EVALUATION OF AVIATION MAINTENANCE WORKING ENVIRONMENTS, FATIGUE AND MAINTENANCE ERRORS/ACCIDENTS

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Galen C. Bosley, PhD.
JIL Information Systems, Inc.

Ronald M. Miller, MS
Purdue University

Jean Watson
FAA Office of Aviation Medicine

1.1 EXECUTIVE SUMMARY

Human fatigue is a safety issue in aviation, and has been from the beginning because it affects all of those who are responsible for safety of flight, including the pilot, the air traffic controller, and the aviation maintenance professional. In 1989, the National Transportation Safety Board issued recommendations urging all modes of transportation to conduct research on fatigue in order to educate workers on the effects of fatigue and the proper health habits to reduce fatigue and its results, and thus achieve a greater level of transportation safety. This research focused on fatigue in the aviation maintenance environment.

The investigation addressed fatigue from the traditional sleep issues, but also examined environmental issues such as noise, working temperatures, and lighting. These environmental factors have been found to affect the onset of fatigue. In addition, background data was collected on lifestyle habits that may further affect whether an aviation maintenance worker would experience greater fatigue. The overall goal of the project was limited to: (1) determining the feasibility of collecting data at a maintenance facility; (2) evaluating the durability of data collection devices; (3) determining if different environmental conditions exist within the maintenance workplace; (4) identifying possible fatigue producing problem areas which can be examined; and (5) determining if this methodology is valid for use in the overall aviation maintenance industry.

Each aviation maintenance specialty was examined to determine whether the working environment differed from other specialty's working environments and how the environments changed with each shift. A specialty that may have an environment different from that of other aviation maintenance technicians (AMTs) was considered to be a microenvironment.

The findings of this research showed that valid data could be collected in a maintenance facility, and that data collection devices were accurate, reliable, and durable. Noise and low illumination appear to be significant factors that could increase fatigue across most AMT specialties. Outside ambient temperatures at the time of this study were unseasonably mild. Therefore temperature did not pose much of a problem during the study but it may have been if weather conditions were closer to seasonal norms. Additionally, sleep recordings found that sleep duration was inadequate to maintain alertness and prevent fatigue, and also there were variations in sleep duration between shifts. While the environmental parameters were similar at this site, further research needs to be conducted to determine whether environmental differences exist between AMT specialties. It was also concluded that the overall methodology is valid for use at other aviation maintenance locations.

1.2 INTRODUCTION

Airline safety depends on a multitude of individuals and professions, but there are three groups that stand in the forefront of this task: the pilots who fly the aircraft, the air traffic controllers who direct and choreograph flights, and the aviation maintenance technicians who keep the aircraft maintained and flying. Much attention has been given to pilot[1] and air traffic controller fatigue and error-making since they interface directly with the actual flight.[2,3] However, little attention has been focused on the aviation maintenance technician , whose work directly interfaces with each and every flight, starting with backing away from the gate, to blocking, and finally engine shutdown. Although the working environment of pilots and air traffic controllers is usually comfortable and uniform, the opposite exists for the working environment of area AMTs. In fact, the working environment for AMTs can vary considerably from day to day and from task to task. Hot days can be made worse by working in confined aircraft quarters or in poorly ventilated hangers. Working temperatures within hangers can vary greatly from floor to tail section, depending on the height at which the AMT is working. In addition, there is engine noise to cope with and poor weather when working on flight lines. Many of these environmental factors have been shown to impact worker performance over time by accelerating the onset of fatigue.[4] The onset of fatigue results in error-making and accidents in a wide variety of occupational pursuits. Unlike the pilots and air traffic controllers, there are few regulations to govern the working environments of aviation maintenance personnel or which address fatigue issues in this segment of the aviation industry. Therefore, understanding the conditions that predispose a worker toward maintenance errors/accidents could pay big dividends in safety, profitability and employee satisfaction. With competition continually increasing, the advantage of helping employees do their best by optimizing their environment is in the best interest of the company, the flying public, and the aviation maintenance professional.

1.3 TECHNICAL BACKGROUND

Aircraft maintenance errors have been reported as a contributing factor in 15% of major aircraft accidents from 1982 to 1991, at a cost of over 1400 lives.[5] Maintenance errors also contribute considerably to operational costs. Rankin, et al.[6] states that 50% of flight delays due to engine problems are maintenance error related and cost the airlines $10,000 per hour. At least 20-30% of in-flight error shutdowns are similarly related at a cost of $500,000 per shutdown, and 50% of flight cancellations due to engine problems are caused by maintenance errors at a cost of $50,000 per cancellation. In addition, on-the-job injuries in one airline during 1994 alone resulted in 785 reported injuries at a cost of $1.2 million, a figure that excludes costs of lost productivity and other related issues.[7] The magnitude of the problem of maintenance errors begins to take on major significance. Maintenance errors have many root causes. They can be the result of policies and procedures, lack of training, lack of proper equipment, equipment which is of poor design, environmental factors, lack of communication, high workload, fatigue, drugs, illness and stress, to name a few.[8]

As the airline industry underwent dramatic changes resulting from deregulation, fierce increases in competitiveness caused numerous airlines to go out of business. Those that survived continue to press for more efficient operations. Aviation maintenance costs, though, have been increasing as a percent of total operating costs.[9] These costs can be attributed to the increasing age of aircraft fleets, increasing number of aircraft, accidents, errors on the job, and other economic reasons.

The drive to decrease aviation maintenance costs both as a percent of operating budgets, and to reduce the overall error and accident rate is based on a need to increase efficiency and productivity. This translates into enabling an AMT to be more productive with less effort, for a longer time before tiring. As fatigue begins to set in, errors and accidents begin to increase and the quality of workmanship and productivity declines. These effects of fatigue are not desirable for any industry, but for the aviation industry, the quality of workmanship greatly affects flight safety and operational costs.

The effects of fatigue on transportation safety have been well recognized since the 1989. It was at this time that the National Transportation Safety Board (NTSB)[10] issued its first major intermodal recommendations regarding fatigue. NTSB strongly recommended research and education regarding the effects of fatigue and proper health habits in transportation safety. The recommendations were directed to all modes and were meant to include all personnel involved in transportation safety. To date, much research has been conducted on fatigue with regard to sleep loss and hours of service, which has focused primarily on pilots, train engineers, truck drivers and air traffic controllers and their counterparts in the railroad. Yet there has been little attention given to the effects of fatigue-related issues in aviation maintenance, a critical aviation safety profession.

Fatigue is a cumulative process that continues to build not only through the day, but from day to day, if not alleviated by adequate rest, sleep, and nutrition. Fatigue is accompanied by an increasing awareness and focus on bodily discomfort.[11] In general, the onset of fatigue brings a decline in cognitive performance.[12] Fatigue has its greatest effects on the executive functions of the brain. These functions include motivation, initiative, reasoning, short-term memory, communication, decision-making, and perceptual tasks requiring interpretation and response.[13] It also lowers mood and a helping spirit while increasing indifference.[14] Because of the decline in executive functions, there is a decline in performance and an increase in errors and accidents. Numerous programs have been developed to address the problem of errors and accidents: for example, establishing procedures and guidelines, teaching better communication skills, and making parts less prone to improper installation. All have helped in some way, but none will overcome the problem of errors and accidents without addressing fatigue as a daily part of the workplace. This assessment is made because as fatigue attacks the executive functions of the brain, it causes an individual to lower his/her standard of performance even though we believe we are performing as well as always. Individuals also have a disinclination to work, and tend to avoidance effort when possible. This can lead to cutting corners and not following all guidelines and procedures, actions which often add effort to the task. Therefore, the barriers set up to prevent accidents and assure quality can be dissolved by the physiology of fatigue.

Although there has been considerable research into the various factors that contribute to the onset of fatigue, little attention has been given to many of these factors in transportation, with even less focus on their role in aviation maintenance accidents and errors. The research community has also failed to look at the combined effects of environmental factors such as temperature, noise, light, vibration, and lifestyle habits on fatigue and human performance. The present study looks at multiple factors of temperature, noise, light and sleep, which are known to accelerate fatigue onset. Future studies will model the data to be able to predict situations that are conducive to fatigue, accidents and errors.

A brief overview of the research parameters monitored in this study (temperature, noise and lighting) is appropriate to understand their potential impact on cognitive functions and performance.

1.3.1 Sleep

As social and economic pressures increase the demand on one’s time, it appears that instead of eliminating other activities to preserve sleep time, workers and executives are opting to do more work with less sleep. Thus, habitual sleep can be whatever the individual chooses it to be with regard to his or her lifestyle, although it is not necessarily the amount of sleep one physiologically requires for alertness and optimal performance. It is often curtailed to accommodate work, school, family, social needs, or recreational pursuits. In addition, sleep is shortened by lifestyle habits of smoking, consuming alcoholic beverages, not exercising, and eating irregularly and/or close to going to sleep.

