracy	# of errors	read from graph	
20	Williams_1959	20.17	13	RM	54		Accuracy	# of errors	read from graph	
20	Williams_1959	20.18	13	RM	70		Accuracy	# of errors	read from graph	
49	Eastridge_2003	49.1	172	RM	-	08:00 to 11	Accuracy	# of errors	read from graph	
67	Binks_1999	67.2	331	2GC	35	18:00	Accuracy	# of incorr	table	BFCT err
67	Binks_1999	67.3	332	2GC	35	18:00	Accuracy	total error	table	WSCT tot
67	Binks_1999	67.4	332	2GC	35	18:00	Accuracy	error	table	WSCT pe
72	Linde_1999	72.1	703	2GC		16:00	Accuracy	# error	table	
72	Linde_1999	72.2	703	2GC		22:00	Accuracy	# error	table	
72	Linde_1999	72.3	703	2GC		4:00	Accuracy	# error	table	
72	Linde_1999	72.4	703	2GC		10:00	Accuracy	# error	table	
72	Linde_1999	72.5	703	2GC		16:00	Accuracy	# error	table	
72	Linde_1999	72.6	703	2GC		22:00	Accuracy	# error	table	
72	Linde_1999	72.7	703	2GC		4:00	Accuracy	# error	table	
72	Linde_1999	72.8	703	2GC		10:00	Accuracy	# error	table	
72	Linde_1999	72.9	703	2GC		16:00	Accuracy	# error	table	
92	Elkin_1974	92.14	195	2GC	12	21:00	Accuracy	median # copying erro		median # c
92	Elkin_1974	92.15	195	2GC	25	9:00	Accuracy	median # copying errors		
92	Elkin_1974	92.16	195	2GC	31	15:00	Accuracy	median # copying errors		
92	Elkin_1974	92.17	195	2GC	37	21:00	Accuracy	median # copying errors		
92	Elkin_1974	92.18	195	2GC	49	9:00	Accuracy	median # copying errors		
92	Elkin_1974	92.19	195	2GC	55	15:00	Accuracy	median # copying errors		
100	Lieberman_2005	100.3	425	RM	77	18:00, 12:0	Accuracy	# incorrec	table	4CRT-erro
100	Lieberman_2005	100.4	425	RM	94	18:00, 05:0	Accuracy	# incorrec	table	
103	Doran_2001	103.45	257	RM	0	8:00	Accuracy	# of errors	read from graph	
103	Doran_2001	103.46	257	RM	2	10:00	Accuracy	# of errors	read from graph	
103	Doran_2001	103.47	257	RM	4	12:00	Accuracy	# of errors	read from graph	
103	Doran_2001	103.48	257	RM	6	14:00	Accuracy	# of errors	read from graph	
103	Doran_2001	103.49	257	RM	8	16:00	Accuracy	# of errors	read from graph	
103	Doran_2001	103.5	257	RM	10	18:00	Accuracy	# of errors	read from graph	
103	Doran_2001	103.51	257	RM	12	20:00	Accuracy	# of errors	read from graph	
103	Doran_2001	103.54	257	RM	18	2:00	Accuracy	# of errors	read from graph	
103	Doran_2001	103.57	257	RM	24	8:00	Accuracy	# of errors	read from graph	
103	Doran_2001	103.6	257	RM	30	14:00	Accuracy	# of errors	read from graph	
103	Doran_2001	103.63	257	RM	36	18:00	Accuracy	# of errors	read from graph	
103	Doran_2001	103.66	257	RM	42	24:00:00	Accuracy	# of errors	read from graph	
103	Doran_2001	103.69	257	RM	48	6:00	Accuracy	# of errors	read from graph	
103	Doran_2001	103.72	257	RM	54	12:00	Accuracy	# of errors	read from graph	
103	Doran_2001	103.75	257	RM	60	16:00	Accuracy	# of errors	read from graph	
103	Doran_2001	103.78	257	RM	66	22:00	Accuracy	# of errors	read from graph	
103	Doran_2001	103.81	257	RM	72	4:00	Accuracy	# of errors	read from graph	
103	Doran_2001	103.84	257	RM	78	10:00	Accuracy	# of errors	read from graph	
103	Doran_2001	103.87	257	RM	84	16:00	Accuracy	# of errors	read from graph	

