EVALUATION OF AVIATION MAINTENANCE WORKING ENVIRONMENTS, FATIGUE, AND HUMAN PERFORMANCE

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EXECUTIVE SUMMARY

This study is the continuation of a previous study done to characterize selected environmental conditions of the aviation maintenance workplace and the amount of sleep obtained by aviation maintenance personnel. This research is an FAA response to an NTSB recommendation (A-97-71) regarding personnel fatigue in aviation maintenance. The second phase of the study collected data during the summer months in southern locations. The current study collected data during the winter months in the mid-west. Twenty-three technicians from two large carriers voluntarily wore sophisticated measurement devices to monitor temperature, lighting, and sound levels while working. In addition, twenty-five technicians wore devices to measure actual sleep obtained on a daily basis. Approximate average daily sleep duration for maintenance personnel was 5 hours and 7 minutes, which is consistent with earlier findings. Forty-eight airline maintenance personnel responded to a 29-item questionnaire about work conditions and personal habits. On the whole, respondents viewed extreme temperatures on the job and a lack of sleep as problematic. The primary recommendations are focused on the proposed development of education materials, mostly regarding sleeping habits, for aviation maintenance technicians.

1.0 MEASURING WORK CONDITIONS AND FATIGUE: ACTIVITY TO DATE

Most FAA, NASA, and other research has focused on pilot fatigue and proper rest. The term “fatigue research” is increasingly being substituted with the newer term “alertness research.” Alertness is a more encompassing term of which fatigue is only a subset. This report certainly respects the importance of that research and of the safety associated with related flight crews. However, the total safety chain requires that all aviation personnel be rested, alert, and fit for duty to perform their tasks in a reasonable work environment. For example, it may be difficult for even the most rested pilot to overcome an error caused by a fatigued maintenance crew. Therefore, the importance of alertness for maintenance must not be underestimated.

Workplace environmental conditions can contribute to the quality of work performance and to worker fatigue. However, each day aviation maintenance workers are faced with sub optimal work conditions and possible resultant fatigue. For example, during the Summer-2000 data collection, almost all of the work was performed outside the human working comfort zone (Johnson, Mason, Hall, & Watson, 2001). When these conditions can be controlled or mitigated they must be. Portable cooling and lighting systems are common examples of such safety interventions. When such conditions cannot be controlled then the system must help the human to work in a manner that is safe, healthy, efficient, and effective.

The initial phase (Phase 1) of this multi-phased study commenced in 1999 (Bosley, Miller, & Watson). That study was followed by the summer fatigue study (Phase 2) (Johnson, et al., 2001). The current study (Phase 3) continued to use the same basic research paradigm and tools, namely the Mini Mitter and Actiwatch measurement devices. Maintenance technicians wore the Mini Mitter devices to measure temperature, sound, and light on the job. Maintenance technicians also wore the Actiwatch devices, which measured the amount of sleep obtained in a 24-hour cycle over a 14-day period. More details regarding these devices are available in the Phase 2 report.

2.0 PHASE 3 DATA COLLECTION

Phase 1 showed that the data collection tools were dependable and accurate. Phase 1 also demonstrated that the industry is willing and able to participate in the study of fatigue and working condition measurement. The companies and the labor unions were very positive about collecting this data. Phase 1 activity collected the data in a very temperate climate, mostly with fixed indoor work. For that reason Phase 2 of the research sought to collect data on hot weather working conditions. The team focused data collection on airlines in the Southeast and the Southwest from early July through September. The team sought the jobs that were in the environment including line maintenance, unscheduled nighttime repairs on the ramp, and heavy maintenance in large hangars. During Phase 2, the team did not collect data in the small component repair shops or climate-controlled areas like the engine shops. During Phase 3, the same type of data was collected during the cold winter months, providing a more complete picture of environmental factors and fatigue. Data were collected during the months of January and February at two maintenance facilities in the Mid-west.