The physiological sleep requirement is the duration of sleep necessary to maintain optimal alertness and cognitive performance throughout daytime hours or waking hours without drowsiness. Adequate sleep is essential to preventing fatigue-related decreases in productivity, increased errors, and accidents. The universal need for sleep does not change due to cultural and environmental factors, even when living with continuous daylight in polar regions.[15]

Most researchers advocate an average sleep requirement for adults is 7.5-8.0 hours per day.[16,17,18] Although early researchers[19] indicated that 9 hours was necessary for optimal alertness throughout the day, recent sleep extension studies indicate that our sleep requirement is about 8.5 hours sleep per night.[20,21]

Research has found that sleep loss has acute effects on human performance, and there is also evidence of a cumulative effect on performance from repeated unfulfilled sleep requirements. Subjects restricted from their usual 7.41 hours sleep to 4.98 hours show significant cumulative effects on waking functions.[22] Across seven or eight days of sleep restriction, subjects exhibit increasing levels of sleepiness, fatigue, confusion, tension, mental exhaustion, and stress. Lapses also increase in frequency and duration (lapses being times when the brain goes into a micro sleep and misses information that would normally be observed and often require a reaction). These escalating changes provide strong evidence that partial sleep restriction similar to that experienced by many workers has cumulative effects similar to those found in more extreme sleep restriction.

Positron Emissions Topography (PET) scans of recovery sleep taken sequentially through the night and synchronized with EEG changes[23] show that slow wave sleep appears to have its greatest effects on the frontal lobes of the brain. This indicates that areas of the brain involved in alertness, attentional focus, concentration, short term memory, drive/initiative, problem solving, complex reasoning and decision making are the greatest beneficiaries of deep sleep.[24] These functions lie in the frontal lobes of the brain and are some of the primary functions that make man unique and so productive.

Dr. M. Marsel Mesulam, a neurologist at Harvard University School of Medicine, says with reference to damage to the frontal lobes:

> “The orderly planning and sequencing of complex behaviors, the ability to attend to several components simultaneously, and then flexibly alter the focus of concentration, the capacity for grasping the context and gist of a complex situation, resistance to distraction and interference, the ability to follow multi-step instructions, the inhibition of immediate but inappropriate response tendencies, and the ability to sustain behavioral output may each become markedly disrupted”.[25]

Although sleep loss and long hours of service do not damage the brain, they diminish its capacity to function. Sleep functions to "recharge the batteries", and therefore is a process of restoration to the frontal lobes of the brain. Fatigue is mostly a state of diminished frontal lobe function and has a major effect on human performance on and off the job.

1.3.2 Temperature

Little doubt exists that cognitive performance is much more sensitive than physical performance to the effects of fatigue producing heat.26 Exposure to 90 degrees Fahrenheit (F) heat with 80 percent humidity for 20 minutes has been shown to decrease attentiveness by 30 percent and cognitive reasoning by 55 to 65%.27 Additionally, working in hot humid weather has been said to be cognitively similar to working at altitudes of 14,000 feet. With a rise in temperature from 69 to 86 degrees F, reading and comprehension drop 30 percent 28, and as time pressures increase, both day and night workers show increased deterioration in performance.29 Heat stress can be overcome at the expense of additional effort, but this extra effort appears to function by narrowing an over-engaged focused attention, at the expense of divided attention and flexibility. Night workers were more adversely affected by heat than were day workers. As body temperature rises with heat stress, there is a false increase in subject confidence accompanied by an increase in risky decision making.30 Heat though is not the only temperature issue in performance. Hartman31 indicates that performance declines on either side of a temperature interval of 65–70 degrees F. This was most recently shown in a Federal Railroad Administration (FRA) accident data analysis. From FRA records, it was determined that accidents increased as ambient temperatures increased or decreased from the low of around 70 degrees F. The U-shape curve was similar to that found in the munitions factories during World War I.32,33

A review of the effects of cold temperatures found consistent decrements in complex task performance and reaction time. Core temperatures of 2-4 degrees Celsius (C), 34-38 degrees F, have been found to have no effect on simple auditory and visual tasks, but had significant effects on complex mental processing, analysis, and short-term memory.34 Cold can also impair performance by decreasing manual dexterity and strength when hand skin temperature drops. Lower body temperatures, even with warm hands, can still bring decrements in performance from brain impairments.35

Rapid cooling of skin brings with it a significant level of discomfort, distraction and urgency, whereas the deeper cooling that occurs over longer exposure periods may produce a dazed state or numbness that has a slowing effect on time estimates. Lower skin temperature appears to increase time estimates whereas deep tissue cooling slows time estimates.36

One of the dichotomies in performance and temperature is that initially sudden temperature change can have a stimulating effect. However, this effect can wear off after a short period and begin to produce performance decrements.37

Finally, heat has been shown to consistently produced performance decrements on a variety of tasks, but when experienced with the effects of noise, performance decrements worsen.38

1.3.3 Noise

No one familiar with aviation will question whether noise is an issue in the industry. This is especially true for AMTs that work on or close to the aircraft. Noise affects performance in a variety of ways that ultimately increase the incidence of accidents.39,40 It adversely affects both simple and complex tasks41,42 increasing errors of omission, and increases variability 2-5 fold.43 The non-auditory effects of noise are summarized in an International Civil Aviation Organization (ICAO)44 circular. Psychologically, it increases annoyance, frustration, anxiety, workload, and fatigue. Physically, noise exposure increases hearing loss, heart rate, blood pressure, headaches, tiredness, and gastrointestinal problems. In addition, with increased levels of noise, there is steady decline in visual convergence and accommodation resulting in an increase in errors and reading times.45 Noise decreases search and memory tasks46 and narrows one's attention to a central task at the expense of peripheral tasks. Blood pressure increases with increasing exposure in 80% of studies,47 and appears to be the result of a sustained peripheral vasoconstriction, possibly the result of a reduced frustration threshold. Noise levels of 69 decibels (dB) increased annoyance levels and required increased effort over that of 46 dB.48 Similar findings show that noise decreases a subjects' resistance to frustration and tolerance, lowers mood and feelings about one's environment, and reduces one's perception of competency and aspirations. Lower noise levels (50-60 dB) appear to increase detection performance while louder noise (75 dB vs. 94 dB) accelerates the onset of decrements in performance.49 The effects of noise increase with increasing dB levels, longer exposure, and greater time-on-task.50,51 Serial reaction tasks have been shown to decrease after five hours exposure to 75 dB, whereas at 95 dB, increased lapses of monitoring began after 30 minutes. When actual productivity is measured at two different levels of noise, over days and weeks, the production curves are very similar in shape for both high and low noise groups, with the exception that higher noise shifts the entire productivity curve downward across all work periods.52

The type of noise is also an issue. Periodic intermittent noise has been shown to affect performance more than continuous noise. Intermittent noise slows performance, produces decrements in subsidiary tasks and multiple tasks,53,54 and increases response time (85dB).55 Higher frequency noise also has a greater effect than low frequency noise.56,57

1.3.4 Lighting

The invention of the light bulb brought with it substantial increases in human productivity. Measuring the relationship between lighting and job performance has traditionally focused on output per unit of time or measures of accuracy, errors or number of accidents. Early research into lighting and workplace accidents found an inverse relationship between accidents and light levels (Vernon, Ibid.). Lower illumination was related to a higher number of accidents. More recently, increased illumination has been found to increase vigilance, task accuracy, and output.58 Recent research indicates that at 300 and 500 lux, there is a concomitant increase in accuracy of task performance with increased lighting.59 In relatively low light, 33, 86, and 170 lux, auditory vigilance task performance improved with increased illumination.60

A partial explanatory mechanism for this may lie in the neurophysiology of the human brain. At the brain level, increasing levels of light have a suppressing effect on neurotransmitters that decrease alertness and increase drowsiness.61 Another reason for the increase in human performance is that light functions by allowing the resolution of detail and faster visual processing. Factors that affect the amount of illumination necessary to do a given task depend on the size of the stimuli or object, the level of contrast in the task or object, and the age of the individual performing the task.62 Thus, the smaller the object and the less contrast with the surroundings in which task must be performed, the greater the necessary illumination. With age, there is a greater need for increased task lighting. This is the result of a decrease in visual acuity due to increased scattering of light by the lens of the eyes. This scattering effect decreases the contrast , requiring higher illumination to distinguish objects. In aviation maintenance, this could create problems in crack inspections, and the repair and inspection of wiring where wires are fine or the color codings are of low contrast.63

Much of the recent literature on lighting requirements is concerned with the cost of providing light - purchase price, operating expenses, or maintenance. However, the purpose of lighting is to allow rapid and effective human performance. The costs of personnel time and the potential cost of even a single human error are orders of magnitude higher than the costs of providing the lighting. Thus, in this study, adequacy of lighting is the major criterion for lighting choice.64

This brief review addressed some environmental issues that are believed to be issues in AMT working environments. Many of the noise, temperature and lighting levels cited above are considered relevant measures in this profession and may be factors in the occurrence of maintenance errors and accidents.