Table 134: Number of Errors Raw Data Part 1b

	N				Statistical Data								
	Control		Test		Mean		Stdev		Standard Error		Diff Means	Poooled	
Study Id #	Assigned	Observed	Assigned	Observed	Control	Test	Control	Test	Control	Test	T-C	Stdev	B Stdev
5	39	39	39	39	0.36	0.39					-0.03		
5	39	39	39	39		1.08					-1.08		
5	39	39	39	39		0.98					-0.98		
5	39	39	39	39		1.67					-1.67		
5	39	39	39	39		3.1					-3.1		
10	12	12	12	12	0.88	0.79	0.762102	0.796743	0.22	0.23	0.09	0.779615	1.102543
20	74	74	74	74	0	-	visual vigilance						
20	74	74	74	74	0	5					-5		
20	74	74	74	74	0	20					-20		
20	74	74	74	74	0	40					-40		
20	74	74	74	74	0	-							
20	74	74	74	74	0	5					-5		
20	74	74	74	74	0	17					-17		
20	74	74	74	74	0	25					-25		
49	35	35	35	35	6	12	2.366432	3.549648	0.4	0.6	-6	3.016621	4.266146
67	32	32	29	29	43.8	35	20.1	20.6			8.8	20.33882	28.78142
67	32	32	29	29	43.5	35.1	28.8	27			8.4	27.96021	39.47708
67	32	32	29	29	13.4	11.3	12.4	11.2			2.1	11.84567	16.70928
72	12	12	12	12	27.2	24.5	18	16.9			2.7	18.10632	24.69028
72	12	12	12	12	14.6	15.7	18.6	13.1			-1.1	19.06292	22.75016
72	12	12	12	12	8.5	16.1	9.7	20.3			-7.6	7.892401	22.49844
72	12	12	12	12	5.8	14.2	4.7	23.3			-8.4		23.76931
72	12	12	12	12	4.3	11.6	3.4	20.3			-7.3		20.58276
72	12	12	12	12	0.58	0.37	0.29	0.35			0.21	0.283302	0.454533
72	12	12	12	12	0.74	0.33	0.16	0.56			0.41		0.582409
72	12	12	12	12	0.77	0.43	0.16	0.62			0.34		0.640312
72	12	12	12	12	0.83	0.5	0.11	0.65			0.33		0.659242
92	20	20	20	20	2	1					1		
92	20	20	20	20	2	2.2					-0.2		
92	20	20	20	20	2	2.5					-0.5		
92	20	20	20	20	3	1					2		
92	20	20	20	20	5	1					4		
92	20	20	20	20	7	1					6		
100	31	31	31	31	12.5	24.7	18.9304	16.70329	3.4	3	-12.2	17.85161	25.24599
100	31	31	31	31	12.5	39.8	18.9304	25.05494	3.4	4.5	-27.3	22.20484	31.40239
103	15	15	15	13		1.25	1.25	2.25347			-1.25	1.784684	2.576941
103	15	15	15	13		2	1.25	2.25347			-2	1.784684	2.576941
103	15	15	15	13		2.3	1.25	2.25347			-2.3	1.784684	2.576941
103	15	15	15	13		2.55	1.25	2.25347			-2.55	1.784684	2.576941
103	15	15	15	13		2.75	1.25	2.25347			-2.75	1.784684	2.576941
103	15	15	15	13		1.75	1.2	2.163331			-1.75	1.713296	2.473863
103	15	15	15	13		3	2.5	4.506939			-3	3.569368	5.153882
103	15	15	15	13		3.75	1.3	2.343608			-3.75	1.856071	2.680019
103	15	15	15	13		7.5	4.5	8.11249			-7.5	6.424862	9.276988
103	15	15	15	13		5	2.5	4.506939			-5	3.569368	5.153882
103	15	15	15	13		3	1.25	2.25347			-3	1.784684	2.576941
103	15	15	15	13		5	3	5.408327			-5	4.283241	6.184658
103	15	15	15	13		6.25	4.25	7.661796			-6.25	6.067925	8.761599
103	15	15	15	13		5.5	1.5	2.704163			-5.5	2.141621	3.092329
103	15	15	15	13		6.25	4.75	8.563184			-6.25	6.781798	9.792376
103	15	15	15	13		8.75	6.25	11.26735			-8.75	8.923419	12.88471
103	15	15	15	13		9	8.75	15.77429			-9	12.49279	18.03859
103	15	15	15	13		12.5	6.25	11.26735			-12.5	8.923419	12.88471
103	15	15	15	13		13.75	7.5	13.52082			-13.75	10.7081	15.46165