The hardware data collection was supplemented with a questionnaire that included not only those participants who wore equipment but also numerous other volunteers throughout the maintenance organization. The questionnaire used during Phase 3 was a revised version of the one used during Phases 1 and 2. The revised questionnaire focused on assessing the perceived impact of environmental factors and fatigue on work performance.

Tables 1 and 2 show the timetable, location, number of shifts and number of volunteers that participated in the collection of light, temperature, and sound data (Table 1) and the collection of sleep data (Table 2).

Table 1: Light, Temperature, and Sound Data Collection Timetable, Location, and Participants

Dates	Location	Shift	Number of Participants
January	Chicago	Day	3
		Afternoon	1
		Swing	6
		Total	**10**
February	Cleveland	Day	5
		Afternoon	2
		Swing	6
		Total	**13**
		TOTAL	**23**

Table 2: Actiwatch Sleep Data Collection Timetable, Location, and Participants

Dates	Location	Shift	Number of Participants
January	Chicago	Day	0
		Afternoon	1
		Swing	9
		Total	**10**
February	Cleveland	Day	5
		Afternoon	3
		Swing	7
		Total	**15**
		TOTAL	**25**

2.1 Demographics

The majority of the participants in this study were male. Most of the participants were line personnel. The research team asked for volunteers who were engaging in "hands-on" work as compared to predominately supervisory/management tasks.

The average age of the participants was 39 years. The group ranged from 27 to 54, thus comprising an excellent sample of the total population of aviation maintenance workers.

3.0 DATA ANALYSIS AND RESULTS

Data reporting, throughout this report, was done in a manner in which the identity of the company or any individual cannot be determined. Statistical analysis of the data was limited given the small and uneven sample sizes across the various groups (i.e. shifts). Appropriate and meaningful statistical comparisons were made when necessary.

3.1 Sleep Data

The Actiwatch devices measure activity using an accurate accelerometer designed for long term monitoring of motor activity. It measures any motion and is sensitive to a force of 0.01 g. The motion data can be downloaded to a computer and can be analyzed with proprietary software to analyze sleep activity and estimate the hours of sleep obtained during a sleep cycle. The Actiwatch maker also offers a number of additional measures, like sleep latency (how fast one falls asleep), sleep efficiency (sleep quality based on interrupted sleep), and other movement-related activity measures. However for the purposes of this study and for this report the single focus is on the number of hours of actual sleep.

Participants were asked to wear the watch at all times of the day and night over a 14-day period. At the end of the data collection period, the data from the watches were extracted and stored using the Actiwatch software package. Extended periods of minimal or no activity are usually assumed to be periods of sleep. Periods of rest (like watching television or reading a book) are usually much shorter than periods of sleep and are usually the two types of inactivity are distinguishable from each other. The Actiwatch software only allows the data analyst to identify one period of inactivity as a sleep cycle during a 24-hour time period. This is unfortunate because it is possible that a participant may sleep in "shifts", or naps, during a 24-hour period. The software will only analyze one of these "shifts", meaning that the data may underestimate the amount of actual sleep obtained in any given 24-hour period.

Figure 1 shows the nature of the data collected by the Actiwatch. This figure is not meant to necessarily convey data for this report. Instead, the figure shows the detail of the Actiwatch information. The dark bars on the graph represent activity, while the gaps between the dark bars indicate inactivity and, in most cases, sleep. It is important to note that even during periods of sleep, some activity (tossing and turning) is to be expected. The data analyst must mark one section of time during a 24-hour period so that the software can analyze it. The software will compute assumed sleep (the amount of time selected), actual sleep (the actual amount of sleep obtained by the wearer during that block of time), and sleep efficiency.

For analysis, estimated and actual sleep values in hours and minutes were exported from the Actiwatch software into Excel. Each set of sleep values was identified with a unique identification number and date tag for each participant for each day that he or she wore the watch. The Excel data was then exported into SPSS format for analysis.