1.4 RESEARCH OBJECTIVES:

This initial study was designed to collect data in the aviation maintenance work environment on known factors that affect human fatigue and performance. The major objectives of the project included:

- Determining the feasibility of collecting data at a task level on environmental parameters of noise, light, and temperature that affect the onset of fatigue. Additional data on personal lifestyle habits including timing and duration of sleep, diet, and other parameters were also collected in an effort to identify other fatigue factors.
- Evaluating the durability of data collection devices within the rigors of the aviation maintenance workplace. Also, to profile the environment in which the AMT works.
- Determining whether there are differences in workplace environmental conditions between the various AMT specialties.
- Identifying possible fatigue producing problem areas and provide industry partners with an understanding of why these areas can be potential causes of reduced productivity and higher errors.
- Using the profile data to begin to develop a model that may predict conditions that would accelerate fatigue onset.

1.5 STUDY DESIGN AND METHODOLOGY

Data was collected at an aviation maintenance facility in the northwest United States during July 1999. The study approached data collection with the hypothesis that the various AMT specialties have different working environments or microenvironments. A microenvironment is a place such as a fuselage on the ramp which exposes the AMT to different levels of noise, heat, cold, and lighting. These microenvironments may also change within a specialty and from shift to shift. Thus, understanding the environments for each AMT specialty across all shifts could help identify micro environmental factors in each that could predict the onset of fatigue and, in turn, predict performance decrements in the form of accidents, injuries, and maintenance errors.

The methodology consisted of three approaches; a background survey, mini-logger monitors that recorded data from the selected parameters of light, noise levels, and temperature, and activity monitors (actiwatches) that monitored physical activity, sleep, and sleep quality. The study was designed to cover two full five-day work cycles. Shifts were eight hours long, with morning shift from 7:00 AM to 3:00 PM, afternoon shift from 3:00 PM to 11:00 PM, and night shift from 11:00 PM. to 7:00 AM. Actiwatch data collection was to be continuous for 12 days. Data was captured to include weekend activity and sleep habits to determine possible differences in sleep duration and timing from that of the work-day patterns. Tables 1 and 2 depict how the mini-loggers were distributed among AMT specialties and across shifts in order to adequately sample the nine specialty areas selected over the two-week period. Table 1 represents mini-logger assignments for the first week and Table 2 the second week.

The participants were licensed, full-time AMTs. A total of 101 AMTs participated in the environmental profiling portion of the project. Of these, forty-one were involved during week one and sixty during week two.

The choice of the data collection dates was the result of equipment production constraints and the impending destabilization of the AMTs' work routine caused by a semi-annual shift change. Facility managers recommended that data collection occur either before the shift change or at least 4-6 weeks after. Their recommendation was based on a history of numerous employee requests for changes to different work times or tasks after shift change. This maneuvering for more likable shifts settled down after a few weeks and stayed fairly stable until the next shift change occurred about five months later.

The study design also explored the subjective assessments of the AMTs as to what environmental factors they felt affected job performance, as well as some background data on personal habits that can also increase fatigue and degrade performance. This entailed filling out an Environmental Profiling Survey.

1.5.1 Equipment

The environmental data was collected using Miniloggers Series 2000 manufactured by Minimitter, Inc. Each device was programmed to measure environmental conditions of temperature in Fahrenheit degrees, noise level in decibels, and light levels in lux, once per minute. The miniloggers were to be worn by technicians during all shifts, resulting in 24 hour a day monitoring for a period of two weeks. Twenty miniloggers were used, with three given to each of the AMT specialties, airframe (AF), avionics (AV), modification line (ML), machine shop (MS), power plant (PP), and structure/bond (SB) for 24-hour monitoring. Two miniloggers were given to the quality assurance (QA) technicians.

The miniloggers sampled the environment three times per second and averaged the data over one minute intervals. Thus, for each parameter of noise, temperature, and light, there were 60 data points per hour, and 480 data points per eight-hour shift.

For the sleep profiling, data was collected using Minimitter Actiwatches also manufactured by Minimitter, Inc. These devices collected movement continually and recorded the results at one-minute intervals. A total of 22 actiwatches were used in monitoring sleep and activity. Three actiwatches were assigned to seven AMT specialties, with one assigned to each shift of the three shifts. Therefore, for airframe there was an AMT on morning, afternoon and night. The specialties assigned actiwatches included AF, AV, PP, ML, MS, SB, and QA.

1.5.2 Description of Background Survey:

For the survey portion of this study, the participants were asked to complete the Aviation Maintenance Environmental Profiling Survey. This document consisted of 47 questions and took an average of 10 minutes to complete. Questions were predominantly multiple-choice, with a few fill-in-the-blank. Areas covered included environment factors and personal habits such as nutrition, sleep, water intake, caffeine intake, tobacco use, feelings of stress, commuting time and distance, and alertness at various times of the day. Also included were questions regarding management and its relation to work factors which the AMT felt affected job performance. These questions probed areas such as locus of control, and whether workers felt they were in control of their job tasks or were heavily supervised and had little control. These factors were probed as they contribute to additional job related stress.

1.6 RESULTS

Data analysis results are covered by the type of parameters: sleep data, environmental data, and background data.

1.6.1 Analysis of Sleep Data

The sleep data showed a general trend of less than optimal sleep patterns. Combining all of the AMTs sleep data, analysis showed that 20% of AMTs obtained less than 5 hours sleep per night (Graph 1). On a shift basis, afternoon shift workers (Graph 2) fair better than morning (Graph 3) and night shift workers (Graph 4). Afternoon shift workers, though, only average 6.7 hours of sleep per night. Night shift AMTs had the highest percentage (33%) of individuals sleeping less than five hours. Whereas, twenty percent and nine percent, respectively, of morning and afternoon shift AMTs received less than five hours of sleep. Night shift AMTs also had more split sleep schedules. This style of sleep is characterized by getting all of one's sleep in two or more separate periods instead of one 7-8 hour sleep period.

Two interesting findings occurred in comparing morning and afternoon shift AMT sleep durations. First was the finding that the percentage of AMTs getting 7or more hours of sleep was less than 6% for morning AMTs compare to 26.5% and 40% for night and afternoon shift AMTs, respectively. If one examines the percentage of shifts worked with less than 6 hours sleep, morning shift workers had 57%, night shift 47%, and afternoon 9%. Sleep duration increased on off days for morning shift AMTs by about 35 minutes compared with a 1 hour 24 minute increase in night shift AMTs. The afternoon shift AMTs actually showed a small decrease in sleep over the weekend. Data showed a somewhat irregular sleep pattern by many AMTs. This could be seen in irregular bed times, and compensatory sleep scattered throughout the data.

1.6.2 Analysis of Environmental Data

While the majority of the environmental data did not show significant differences between AMT specialties or work shifts, the data did reveal that overall the environmental factors of high noise and low lighting levels appeared to be a consistent problem for virtually all shifts and AMT specialties. The differences found in the data are discussed in the following sections.

1.6.2.1 Temperature

During this period of data collection, temperatures were unseasonably mild; therefore the majority of temperature exposures fell between 68 and 79 degrees. Temperatures did not pose an issue to performance except in one or two instances where recordings did show exposures of around an hour at temperatures in the upper 90's. Temperature recordings for the afternoon shift were the warmest, with the night shift the coolest. Temperature exposure analysis showed remarkable similarities across all but two AMT specialties. Exposures to higher temperatures were experienced by Interiors (IN) AMTs while QA data (Graph 5) showed an unexplainably longer exposure to temperatures below 60 degrees F.

Morning shift temperatures showed a slight 3-4 degree F lower temperature exposure among AF, ML and MS AMTs, centered around 68-71 degrees, compared to the remaining AMTs, where temperatures centered around 72-75 degrees F.

Afternoon shift temperatures centered around 72-75 degree F, with the greatest exposures in this range. There were two specialties that appeared distinct, IN and QA. In the former, the data showed a considerably higher temperature exposure centering around 76-79 degrees (39.8%), with 26.8% of exposure between 80-83 degrees. In the latter, there was also the longest exposure to temperatures below 60 degrees (36%).