Table 135: Number Correct Raw Data Part 1a

Study Id #	1st Author_year	Effect Size Id #	Page #	Type of Comparison	Hours of Wakefulness	Time of Measure	Performance Var	Task Info	Calc Procedure	Var/task Info
5	Williamson_2000	5.16	652	RM	2.27	8:00	accuracy	Mackwort	table	Mackwort
5	Williamson_2000	5.17	652	RM	13.27	19:00	accuracy	Mackwort	table	Mackwort
5	Williamson_2000	5.18	652	RM	14	19:44	accuracy	Mackwort	table	Mackwort
5	Williamson_2000	5.19	652	RM	18	23:44	Accuracy	Mackwort	table	Mackwort
5	Williamson_2000	5.2	652	RM	22	27:44:00	Accuracy	Mackwort	table	Mackwort
21	Wilson_2007	21.1	228	RM	16.5	21:00	accuracy	# of respo	read from graph	
21	Wilson_2007	21.2	228	RM	19.5	0:00	accuracy	# of respo	read from g	PVT - acc
21	Wilson_2007	21.3	228	RM	22.5	3:00	accuracy	# of respo	read from g	PVT - acc
21	Wilson_2007	21.4	228	RM	25.5	6:00	accuracy	# of respo	read from g	PVT - acc
21	Wilson_2007	21.5	228	RM	28.5	9:00	accuracy	# of respo	read from g	PVT - acc
27	Porcu_1998	27.1	1198	RM	acute shift of w	baseline	accuracy	# hits in digit symbol su		DSST
27	Porcu_1998	27.2	1198	RM	1	23:00	accuracy	# hits in digit symbol su		DSST
27	Porcu_1998	27.3	1198	RM	3	1:00	accuracy	# hits in digit symbol su		DSST
27	Porcu_1998	27.4	1198	RM	5	3:00	accuracy	# hits in digit symbol su		DSST
27	Porcu_1998	27.5	1198	RM	7	5:00	accuracy	# hits in digit symbol su		DSST
27	Porcu_1998	27.6	1198	RM		baseline	Accuracy	# hits in Deux barrage		DBT
27	Porcu_1998	27.7	1198	RM		23:00	Accuracy	# hits in Deux barrage		DBT
27	Porcu_1998	27.8	1198	RM		1:00	Accuracy	# hits in Deux barrage		DBT
27	Porcu_1998	27.9	1198	RM		3:00	Accuracy	# hits in Deux barrage		DBT
27	Porcu_1998	27.10	1198	RM		5:00	Accuracy	# hits in Deux barrage		DBT
27	Porcu_1998	27.16	1198	RM		baseline	Accuracy	# hits in LCT		LCT
27	Porcu_1998	27.17	1198	RM		23:00	Accuracy	# hits in LCT		LCT
27	Porcu_1998	27.18	1198	RM		1:00	Accuracy	# hits in LCT		LCT
27	Porcu_1998	27.19	1198	RM		3:00	Accuracy	# hits in LCT		LCT
41	Monk_1997	41.1	15	RM	2	9:00	Accuracy	residuals	read from g	Reasoning
41	Monk_1997	41.2	15	RM	4	11:00	Accuracy	residuals	read from g	Reasoning
41	Monk_1997	41.3	15	RM	6	13:00	Accuracy	residuals	read from g	Reasoning
41	Monk_1997	41.4	15	RM	8	15:00	Accuracy	residuals	read from g	Reasoning
41	Monk_1997	41.5	15	RM	10	17:00	Accuracy	residuals	read from g	Reasoning
41	Monk_1997	41.6	15	RM	12	19:00	Accuracy	residuals	read from g	Reasoning
41	Monk_1997	41.7	15	RM	14	21:00	Accuracy	residuals	read from g	Reasoning
41	Monk_1997	41.8	15	RM	16	23:00	Accuracy	residuals	read from g	Reasoning
41	Monk_1997	41.9	15	RM	18	1:00	Accuracy	residuals	read from g	Reasoning
41	Monk_1997	41.1	15	RM	20	3:00	Accuracy	residuals	read from g	Reasoning
41	Monk_1997	41.11	15	RM	22	5:00	Accuracy	residuals	read from g	Reasoning
41	Monk_1997	41.12	15	RM	24	7:00	Accuracy	residuals	read from g	Reasoning
41	Monk_1997	41.13	15	RM	26	9:00	Accuracy	residuals	read from g	Reasoning
41	Monk_1997	41.14	15	RM	28	11:00	Accuracy	residuals	read from g	Reasoning
41	Monk_1997	41.15	15	RM	30	13:00	Accuracy	residuals	read from g	Reasoning
41	Monk_1997	41.16	15	RM	32	15:00	Accuracy	residuals	read from g	Reasoning
41	Monk_1997	41.17	15	RM	34	17:00	Accuracy	residuals	read from g	Reasoning
41	Monk_1997	41.18	15	RM	36	19:00	Accuracy	residuals	read from g	Reasoning
41	Monk_1997	41.73	14	RM	2	9:00	Accuracy	residuals	read from g	Vigilance l
41	Monk_1997	41.74	14	RM	4	11:00	Accuracy	residuals	read from g	Vigilance l
41	Monk_1997	41.75	14	RM	6	13:00	Accuracy	residuals	read from g	Vigilance l
41	Monk_1997	41.76	14	RM	8	15:00	Accuracy	residuals	read from g	Vigilance l
41	Monk_1997	41.77	14	RM	10	17:00	Accuracy	residuals	read from g	Vigilance l
41	Monk_1997	41.78	14	RM	12	19:00	Accuracy	residuals	read from g	Vigilance l
41	Monk_1997	41.79	14	RM	14	21:00	Accuracy	residuals	read from g	Vigilance l
41	Monk_1997	41.8	14	RM	16	23:00	Accuracy	residuals	read from g	Vigilance l
41	Monk_1997	41.81	14	RM	18	1:00	Accuracy	residuals	read from g	Vigilance l
41	Monk_1997	41.82	14	RM	20	3:00	Accuracy	residuals	read from g	Vigilance l
41	Monk_1997	41.83	14	RM	22	5:00	Accuracy	residuals	read from g	Vigilance l
41	Monk_1997	41.84	14	RM	24	7:00	Accuracy	residuals	read from g	Vigilance l