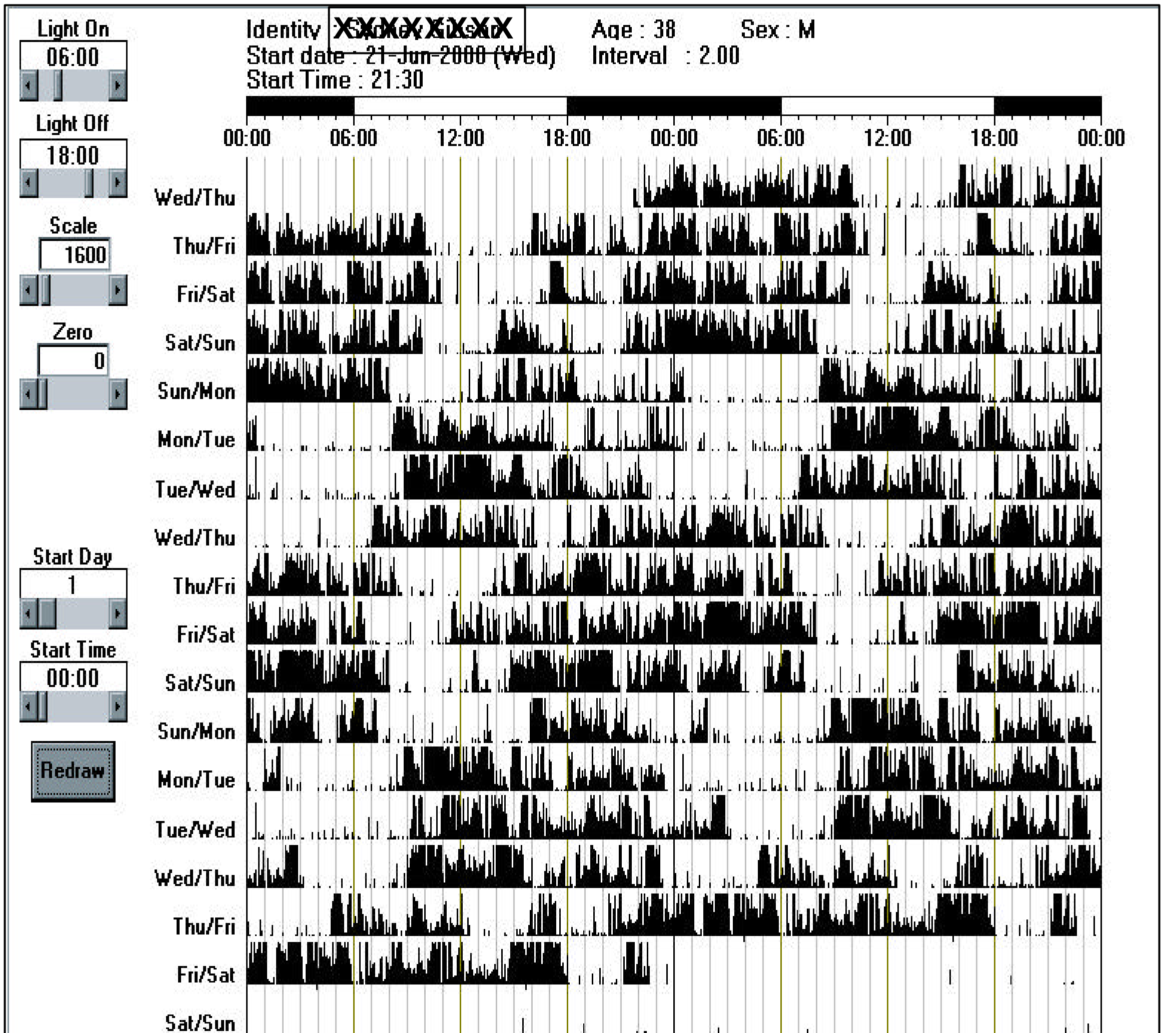

Figure 1: Chart Showing the Sensitivity of Actiwatch Data

Table 3 shows the sleep descriptive data. These data represent sleep information that has been aggregated across several days for each participant. The sample sizes reported in the table refer to the number of participants, but sleep data for each participant was collected over a five to 14 day period. The report is further broken down by shift worked. The minimum and maximum sleep values reported in the table represent the average amount of sleep reported for an individual participant. It is very likely that a participant may have obtained more or less sleep on any given night.