Temperature data for night shift showed that across all AMT specialties, most AMTs spent less than one percent of the recorded work time in temperatures equal to or greater than 80 F. On the lower end of the temperature range, few AMTs spent any measurable work time in temperatures less than 60 F, with the exception of QAs which recorded 36.1 percent of their recorded night shift in this temperature range.

1.6.2.2 Noise

Overall, the level of noise stayed quite high across all shifts, with only a slight decrease at night. Night exposure to levels above 80 dB accounted for 43% of the time recorded compared with 50% and 52%, for the afternoon and morning shift, respectively. These same noise levels were experienced by all AMTs at least 50% of the time (QAs) to a maximum of 79% (IN). Examination of noise data across work specialties showed that there were some qualitative differences. For example, PP AMTs spent greater than 77% of their work time at or above 72 dB, a level very similar to that of IN (79%). Yet, their exposure levels center around 80-82 dB while INs center around the 92 dB level. Those experiencing the highest percentage of exposure above 88 dB were IN and AV with 42% and 35%, respectively. All other AMT specialties show similar noise exposure above 88 dB, ranging between 22% (QA) to 28% (ML).

Among the morning shift specialties, the MS AMTs stood out with the least exposure to high noise levels (21%) with IN AMTs having the greatest exposures to high noise (54%). (Graph 6)

For afternoon shift differences, QAs had the least exposure to high decibel levels with 43 percent of work time spent below 68 dB, while AV spent only 16 percent of time below 68 dB. Both AVs' and INs' percent of exposure time to dB levels above 88 dB was 36 percent compared with 23 and 20 percent for QAs and PP, respectively.

Noise levels during night shift were understandably lower than daytime levels. QA and AF AMTs had 17.2 and 18 percent respectively of the recorded work time exposed to noise levels equal to or above 88 dB. These two specialties had the least exposure to the highest levels. IN had the greatest time exposure with 34.4 percent of their recorded work time. AF was by far the quietest specialty on night shift with nearly 39 percent of recorded shift time below 60 dB.

1.6.2.3 Lighting

Light exposure across shifts showed a progressive decline from morning, through afternoon and night. The percent of work-time spent in less than 200 lux lighting, was 55%, 62%, and 80% for morning, afternoon and night shift workers, respectively. Analysis by work specialty found that MS had the best lighting levels, with IN having the worst. The percent of time spent working in under 200 lux illumination was 37%, 85%, 70%, 70%, and 60% for MS, IN, AF, PP and AV, respectively. A large percent of time in nearly all work specialties was spent in very low lighting levels.

Among morning shift specialties, the IN AMTs experienced low light illumination 84% of the working time, while MS AMTs experienced low lighting only 30% of the working shifts.

Lighting among afternoon specialties appears best for the MS AMTs, with only 42% of work-time spent below 200 lux compared with 60% for QAs and 79% for IN (Graph 7).

Lighting for night shift specialties was best for QA. While IN spent only 10 percent of their work time exposure above 200 lux, and AV only 19 percent, QA enjoyed 35 percent of their work time in lighting above 200 lux (Graph 8).

1.6.3 Background Data

Descriptive Data

A demographic profile of the 503 AMTs who responded to the background data survey found males made up 94% of respondents vs. 6% for females. Age categories were by ten year intervals starting with 25 years and younger up to 66 years. All respondents were under age 66, with 9.4% 25 years and younger, 45.8% ages 26-35 years, 32.0% between 36-45 years, 11% 46-55 years, and 1.8% ages 56-66 years old. Except for the two highest categories of years of experience, distribution was 25% in each of the first three experience levels of less than 5 years, 5-9 years, and 10 -14 years. The last two categories of years of experience 15-19 years, and 20 plus years had 8.8% and 16.8%, respectively. Commuting distances varied considerably, with nearly 40% living within 10 miles of work and another 20.8 % within 11 - 20 miles. Commuting distance categories of 21-30, 31- 40, 41-50 and 51-60 miles had 13.6%, 6.6% and 2.4% respectively. Fully ten percent of workers commuted 61 or more miles.

At the time of data collection, 25% responded that they were experiencing feelings of tiredness.

1.7 CONCLUSIONS

Conclusions drawn from this study about AMTs are not to be extrapolated to the industry as a whole. Additional sites will need to be studied before such conclusions can be made. The use of the miniloggers, actiwatches and the background survey tool provided a good study-design and increased the reliability of the data. Background data showed that AMTs felt the stress associated with lighting and noise, issues we detected in the monitoring of their working environments. In addition, the subjective level of importance placed on each factor was very similar to the data collected.

One of the main objectives of this pilot study of AMT working environments was to determine whether the data collection equipment could withstand the abuse it would receive in this environment. Equipment reliability began to be shown from the first morning of data collection when a power plant leader came in with the data logger in hand and remarked that he thought the instrument was damaged. The AMT wearing the data logger had opened an engine cowling and was covered with a flood of oil. The oil had covered the minilogger and sensors. After cleaning the instrument and sensor connections, it was connected to a computer and found to be recording normally and had not missed recording any data except when sensor probes were removed for cleaning. After two weeks, the only damage to any of the logger devices was found on two temperature probes. The flexibility of the noise and light sensors proved adequate to prevent damage and costly replacements. Therefore, this pilot study adequately proved equipment reliability.

Secondly, this study demonstrated the feasibility of collecting data in various AMT operational environments at the task level. This was an important issue due to the nature of the work. AMTs often have to work in confined places, in elevated areas, and in areas that don't get direct lighting from overhead light sources. Understanding how these areas change the working environment may help explain possible differences in productivity, errors and accidents.

The objective of determining whether there are environmental differences between specialties was met with an indication of minimal differences. Results in this aircraft repair facility show many of the environmental conditions appear to be similar across shifts and specialties, with a few exceptions in certain environments noted above. There were instances where the data showed that individuals were subject to fatigue producing conditions, but they appeared to be related more to the task or location than the overall environment of a particular specialty or shift. QAs across nearly all parameters examined had the most optimal working conditions. Interiors had more exposure to fatigue producing parameters than most other specialties. Therefore, for this study, the answer to the question of whether the various specialties work in microenvironments of their own appears to be a guarded "No", the exceptions being quality assurance and interiors.

Although we did not find major differences between most specialties and work shifts, it is premature to conclude that this holds true throughout the industry. For example, it may only hold for repair facilities. Operational airline facilities may show major differences. Because of this possibility, additional sites should be monitored using the same research design, again sampling from all AMT specialties and shifts.

The levels recorded in this study fall below those considered adequate for this type of work and established by the aviation industry.65 Lighting rarely came close to the 300-750 lux levels recommended. In fact, the major lighting level recommended for most tasks in aviation maintenance is between 500-750 lux. The lowest lighting recommended is 300 lux for non-technical tasks as blocking an aircraft.

The effect of this low lighting is confirmed from background data, where AMTs indicated that these factors affect their work performance. Low light levels as found in the background data were a significant factor that AMTs felt affected quality of work, and significantly increased feelings of tiredness, produced greater stress, and resulted in less job satisfaction. Poor lighting was predictive of AMTs feeling less in control of workspace and having inadequate time to complete tasks. In addition, low lighting is related to decreased alertness and greater feelings of fatigue. Although literature on the effects of lighting on performance is not plentiful, its relationship to today's job atmosphere of faster and faster production can be understood. With poorer lighting, tasks require greater time to complete due to less visual clarity of task. The result is that more time is required if accuracy and quality of workmanship are to be maintained.

Increased lighting would be one change that is recommended. Today, the emphasis has been placed on the square foot cost of utilities compared to manpower. When examined from this perspective, utilities are but a small percent of manpower costs on a square foot basis. Improving worker's lighting has shown considerable benefits in productivity over very small increases in utility costs.66

Our finding suggests that fatigue is an issue in this work force. Data from the actiwatches and the background questions clearly indicate that sleep durations are inadequate to prevent fatigue. For most AMT specialties, sleep durations of less than 6 hours accounted for 30-40 percent of the specialty, and 25 percent of respondents reported feeling fatigued or exhausted. The obvious guidance to this facility would be to implement a general fatigue education program that would be ongoing and not a one-time event. AMTs should understand the importance of not only adequate rest and its effects on performance, but also the various factors that accelerate fatigue onset. This type of program could have a considerable impact on employee productivity, decrease absenteeism, increase general well being, and improve worker attitude and job satisfaction.