Table 136: Number Correct Raw Data Part 1b

	N				Statistical Data								
	Control		Test		Mean		Stdev		Standard Error		Diff Means	Poooled	
Study Id #	Assigned	Observed	Assigned	Observed	Control	Test	Control	Test	Control	Test	T-C	Stdev	B Stdev
5	39	39	39	39	12.64	12.77					0.13		
5	39	39	39	39	12.64	12					12		
5	39	39	39	39	12.64	11.89					11.89		
5	39	39	39	39	12.64	9.86					9.86		
5	39	39	39	39	12.64	7.04					7.04		
21	9	9	9	9		82.5					82.5		
21	9	9	9	9		81					81		
21	9	9	9	9		81					81		
21	9	9	9	9		72					72		
21	9	9	9	9		81					81		
27	10	10	10	10	135.6		32.1				-135.6	22.69813	32.1
27	10	10	10	10	135.6	139	32.1	37.8			3.4	35.06601	49.59083
27	10	10	10	10	135.6	137.5	32.1	27.5			1.9	29.88863	42.2689
27	10	10	10	10	135.6	131.9	32.1	29.6			-3.7	30.87531	43.66429
27	10	10	10	10	135.6	138.9	32.1	37.7			3.3	35.01214	49.51464
27	10	10	10	10	234.3		16.5				-234.3	11.66726	16.5
27	10	10	10	10	234.3	239.5	16.5	8.6			5.2	13.15694	18.60672
27	10	10	10	10	234.3	240.4	16.5	8			6.1	12.9663	18.33712
27	10	10	10	10	234.3	236.5	16.5	8.1			2.2	12.99731	18.38097
27	10	10	10	10	234.3	232.1	16.5	78			-2.2	56.37486	79.72609
27	7	7	7	7	265.4		36.9				-265.4	26.09224	36.9
27	7	7	7	7	265.4	267.6	36.9	17.7			2.2	28.93873	40.92554
27	7	7	7	7	265.4	263.3	36.9	37.4			-2.1	37.15084	52.53922
27	7	7	7	7	265.4	265	36.9	42			-0.4	39.53233	55.90716
41	17	17	17	17		0.5		1.236932		0.3	0.5	0.943398	1.334166
41	17	17	17	17		0.25		1.030776		0.25	1.5	0.75	1.06066
41	17	17	17	17		-1.8		3.710795		0.9	2.5	2.916333	4.124318
41	17	17	17	17		0.5		1.030776		0.25	3.5	0.810093	1.145644
41	17	17	17	17		-1		1.236932		0.3	4.5	1.124722	1.590597
41	17	17	17	17		0.8		1.236932		0.3	5.5	1.041633	1.473092
41	17	17	17	17		0.5		1.236932		0.3	6.5	0.943398	1.334166
41	17	17	17	17		0.7		1.236932		0.3	7.5	1.004988	1.421267
41	17	17	17	17		1		1.649242		0.4	8.5	1.363818	1.92873
41	17	17	17	17		0.5		0.412311		0.1	9.5	0.458258	0.648074
41	17	17	17	17		-1		0.824621		0.2	10.5	0.916515	1.296148
41	17	17	17	17		0.75		3.710795		0.9	11.5	2.676985	3.785829
41	17	17	17	17		0		3.710795		0.9	12.5	2.623928	3.710795
41	17	17	17	17		-1.8		2.886174		0.7	13.5	2.405203	3.40147
41	17	17	17	17		-1.9		3.298485		0.8	14.5	2.691654	3.806573
41	17	17	17	17		-1.1		3.710795		0.9	15.5	2.736786	3.8704
41	17	17	17	17		-1.5		3.298485		0.8	16.5	2.562226	3.623534
41	17	17	17	17		-1.3		3.710795		0.9	17.5	2.780288	3.931921
41	17	17	17	17		-3		12.36932		3	18.5	9	12.72792
41	17	17	17	17		-2		10.30776		2.5	19.5	7.424621	10.5
41	17	17	17	17		-5		11.33854		2.75	20.5	8.762491	12.39203
41	17	17	17	17		4		11.33854		2.75	21.5	8.501838	12.02341
41	17	17	17	17		7		10.30776		2.5	22.5	8.810505	12.45994
41	17	17	17	17		8		7.215435		1.75	23.5	7.617824	10.77323
41	17	17	17	17		12		7.215435		1.75	24.5	9.901073	14.00223
41	17	17	17	17		5		13.40009		3.25	25.5	10.11342	14.30253
41	17	17	17	17		0		13.40009		3.25	26.5	9.475297	13.40009
41	17	17	17	17		-8		16.49242		4	27.5	12.96148	18.3303
41	17	17	17	17		-14		13.40009		3.25	28.5	13.70333	19.37943
41	17	17	17	17		-13		13.40009		3.25	29.5	13.20156	18.66983
41	17	17	17	17		-5		13.40009		3.25	30.5	10.11342	14.30253
41	17	17	17	17		-4		11.33854		2.75	31.5	8.501838	12.02341
41	17	17	17	17		-2		14.43087		3.5	32.5	10.3017	14.5688
41	17	17	17	17		2		10.30776		2.5	33.5	7.424621	10.5
41	17	17	17	17		9		13.40009		3.25	34.5	11.41408	16.14195
41	17	17	17	17		9		12.36932		3	35.5	10.81665	15.29706