Average sleep duration did not statistically differ as a function of airline. The average sleep for aviation maintenance personnel across all work shifts was 5 hours and 7 minutes, which is almost identical to the average amount of sleep recording during Phase 2, the summer data collection period. Given the small and uneven sample sizes across shifts, statistical comparison of sleep obtained by shift was not performed, but the general trend in the data was that average sleep decreased as the participants' shift started later in the day. There was not a significant correlation between average sleep for each participant and participant age.

Table 3: Summary of Sleep Data

Shift	Number of Participants	Minimum	Maximum	Mean	SD
Day	5	5:06	6:13	5:37	:32
Afternoon	4	4:20	5:41	5:05	:42
Swing	16	3:00	6:23	4:59	:53
All	25	3:00	6:23	5:07	:49

3.2 Environmental Data

Environmental data (light, temperature, and sound) was collected using the Mini Mitter devices. Twenty-five maintenance technicians volunteered to wear the devices over a two-week period. Participants were instructed to wear the devices on the outside of whatever garments they may wear during the workday. During data analysis, it was noted that the temperature data were unrealistically high given that the data were collected during the winter months. Average temperature readings in excess of 90 degrees Fahrenheit were common. Additionally, light readings were very stable and tended to be very low. The research team views these facts as an indication that the collected data were not valid and further analysis would be fruitless. There are several plausible explanations for the anomalies in the data, all of which were investigated. The most likely explanation is that the participants wore the devices on their coveralls as they did in the summer study, but covered up the devices with heavy jackets when they were required to work outside. This would inflate temperature readings and would drastically reduce light readings. Sounds readings would also be attenuated. The research team collaborated with the scientists from the Mini Logger Corporation to arrive at the conclusion that these data, for whatever reason, should not be used to generalize work conditions during Mid-Western winters. This activity should be repeated with attachable pockets for winter outerwear.

In any event, the research team believes that the environmental data collected during Phase 3 were not accurate or reliable. Therefore, this report will focus on the sleep data and the questionnaire data. The only “saving grace” to this unfortunate situation was that the sample size of 25 was relatively small resulting in minimal data loss.

3.3 Questionnaire Data

The research team distributed a 29-item questionnaire to maintenance personnel at one maintenance facility in the mid-west. A total of 48 personnel completed and returned the questionnaires. The items on the questionnaire served to gather basic demographic information, information about several safety provisions in the workplace, subjectively measure alertness on the job and sleep habits, and measure attitudes about the impact of light, temperature, and noise on work performance. A copy of the survey is presented in Appendix A and a complete summary of the results can be found in Appendix B.

Personnel were selected in a non-random fashion to complete the questionnaire. As such, the results of the questionnaire may not be completely representative of aviation maintenance workers in general. Copies of the questionnaire were distributed to the participating airline that then distributed the questionnaires to maintenance workers. Participation in this research was voluntary.

This section (3.3 and subsections) is reported slightly differently than sections 3.1-3.2. Within this section the authors discuss the results of the questionnaire. The reason for this minor style difference is that the nature of the questionnaire data and charts are more conducive to immediate discussion. The additional reason is to ease the logistics of reading and interpreting the data as it is presented.

3.3.1 Demographics

Forty-eight surveys were completed and returned. The first ten items of the survey served to collect demographic information.