Lastly, another educational area that needs to be addressed is in the area of noise and its effects on hearing and performance. Noise was the most frequently mentioned environmental factor affecting job performance in the subjective background data collected. Environmental data showed greater than 50% of work time exposed to noise levels over 80 dB. This clearly indicates that noise exposure in both volume and duration is a problem. It is critical for both productivity and preserving hearing to provide education and implement countermeasures to reduce the impact of this environmental factor. Noise exposure levels of 72 dB and above have been reported to cause performance decrements in pilots. Even with the use of hearing protection devices, noise can be detrimental to performance by accelerating fatigue onset. This is the result of poorly placed and fitted ear protection devices. While noise attenuation laboratory studies can show a 25-40 dB of noise protection, the low levels of care in fitting and inserting hearing protection devices on the job results in about one-third the hearing protection on the job if protective devices were properly used.67 Personal observation during the study period found only limited use of hearing protection devices. Therefore, many AMTs are exposed for the full shift and to the full range of noise level. The levels recorded in this study would result in not only early onset of fatigue, but also both short-term and long-term hearing losses.

1.8 RECOMMENDATIONS AND FUTURE PLANS

Methodology plays an important role in the success or failure of research. Human subject compliance with the methodology therefore must be a prime objective of the preliminary planning. The following recommendations are aimed at insuring quality data collection and better human subject compliance with research methodology.

Prior to all data collection, there should be a face-to-face group explanation to company officials and volunteers participating the study, relative to study design, and how the volunteers will be involved. This should entail a thorough and clearly defined explanation of the procedure and the participants' responsibilities during the data collection period, and the importance of adhering to the study design to maintain scientific validity of the research data to be collected. The fielding of questions and listening to concerns needs to be an integral part of the process. This type of meeting allows the volunteer to assess and decide whether he/she can fulfill the requirements. It also provides an opportunity to evaluate one's commitment at a time when it does not affect the collection process. At this meeting, the issue of reading and signing the volunteer consent forms can also be addressed.

The problem of missing data from non-compliance is an issue in any human subject study. In this pilot study, a number of factors came together to bring about a level of non-compliance. Although preliminary planning trips were made, volunteers were not recruited until the very last week prior to the study. The exact reason for this is unclear. However, it resulted in insufficient volunteers for the first week and because of this, no data collection occurred during the night shift in week one contrary to the study design. The planned meeting with all AMTs to explain the study and their involvement to insure proper data collection never occurred. The last minute recruitment effort curtailed meeting with the participants as a group since they were often being recruited as the miniloggers were being distributed.

On behalf of the industry partner though, the pilot study couldn't have occurred at a more inconvenient time. After all the planning, there was an unexpected FAA inspection that was to start on the very same morning as the study. For a brief time prior the study, there was some discussion of postponing data collection. It was considered to be in the best interest of the research project to continue as planned.

Future preplanning should entail meeting with company and labor representatives to explain the study design, procedures, timetables, and planning requirements as well as participant requirements. A letter from both company and labor supporting the research, explaining the study purpose, and requesting volunteers should go out to all AMTs at least two months prior to the study. The letters need to be signed by company and labor representatives. This gives credible endorsement to the project from both management and labor. Volunteer recruitment needs to be in sufficient number to allowed coverage of all AMT specialties and all three shifts. If an adequate number of volunteers is not obtained prior to the date for the group meeting with the volunteers prior to the study, then serious consideration should be given to postponing or canceling the beginning of the study.

The issue of distance is another barrier to compliance. AMTs passing the minilogger to the next shift need to work in the same hangar and preferably the same area within the hangar. The greater the distance required to pass the monitor to the next shift AMT, the greater the likelihood that it will not occur. Minilogger assignments need to be planned so that passing the monitor to the next shift AMT takes place face to face and with as little inconvenience as possible. Volunteers need to be recruited and assigned a minilogger early enough to provide with each minilogger the names and work numbers for all subjects that will be carrying it. This will assure continued communication between subjects on various shifts. This should also help in the continuity of data collection across shifts.

Lighting levels found in this study were considerably below those recommended for nearly all types of aircraft repair and maintenance tasks.68 Future data collection may want to focus on further defining the seriousness of the problem. This may involve updating the miniloggers to allow more refined incremental recordings of the task lighting and may require an additional approach to monitoring. Additional monitoring of specific work locations needs to be undertaken to determine environmental changes within these areas in relation to ambient changes. An example would be to monitor temperature, noise and light relationships within a fuselage parked in a hangar and on the parking ramp. At the same time, data needs to be collected outside the fuselage in both locations. Comparisons then need to be made. This was initially discussed in the preplanning and has been reinforced after some discussion with industry partner representatives.

A modification of three background survey questions would greatly enhance data collection on environmental concerns and other job related issues that impact performance.

Future data collection should also end with a brief one-page evaluation of problems experienced by participants. Identifying these difficulties could help improve the data collection process. The evaluation may include reasons for non-compliance with the research methodology, how individuals feel data collection could be improved, whether there were inconveniences with the devices, and suggestions on eliminating the problems.

1.9 ACKNOWLEDGMENTS

The authors gratefully acknowledge the efforts and cooperation of the industry partner and the many individual aviation maintenance professionals who have contributed time and effort, and who showed sincere interest in helping with this project. Many thanks.

1.10 ACRONYMS AND ABBREVIATIONS

AF Airframe

AMT Aviation Maintenance Technician

AV Avionics

C
Celsius

dB Decibels

FAA Federal Aviation Administration

F
Fahrenheit

FRA Federal Railroad Administration

ICAO International Civil Aviation Organization

IN Interiors

ML Modification Line

MS Machine Shop

NTSB National Transportation Safety Board

PET Positron Emissions Topography

PP Power Plant

QA Quality Assurance

SB Structure/Bond

1.11 APPENDICES

1.11.1 Appendix 1

1.11.1.1 Study Design Table Week #1

Table 1 - Study Design Table Week #1				
Week 1:	Number of Subjects per Shift			
Environment	Day shift	Afternoon shift	Night Shift	Total Subjects/ Week
Airframe (AF)	3	3	0	6
Powerplant (PP)	3	3	0	6
Avionics (AV)	3	3	0	6
Machine Shop (MP)	3	3	0	6

Mod line (ML)	3	3	0	6
Structure/Bond (SB)	3	3	0	6
Q/A Inspectors (QA)	2	2	1	5
Total Subjects/Shift	20	20	1	41

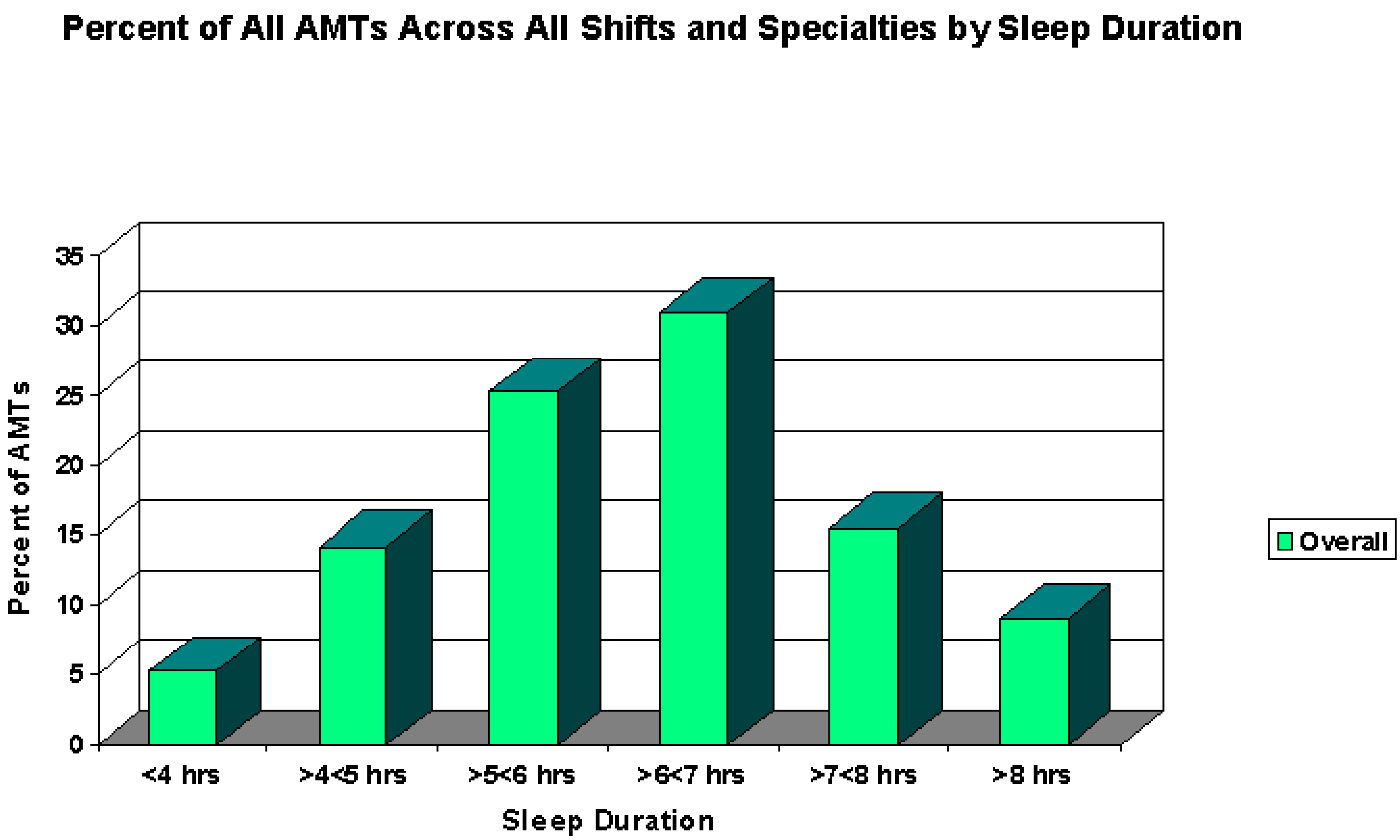
Original study design called for monitoring three volunteers from each AMT specialty covering three shifts. Due to a lack of study volunteers, the industry partner felt that covering two shifts was adequate.