Table 137: Number Correct Raw Data Part 2a

Study Id #	1st Author_year	Effect Size Id #	Page #	Type of Comparison	Hours of Wakefulness	Time of Measure	Performance Var	Task Info	Calc Procedure	Var/task Info
45	Halbach_2003	45.3	1200	RM	one night on call		Accuracy	# of words	table	
45	Halbach_2003	45.4	1200	RM	one night on call		Accuracy	# of words	table	
45	Halbach_2003	45.5	1200	RM	one night on call		Accuracy	# of words	table	
55	Webb_1982	55.1	274	RM			Accuracy	hits	table	AVI
55	Webb_1982	55.2	274	RM			Accuracy	hits	table	AVI
55	Webb_1982	55.3	274	RM			Accuracy	hits	table	AVII
55	Webb_1982	55.4	274	RM			Accuracy	hits	table	AVII
55	Webb_1982	55.7	274	RM			Accuracy	#	table	REA - N
55	Webb_1982	55.8	274	RM			Accuracy	#	table	REA - N
55	Webb_1982	55.11	274	RM			Accuracy	# of words	table	RA
55	Webb_1982	55.12	274	RM			Accuracy	# of words	table	RA
57	Englund_1985	57.11	81	RM	1.5	9:30	Accuracy	# correct	table	Visual Vig
57	Englund_1985	57.12	81	RM	6	14:00	Accuracy	# correct	table	Visual Vig
57	Englund_1985	57.13	81	RM	10.75	18:45	Accuracy	# correct	table	Visual Vig
57	Englund_1985	57.14	81	RM	15.75	23:45	Accuracy	# correct	table	Visual Vig
60	Christensen_1977	60.1	105	RM	worked at least 15hrs conti		Accuracy	# deteced	table	
64	Hoddes_1973	64.1	433	RM	88 hrs		Accuracy	total # cor	table	Wilkinson
64	Hoddes_1973	64.2	433	RM	88 hrs		Accuracy	total # cor	table	Wilkinson
65	Webb_1984	65.1	52	RM	42.5	sesson I	Accuracy	# hits	read from g	Aud Vig
65	Webb_1984	65.2	52	RM	42.5	sesson II	Accuracy	# hits	read from g	Aud Vig
65	Webb_1984	65.3	52	RM	42.5	sesson III	Accuracy	# hits	read from g	Aud Vig
65	Webb_1984	65.4	52	RM	42.5	sesson IV	Accuracy	# hits	read from g	Aud Vig
65	Webb_1984	65.5	52	RM	42.5		Accuracy	# attempte	read from g	Addition
65	Webb_1984	65.6	52	RM	42.5		Accuracy	# attempte	read from g	Addition
65	Webb_1984	65.7	52	RM	42.5		Accuracy	# attempte	read from g	Addition
65	Webb_1984	65.8	52	RM	42.5		Accuracy	# attempte	read from g	Addition
65	Webb_1984	65.9	52	RM	42.5		Accuracy	# correct	read from g	Word Mem
65	Webb_1984	65.1	52	RM	42.5		Accuracy	# correct	read from g	Word Mem
65	Webb_1984	65.11	52	RM	42.5		Accuracy	# correct	read from g	Word Mem
65	Webb_1984	65.12	52	RM	42.5		Accuracy	# correct	read from g	Word Mem
65	Webb_1984	65.13	53	RM	42.5		Accuracy	# attempte	read from g	reasoning
65	Webb_1984	65.14	53	RM	42.5		Accuracy	# attempte	read from g	reasoning
65	Webb_1984	65.15	53	RM	42.5		Accuracy	# attempte	read from g	reasoning
65	Webb_1984	65.16	53	RM	42.5		Accuracy	# attempte	read from g	reasoning
65	Webb_1984	65.17	53	RM	42.5		Accuracy	# mean co	read from g	remote ass
65	Webb_1984	65.18	53	RM	42.5		Accuracy	# mean co	read from g	remote ass
65	Webb_1984	65.19	53	RM	42.5		Accuracy	# mean co	read from g	remote ass
65	Webb_1984	65.2	53	RM	42.5		Accuracy	# mean co	read from g	remote ass
66	Haslam_1982	66.1	168	RM	baseline	13:00	Accuracy	avg # corr	read from g	Baddeley l
66	Haslam_1982	66.2	168	RM	42	13:00	Accuracy	avg # corr	read from g	Baddeley l
66	Haslam_1982	66.3	168	RM	66	13:00	Accuracy	avg # corr	read from g	Baddeley l
66	Haslam_1982	66.4	168	RM	90	13:00	Accuracy	avg # corr	read from g	Baddeley l
66	Haslam_1982	66.5	168	RM	baseline	13:00	Accuracy	avg # corr	read from g	rifle shooti
66	Haslam_1982	66.6	168	RM	42	13:00	Accuracy	avg # corr	read from g	rifle shooti
66	Haslam_1982	66.7	168	RM	66	13:00	Accuracy	avg # corr	read from g	rifle shooti
66	Haslam_1982	66.8	168	RM	90	13:00	Accuracy	avg # corr	read from g	rifle shooti
66	Haslam_1982	66.9	168	RM	baseline	13:00	Accuracy	avg # corr	read from g	decoding
66	Haslam_1982	66.10	168	RM	42	13:00	Accuracy	avg # corr	read from g	decoding
66	Haslam_1982	66.11	168	RM	66	13:00	Accuracy	avg # corr	read from g	decoding
66	Haslam_1982	66.12	168	RM	90	13:00	Accuracy	avg # corr	read from g	decoding
67	Binks_1999	67.5	331	2GC	35	18:00	Accuracy	total # of a	table	word fluen
68	Deaconson_1988	68.1	1723	RM	< 4hrs in past 2	06:00 to 08:	Accuracy	mean test	table	Aud Serial
68	Deaconson_1988	68.2	1723	RM	< 4hrs in past 2	06:00 to 08:	Accuracy	mean test	table	Trail-makin
68	Deaconson_1988	68.3	1723	RM	< 4hrs in past 2	06:00 to 08:	Accuracy	mean test	table	gramm rea
68	Deaconson_1988	68.4	1723	RM	< 4hrs in past 2	06:00 to 08:	Accuracy	mean test	table	paper form
68	Deaconson_1988	68.5	1723	RM	< 4hrs in past 2	06:00 to 08:	Accuracy	mean test	table	purdue peg
69	Leonard_1998	69.2	24	RM	before and afer 32 hrs on c		Accuracy	mean test	table	stroop
69	Leonard_1998	69.3	24	RM	before and afer 32 hrs on c		Accuracy	mean test	table	gramm rea
70	Storer_1989	70.1	31	RM	24		Accuracy	% of ques	table	cogntive te
70	Storer_1989	70.5	31	RM	34		Accuracy	% of ques	table	34-hr grou

Table 138: Number Correct Raw Data Part 2b

	N				Statistical Data								
	Control		Test		Mean		Stdev		Standard Error		Diff Means	Poooled	
Study Id #	Assigned	Observed	Assigned	Observed	Control	Test	Control	Test	Control	Test	T-C	Stdev	B Stdev
45						3.5	7				3.5	4.949747	7
45						0.7	2.5				0.7	1.767767	2.5
45						0.3	2				0.3	1.414214	2
55					15.5	11.2	5	4.4			-4.3	4.709565	6.66033
55					17.3	13.7	2.5	3.4			-3.6	2.984125	4.22019
55					12.8	11.8	4.1	3.1			-1	3.634556	5.140039
55					15.8	12	2.3	5.7			-3.8	4.346263	6.146544
55					28.5	28	3	4.8			-0.5	4.002499	5.660389
55					95.2	93.5	4	5.5			-1.7	4.808846	6.800735
55					7.2	7	2.8	3.5			-0.2	3.169385	4.482187
55					10.2	12.2	3.2	2.2			2	2.745906	3.883298
57	22	22	22	22		74.4		15.2			74.4		15.2
57	22	22	22	22		77		22.4			77		22.4
57	22	22	22	22		75.2		24.3			75.2		24.3
57	22	22	22	22		76.4		23.6			76.4		23.6
60	14	14	14	14				0.74			0	0.523259	0.74
64	5	5	5	5	190.2	189.4	39.85	37.07			-0.8	38.48511	54.42616
64	5	5	5	5	24.1	19.7	4.38	4.2			-4.4	4.290944	6.068311
65	6	6	6	6	13	12					-1	0	0
65					13.5	10					-3.5	0	0
65					14	9					-5	0	0
65					12	8					-4	0	0
65					44	40					-4	0	0
65					46	39.5					-6.5	0	0
65					46	36					-10	0	0
65					41	37					-4	0	0
65					9	6.5					-2.5	0	0
65					13	5					-8	0	0
65					12	6					-6	0	0
65					11.5	7					-4.5	0	0
65					28.5	28					-0.5	0	0
65					31.5	27					-4.5	0	0
65					36	26					-10	0	0
65					35.5	28					-7.5	0	0
65					7.25	7					-0.25	0	0
65					8	9					1	0	0
65					7.75	12.5					4.75	0	0
65					9.5	11.5					2	0	0
66	10	10	10	10	11	-	0.825	-					
66	10	10	10	10	11	7.8	0.825	1.1			-3.2	0.972272	1.375
66	10	10	10	10	11	4.5	0.825	1.1			-6.5	0.972272	1.375
66	10	10	10	10	11	2.9	0.825	0.8			-8.1	0.812596	1.149184
66					6.1						-6.1	0	0
66					6.1	5.1		1.5			-1	1.06066	1.5
66					6.1	4.6		2.5			-1.5	1.767767	2.5
66					6.1	5.3		2.4			-0.8	1.697056	2.4
66	10	10	10	10	39.75						-39.75	0	0
66	10	10	10	10	39.75	35.2		12.6			-4.55	8.909545	12.6
66	10	10	10	10	39.75	22.7		11.3			-17.05	7.990307	11.3
66	10	10	10	10	39.75	15.9		15.5			-23.85	10.96016	15.5
67	32	32	32	29	39.9	41.4	8.8	10.3			1.5	9.541311	13.54732
68	26	26	26	26	81.5	78.22	10.22	15.85			-3.28	13.3355	18.85924
68	26	26	26	26	40.17	41.43	16.41	17.16			1.26	16.78919	23.7435
68	26	26	26	26	21.21	20.05	5.24	5.75			-1.16	5.500914	7.779467
68	26	26	26	26	12.58	12.43	2.16	2.42			-0.15	2.293687	3.243763
68	26	26	26	26	33.84	33.11	3.64	3.56			-0.73	3.600222	5.091483
69	16	16	16	16	42	46.5					4.5	0	0
69	16	16	16	16	24	28.5					4.5	0	0
70					67.31	65.54	-1.77				-1.77	1.251579	1.77
70					67.31	65.36	-1.95				-1.95	1.378858	1.95