3.3.1.1 Participant Characteristics

The mean age of the participants was 39.2 years with a standard deviation of 7.9 years (N=46). Figure 2 depicts the proportion of respondents that fell into each of 5 age groups. As can be seen, a substantial portion of respondents (50.0%) fell in the 36 – 45 year old age bracket. The 26 – 35 year old bracket was second in size, capturing 25.0% of the respondents. There were very few respondents under 26 years old (4.2%) and none of the respondents were over 66 years old.

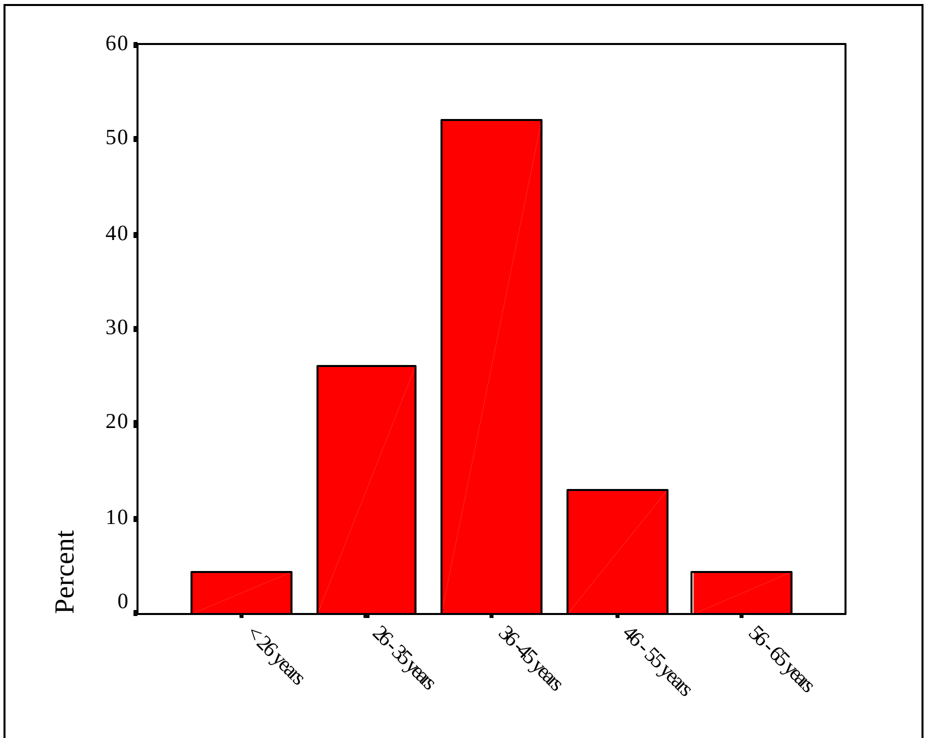

Figure 2. Proportion of Participants Across Age Brackets

The sample of participants was almost exclusively male (95.8%) as only 2 of the 48 participants were female.

3.3.1.2 Work Role

Participants were asked about their primary work role position. Respondents were given 11 role options and an option to specify some "other" role. The researchers recognized that most AMTs have multiple roles. However, participants were instructed to select their "primary role/position". Six individuals (12.5%) selected multiple roles, thus making it impossible to categorize them into a single role for some of the questionnaire responses. The vast majority of individuals selected line maintenance (83.3%), while 2.1% selected avionics and 2.1% selected "other."

3.3.1.3 Shift Work

Maintenance personnel at most facilities worked one of three shifts: day, afternoon, or night (also called graveyard). Personnel were asked to indicate which shift they were currently working, as shift changes are made on a periodic basis. As can be seen in Figure 3, all three shifts are represented in the sample with the bulk of participants (54.2%) working the night shift.