1.11.1.2 Study Design Table Week #2

Table 2 - Study Design Table Week #2				
Week 2:	Number of Subjects per Shift			
Environment	Day shift	Afternoon shift	Night Shift	Total Subjects/ Week
Airframe (AF)	3	3	3	9
Powerplant (PP)	3	3	3	9
Avionics (AV)	3	3	3	9
Interiors (IN)	2	2	2	6
Mod line (ML)	3	3	3	9
Structure/Bond (SB)	3	3	3	9
Q/A Inspectors (QA)	3	3	3	9
Total Subjects/Shift	20	20	20	60

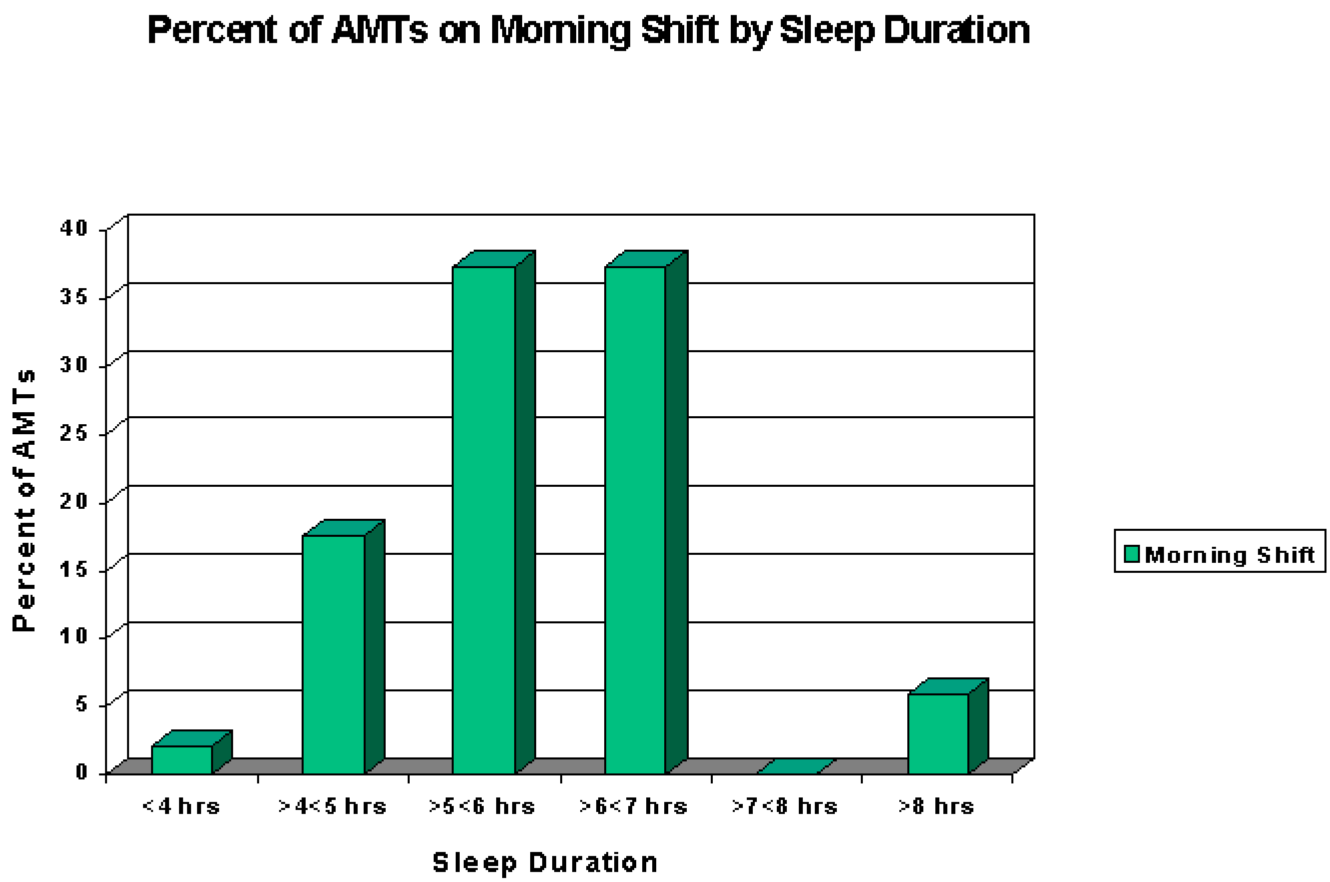
1.11.2 Appendix 2

1.11.2.1 Graph 1



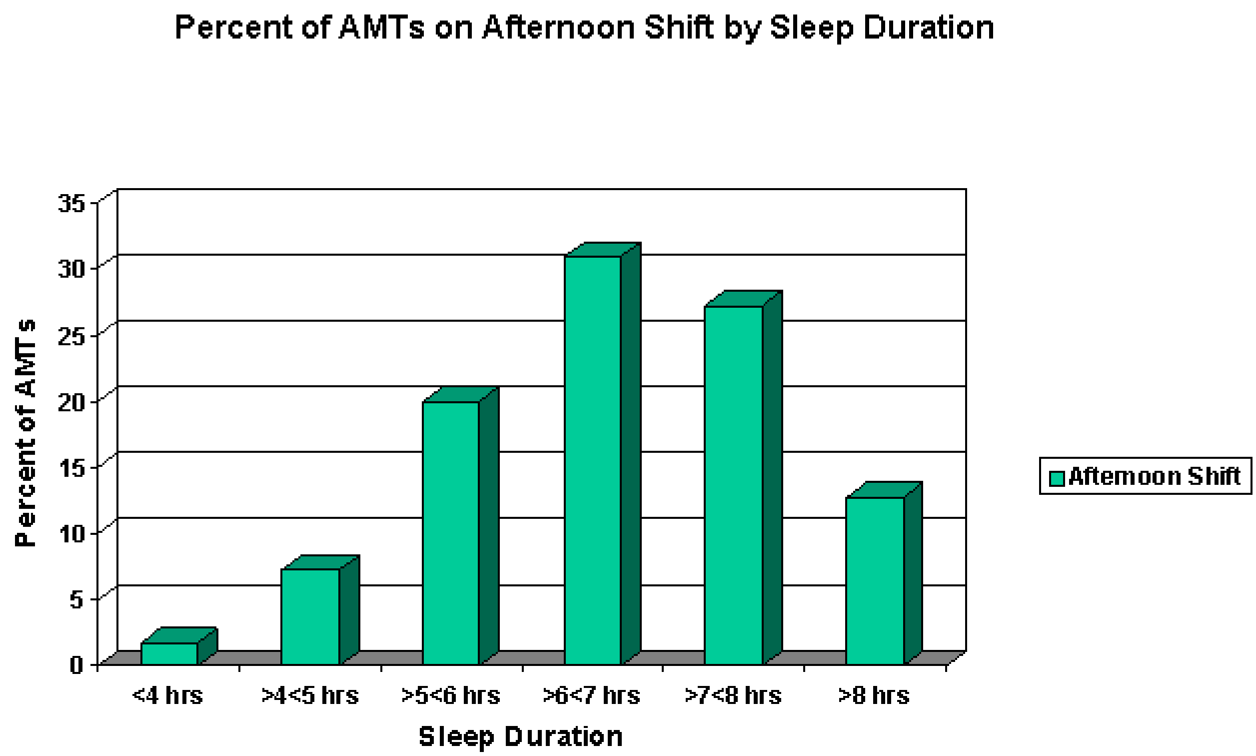
Graph 1 - Percent of All AMTs Across Shifts and Specialties by Sleep Duration