Table 139: Number Correct Raw Data Part 3a

Study Id #	1st Author_year	Effect Size Id #	Page #	Type of Comparison	Hours of Wakefulness	Time of measure	Performance Var	Task info	Calc procedure	Var/task info
78	Akerstedt_1977	78.1	390	RM	24		accuracy	# hits	table	# of hits
78	Akerstedt_1977	78.2	390	RM	48		accuracy	# hits	table	
78	Akerstedt_1977	78.3	390	RM	72		accuracy	# hits	table	
79	Richter_2005	79.1	398	RM		20:00-21:00	accuracy	# hits	read from g	pre/post of
79	Richter_2005	79.2	398	RM		21:00-22:00	accuracy	# hits	read from graph	
79	Richter_2005	79.3	398	RM		22:00-23:00	accuracy	# hits	read from graph	
79	Richter_2005	79.4	398	RM		23-24	accuracy	# hits	read from graph	
79	Richter_2005	79.5	398	RM		24-01	accuracy	# hits	read from graph	
79	Richter_2005	79.6	398	RM		01:00-02:00	accuracy	# hits	read from graph	
79	Richter_2005	79.7	398	RM		02:00-03:00	accuracy	# hits	read from graph	
79	Richter_2005	79.8	398	RM		03:00-04:00	accuracy	# hits	read from graph	
94	Haslam_1983	94.1	366	RM	89.75	10am - base	accuracy	# correct	table	encoding g
94	Haslam_1983	94.2	366	RM	89.75	10:00	accuracy	# correct	table	encoding g
94	Haslam_1983	94.3	366	RM	89.75	2:30	accuracy	# correct	table	encoding g
94	Haslam_1983	94.4	366	RM	89.75	10:00	accuracy	# correct	table	encoding g
94	Haslam_1983	94.5	366	RM	89.75	2:30	accuracy	# correct	table	encoding g
94	Haslam_1983	94.6	366	RM	89.75	10:00	accuracy	# correct	table	encoding g
94	Haslam_1983	94.7	366	RM	89.75	2:30	accuracy	# correct	table	encoding g
94	Haslam_1983	94.8	366	RM	89.75	10:00	accuracy	# correct	table	encoding g
94	Haslam_1983	94.9	366	RM	89.75	23:30	accuracy	# correct	table	encoding g
94	Haslam_1983	94.1	366	RM	89.75	10:00	accuracy	# correct	table	decoding g
94	Haslam_1983	94.11	366	RM	89.75	10:00	accuracy	# correct	table	decoding g
94	Haslam_1983	94.12	366	RM	89.75	2:30	accuracy	# correct	table	decoding g
94	Haslam_1983	94.13	366	RM	89.75	10:00	accuracy	# correct	table	decoding g
94	Haslam_1983	94.14	366	RM	89.75	2:30	accuracy	# correct	table	decoding g
94	Haslam_1983	94.15	366	RM	89.75	10:00	accuracy	# correct	table	decoding g
94	Haslam_1983	94.16	366	RM	89.75	2:30	accuracy	# correct	table	decoding g
94	Haslam_1983	94.17	366	RM	89.75	10:00	accuracy	# correct	table	decoding g
94	Haslam_1983	94.18	366	RM	89.75	23:30	accuracy	# correct	table	decoding g
94	Haslam_1983	94.19	366	RM	89.75	10:00	accuracy	# correct	table	decoding n
94	Haslam_1983	94.2	366	RM	89.75	10:00	accuracy	# correct	table	decoding n
94	Haslam_1983	94.21	366	RM	89.75	2:30	accuracy	# correct	table	decoding n
94	Haslam_1983	94.22	366	RM	89.75	10:00	accuracy	# correct	table	decoding n
94	Haslam_1983	94.23	366	RM	89.75	2:30	accuracy	# correct	table	decoding n
94	Haslam_1983	94.24	366	RM	89.75	10:00	accuracy	# correct	table	decoding n
94	Haslam_1983	94.25	366	RM	89.75	2:30	accuracy	# correct	table	decoding n
94	Haslam_1983	94.26	366	RM	89.75	10:00	accuracy	# correct	table	decoding n
94	Haslam_1983	94.27	366	RM	89.75	23:30	accuracy	# correct	table	decoding n
99	May_1987	99.1	452	RM	64	-	accuracy	mean test	table	
99	May_1987	99.2	452	RM	64		accuracy	mean test	table	
99	May_1987	99.3	452	RM	64		accuracy	mean test	table	CF - flexib
99	May_1987	99.4	452	RM	64		accuracy	mean test	table	CS - speec
99	May_1987	99.5	452	RM	64		accuracy	mean test	table	CV - verba
99	May_1987	99.6	452	RM	64		accuracy	mean test	table	FA - assoc
99	May_1987	99.7	452	RM	64		accuracy	mean test	table	FI - ideatic
99	May_1987	99.8	452	RM	64		accuracy	mean test	table	I - Inductic
99	May_1987	99.9	452	RM	64		accuracy	mean test	table	IP - integra
99	May_1987	99.10	452	RM	64		accuracy	mean test	table	MS - mem
99	May_1987	99.11	452	RM	64		accuracy	mean test	table	N - numbe
99	May_1987	99.12	452	RM	64		accuracy	mean test	table	P - percep
99	May_1987	99.13	452	RM	64		accuracy	mean test	table	RL - logica
99	May_1987	99.14	452	RM	64		accuracy	mean test	table	S - spatial
99	May_1987	99.15	452	RM	64		accuracy	mean test	table	SS - spatia
99	May_1987	99.16	452	RM	64		accuracy	mean test	table	VZ - visua