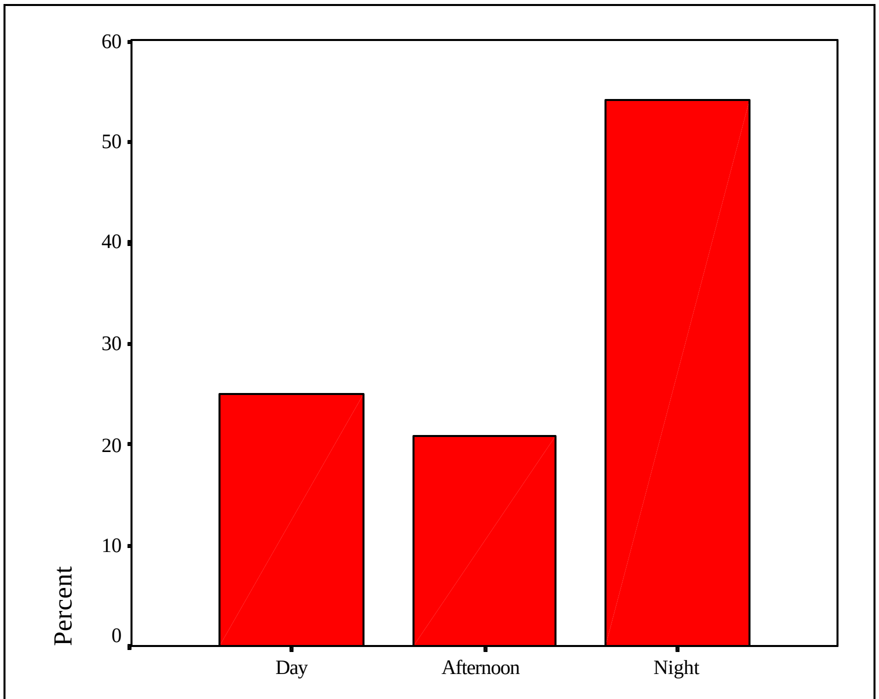

Figure 3. Proportion of Participants Working Each Shift

3.3.1.4 Job Experience

The questionnaire collected information about how long each participant has worked as a mechanic or AMT. Participants reported a mean of 16.6 years on the job (SD = 8.45, N=48). Further examination indicated that members of the sample have a wide range of time on the job, with the bulk of the participants (31.3%) having over 20 years of experience. (see Figure 4). Most importantly, these data demonstrate a broad range of experience suggested that the responses can be generalized to a wide and excellent representation of maintenance personnel who clearly understand the industry.