1.11.2.2 Graph 2



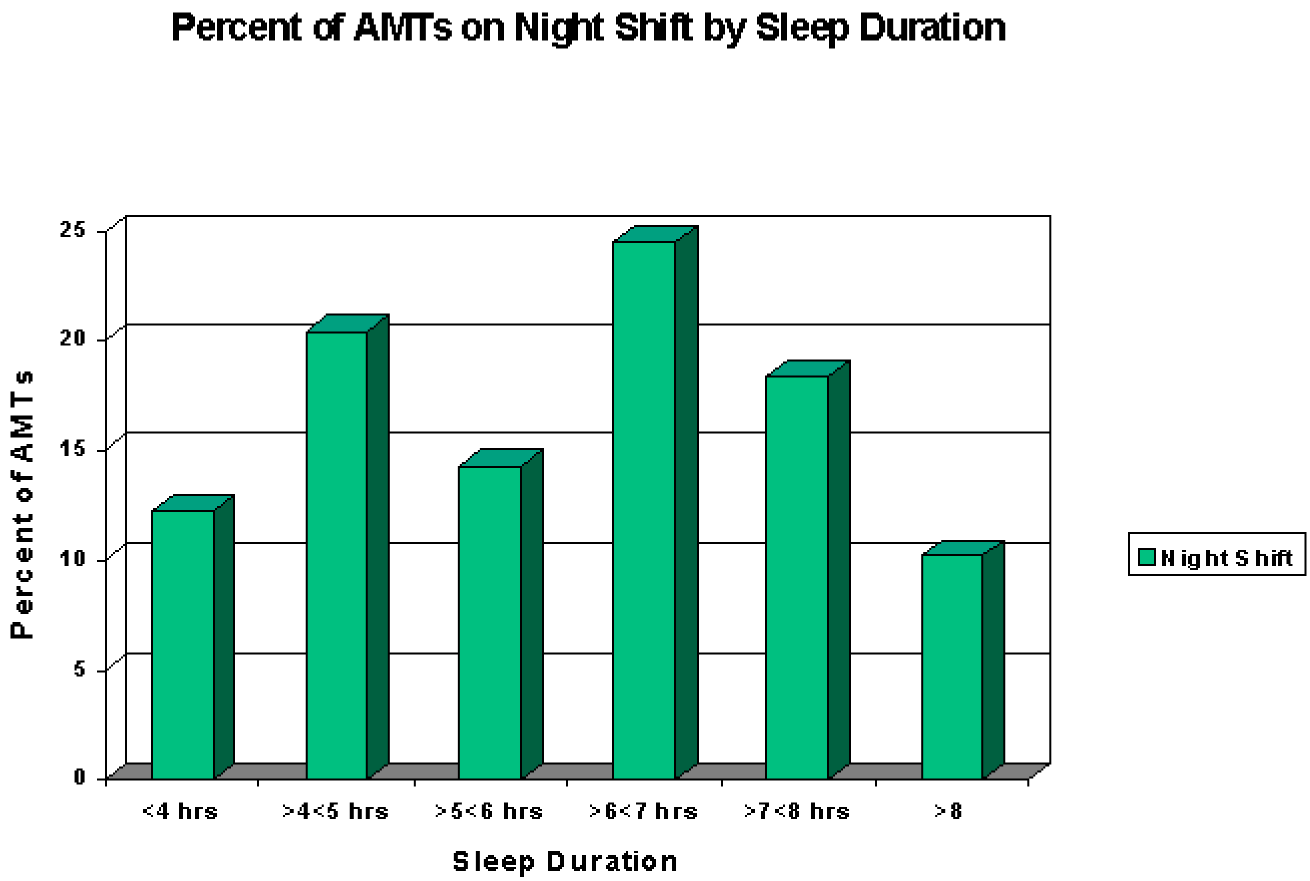
Graph 2 - Percent of AMTs on Morning Shift by Sleep Duration

1.11.2.3 Graph 3



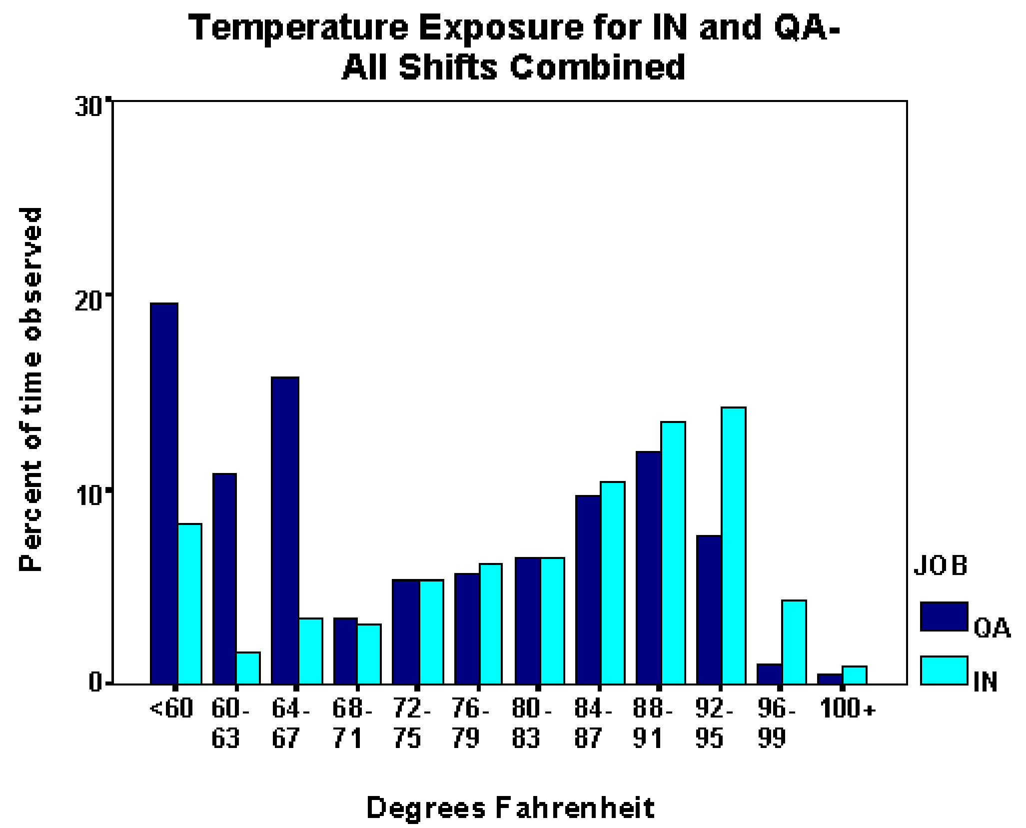
Graph 3 - Percent of AMTs on Afternoon shift by Sleep Duration

1.11.2.4 Graph 4



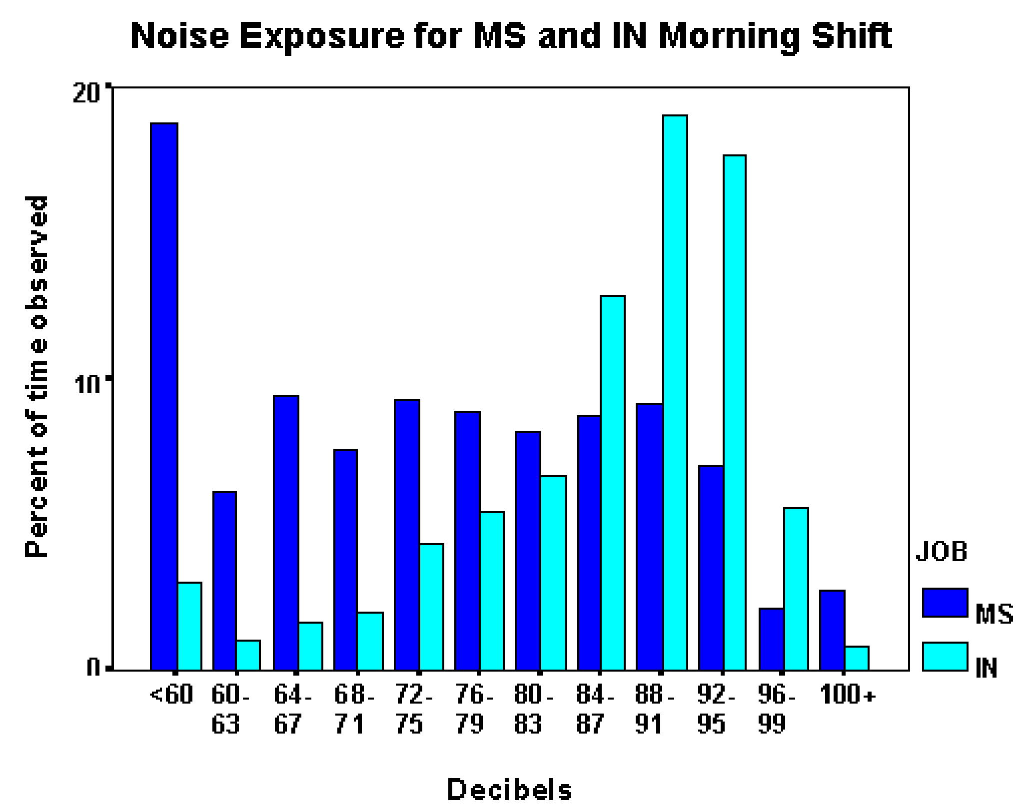
Graph 4 - Percent of AMTs on Night Shift by Sleep Duration