Table 140: Number Correct Raw Data Part 3b

	N				Statistical Data								
	Control		Test		Mean		Standard Deviation		Standard Error		Diff Means	Poooled	
Study Id #	Assigned	Observed	Assigned	Observed	Control	Test	Control	Test	Control	Test	T-C	Stdev	B Stdev
78											0	0	0
78											0	0	0
78											0	0	0
79	20	20	20	20		4.1		1.788854		0.4	4.1	1.264911	1.788854
79	20	20	20	20		3.9		2.236068		0.5	3.9	1.581139	2.236068
79	20	20	20	20		3.5		2.236068		0.5	3.5	1.581139	2.236068
79	20	20	20	20		4		2.236068		0.5	4	1.581139	2.236068
79	20	20	20	20		3.6		2.236068		0.5	3.6	1.581139	2.236068
79	20	20	20	20		2.3		4.472136		1	2.3	3.162278	4.472136
79	20	20	20	20		1.85		4.472136		1	1.85	3.162278	4.472136
79	20	20	20	20		2.6		3.577709		0.8	2.6	2.529822	3.577709
94	10	10	10	10	10.3		4.1				-10.3	2.899138	4.1
94	10	10	10	10	11.4		4				-11.4	2.828427	4
94	10	10	10	10	10.85	10.9	4.05	5.1			0.05	4.605024	6.512488
94	10	10	10	10	10.85	9	4.05	5.1			-1.85	4.605024	6.512488
94	10	10	10	10	10.85	9.1	4.05	3.9			-1.75	3.975707	5.622499
94	10	10	10	10	10.85	8.1	4.05	3.5			-2.75	3.785003	5.352803
94	10	10	10	10	10.85	7.1	4.05	5.1			-3.75	4.605024	6.512488
94	10	10	10	10	10.85	7.7	4.05	3.9			-3.15	3.975707	5.622499
94	10	10	10	10	10.85	10.3	4.05	3.9			-0.55	3.975707	5.622499
94	10	10	10	10	7		4.3				-7	3.040559	4.3
94	10	10	10	10	8		3.8				-8	2.687006	3.8
94	10	10	10	10	7.5	7.6	4.05	3.4			0.1	3.739151	5.287958
94	10	10	10	10	7.5	5.5	4.05	3.7			-2	3.87895	5.485663
94	10	10	10	10	7.5	4.7	4.05	2.9			-2.8	3.522251	4.981215
94	10	10	10	10	7.5	6	4.05	3.4			-1.5	3.739151	5.287958
94	10	10	10	10	7.5	3.3	4.05	3.7			-4.2	3.87895	5.485663
94	10	10	10	10	7.5	2.8	4.05	1.5			-4.7	3.053891	4.318854
94	10	10	10	10	7.5	6.8	4.05	3.4			-0.7	3.739151	5.287958
94	10	10	10	10	35.8		16.7				-35.8	11.80868	16.7
94	10	10	10	10	45.9		8.5				-45.9	6.010408	8.5
94	10	10	10	10	40.85	40.3	12.6	14.2			-0.55	13.42386	18.9842
94	10	10	10	10	40.85	30.6	12.6	12.6			-10.25	12.6	17.81909
94	10	10	10	10	40.85	35.3	12.6	16.4			-5.55	14.62395	20.68139
94	10	10	10	10	40.85	28.2	12.6	15.1			-12.65	13.90629	19.66647
94	10	10	10	10	40.85	27.1	12.6	17.5			-13.75	15.24811	21.56409
94	10	10	10	10	40.85	27.6	12.6	18.7			-13.25	15.94443	22.54884
94	10	10	10	10	40.85	35.5	12.6	16.5			-5.35	14.68009	20.76078
99						168		4.5			168	3.181981	4.5
99						158		5.5			158	3.889087	5.5
99	45	38	45	38		-2.59		8.51			-2.59		8.51
99	45	38	45	38		-4.46		15.29			-4.46		15.29
99	44	37	44	37		-11.94		19.63			-11.94		19.63
99	44	7	44	7		-6.55		12.84			-6.55		12.84
99	46	34	46	34		10.35		22.29			10.35		22.29
99	44	37	44	37		3.92		13.04			3.92		13.04
99	46	34	46	34		7.75		23.58			7.75		23.58
99	46	34	46	34		-6.07		14.13			-6.07		14.13
99	46	34	46	34		-5.84		8.69			-5.84		8.69
99	44	37	44	37		2.8		15.29			2.8		15.29
99	45	38	45	38		-0.23		15.85			-0.23		15.85
99	44	37	44	37		-3.8		13.78			-3.8		13.78
99	45	38	45	38		22.75		15.61			22.75		15.61
99	46	34	46	34		2.63		17.9			2.63		17.9
99	45	38	45	38		-11.88		12.86			-11.88		12.86

F INTER-RATER RELIABILITY DATA

Table 141: Inter-rater Reliability Data Part 1

Study Id #	Variable	Hours of Wakefulness	Main Coder T-mean	Aux Coder T-mean	(M-A)/M T-% change
47	RT	24	2.95	2.9	1.69%
47	Lapse	24	18	18	0.00%
48	False +	22.15	0.195	0.195	0.00%
48	False +	30.75	0.2	0.2	0.00%
48	False +	57.75	0.19	0.19	0.00%
48	Hit Rate	22.15	0.978	0.959	1.94%
48	Hit Rate	30.75	0.96	0.915	4.69%
48	Hit Rate	57.75	0.92	0.985	7.07%
48	Hit RT	22.15	635	631	0.63%
48	Hit RT	30.75	640	641	0.16%
48	Hit RT	57.75	645	643	0.31%
98	RT	5.5	189	187	1.06%
98	RT	8	190	189	0.53%
98	RT	10.5	190.5	189.5	0.52%
98	RT	13	195	195	0.00%
98	RT	15.5	204	203	0.49%
98	RT	18	206	206	0.00%
98	RT	20.5	203	202	0.49%
98	RT	23	200.5	201	0.25%
98	RT	25.5	197	195	1.02%
98	RT	28	196	194.5	0.77%
98	RT	30.5	205	207	0.98%
98	RT	33	222	223	0.45%
98	RT	42	225	224	0.44%
98	RT	48	215.5	219	1.62%
98	RT	54	210	211	0.48%
98	RT	5.5	150.5	150	0.33%
98	RT	8	148	149	0.68%
98	RT	10.5	152	153	0.66%
98	RT	13	156	156	0.00%
98	RT	15.5	159	158	0.63%
98	RT	18	155	155	0.00%
98	RT	20.5	156	155.5	0.32%
98	RT	23	156.5	156.1	0.26%
98	RT	25.5	154.5	154	0.32%

Table 142: Inter-rater Reliability Data Continued Part 2

Study Id #	Variable	Hours of Wakefulness	Main Coder T-mean	Aux Coder T-mean	(M-A)/M T-% change
98	RT	28	154.5	154.5	0.00%
98	RT	30.5	167.5	165	1.49%
98	RT	33	170.5	170	0.29%
98	RT	42	172	172	0.00%
98	RT	48	168	168	0.00%
98	RT	54	158	157	0.63%
103	RT	0	350	310	11.43%
103	RT	2	400	360	10.00%
103	RT	4	350	320	8.57%
103	RT	6	500	500	0.00%
103	RT	8	350	325	7.14%
103	RT	10	350	320	8.57%
103	RT	12	345	315	8.70%
103	RT	14	350	320	8.57%
103	RT	16	350	325	7.14%
103	RT	18	450	400	11.11%
103	RT	20	700	600	14.29%
103	RT	22	1150	610	46.96%
103	RT	24	1500	1450	3.33%
103	RT	26	1550	1500	3.23%
103	RT	28	700	700	0.00%
103	RT	30	1000	900	10.00%
103	RT	32	900	825	8.33%
103	RT	34	600	600	0.00%
103	RT	36	450	325	27.78%
103	RT	38	900	875	2.78%
103	RT	40	600	600	0.00%
103	RT	42	1400	1375	1.79%
103	RT	44	1600	1530	4.38%
103	RT	46	1950	1875	3.85%
103	RT	48	1250	1250	0.00%
103	RT	50	1550	1480	4.52%
103	RT	52	1400	1380	1.43%
103	RT	54	1000	1000	0.00%
103	RT	56	1450	1410	2.76%

Table 143: Inter-rater Reliability Data Continued Part 3

Study Id #	Variable	Hours of Wakefulness	Main Coder T-mean	Aux Coder T-mean	(M-A)/M T-% change
103	RT	58	1100	1390	26.36%
103	RT	60	800	1000	25.00%
103	RT	62	1100	1450	31.82%
103	RT	64	1400	1325	5.36%
103	RT	66	1500	1500	0.00%
103	RT	68	2250	2250	0.00%
103	RT	70	2200	2100	4.55%
103	RT	72	2200	2100	4.55%
103	RT	74	1450	1425	1.72%
103	RT	76	1475	1475	0.00%
103	RT	78	1250	1250	0.00%
103	RT	80	1300	1300	0.00%
103	RT	82	1000	975	2.50%
103	RT	84	1550	1600	3.23%
103	RT	86	1150	1125	2.17%
103	# errors	0	2	1.5	25.00%
103	# errors	2	2.3	2.25	2.17%
103	# errors	4	2.55	2.6	1.96%
103	# errors	6	2.55	2.55	0.00%
103	# errors	8	2.3	2.2	4.35%
103	# errors	10	3	3	0.00%
103	# errors	12	2.75	2.75	0.00%
103	# errors	18	3	3.25	8.33%
103	# errors	24	7.5	7.475	0.33%
103	# errors	30	5	4.9	2.00%
103	# errors	36	3	2.52	16.00%
103	# errors	42	5	5	0.00%
103	# errors	48	6.25	6	4.00%
103	# errors	54	5.5	5.25	4.55%
103	# errors	60	6.25	6	4.00%
103	# errors	66	8.75	8	8.57%
103	# errors	72	9	9	0.00%
103	# errors	78	12.5	12.5	0.00%
103	# errors	84	13.6	12.6	7.35%

G INITIAL SEARCH RESULTS (i.e., 600 STUDIES)

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