1.11.2.5 Graph 5



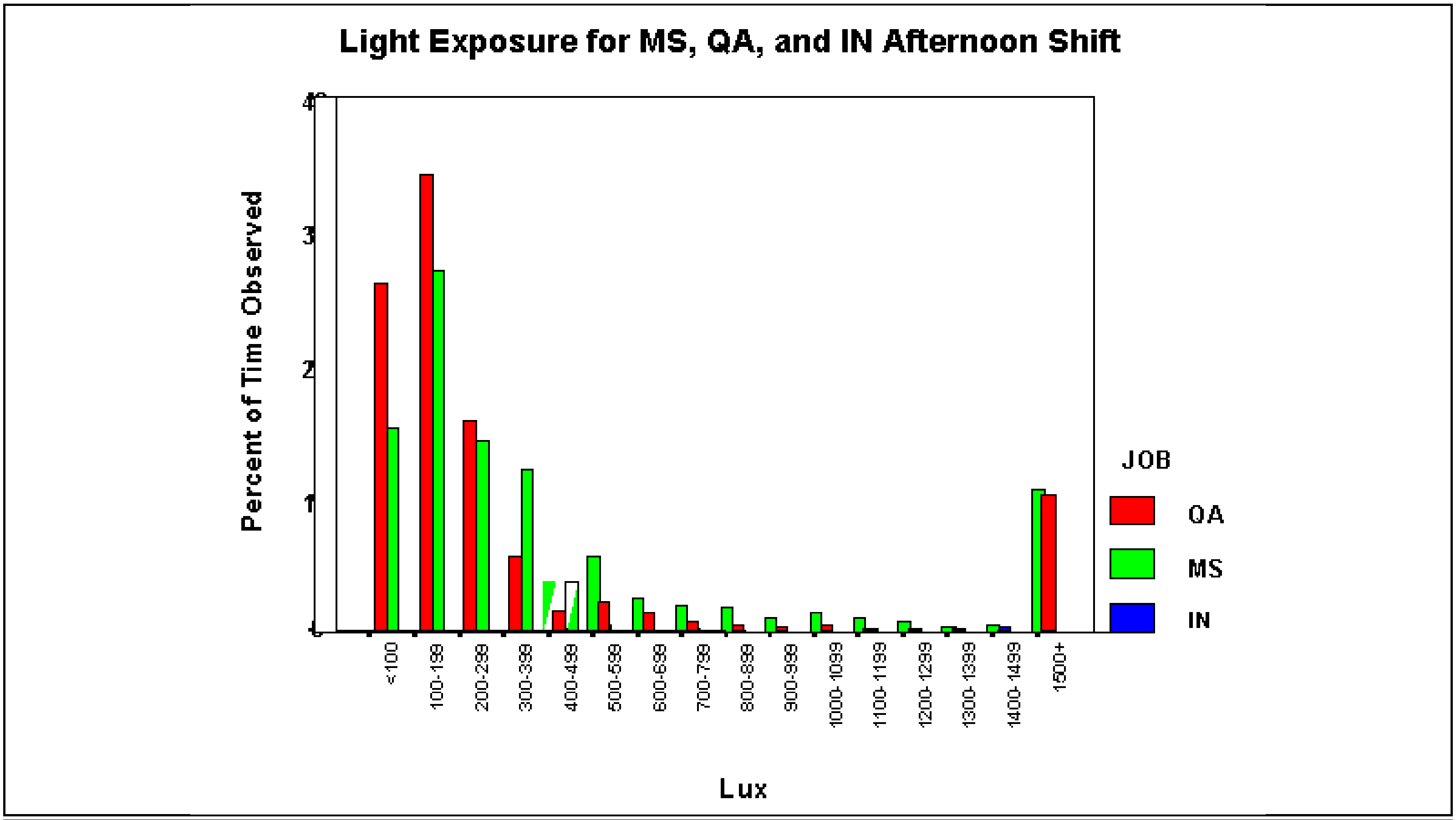
Graph 5 - Temperature Exposure for IN and QA - All Shifts Combined

1.11.2.6 Graph 6



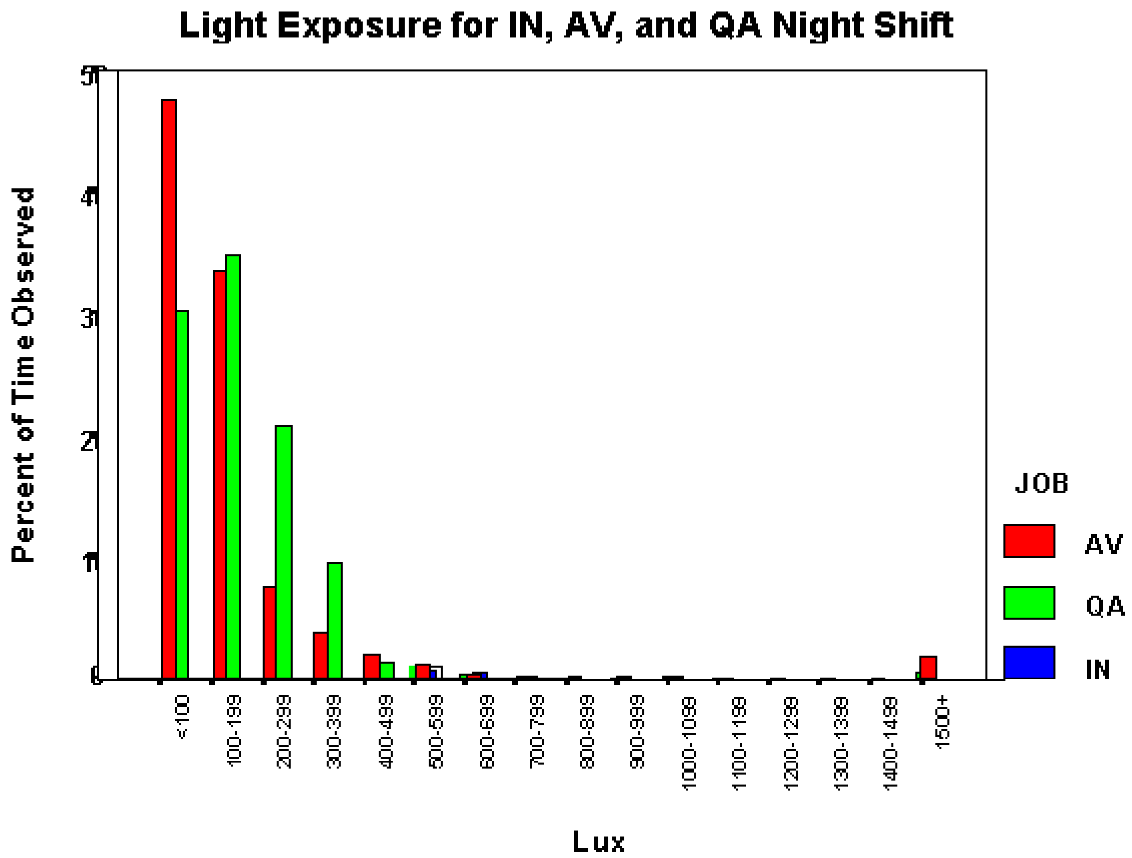
Graph 6 - Noise Exposure for MS and IN Morning Shift

1.11.2.7 Graph 7



Graph 7 - Light Exposure for MS, QA, and IN Afternoon Shift

1.11.2.8 Graph 8



Graph 8 - Light Exposure for IN, AV, and QA Night Shift

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