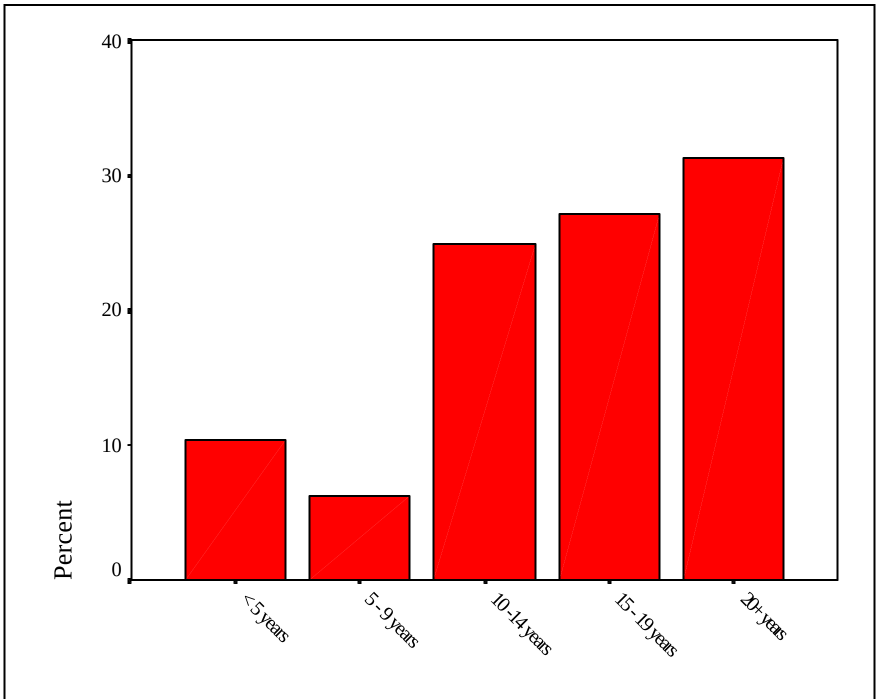

Figure 4. Experience of Participants Working as Mechanic/AMT

3.3.2 Work Related Issues

Several items were presented about various work issues such as working overtime, having a second job, drinking water on the job, safety training, and safety behaviors on the job. Such issues could have an impact on employee performance and safety.

3.3.2.1 Overtime

Participants were asked to estimate the average amount of overtime worked each week. Many participants indicated that they did not work any overtime hours on a weekly basis (45.8%), while 48% of the participants worked an average of between 1 and 10 hours of overtime per week. Overall, the average amount of overtime worked per week was reported to be 3.8 hours with a standard deviation of 6.87 hours (N = 48). These data would suggest that extensive overtime is not a major contributing factor to the low number of hours of sleep collected by the Actiwatches. It must be noted that this conclusion is based only on questionnaire responses and not on company work records related to overtime, consecutive days worked and other such data. For this study the research team felt that it was too intrusive to ask companies for such data. Subsequent studies or company internal error investigations may benefit from such records.

3.3.2.2 Second Jobs

Participants were also asked whether or not they worked a second job. Only 8.5% of the participants indicated they worked a second job. Again, this response would not explain the low hours of sleep collected by the Actiwatches.

3.3.2.3 Training Courses

Participants were asked whether or not they had ever attended maintenance resource management or maintenance human factors training courses. Only 25% of the participants indicated that they had taken such a course. Similarly, participants were asked about receiving adequate safety training for their job. Almost all of the participants agreed to some extent that they had received adequate safety training (see Figure 5).

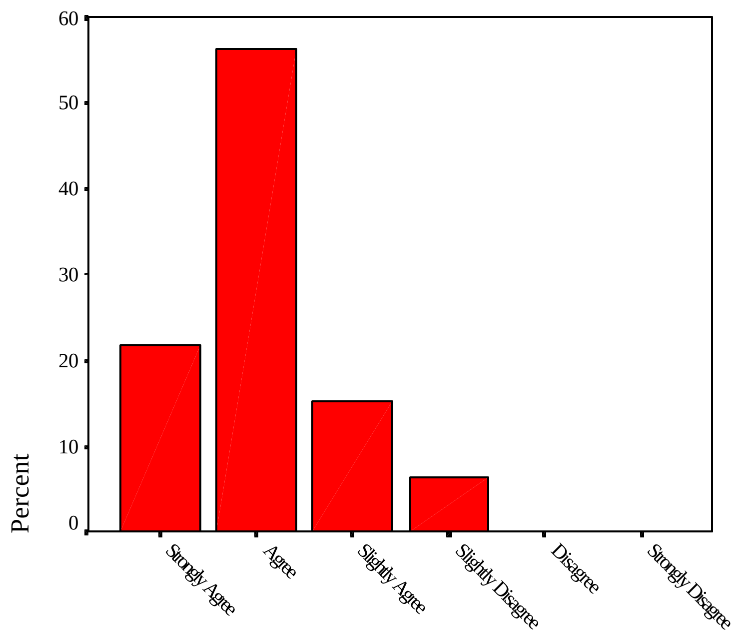

Figure 5. Participant Responses to "I have received adequate safety training for this job"

3.3.3 Sleep

Questionnaire participants were asked to estimate the average amount of sleep they usually get each night. The average for the sample was 6.26 hours with a standard deviation of 1:00 hour (N = 48). Figure 6 shows that over 75% of the questionnaire respondents reported that they sleep 6 or more hours per night on average. However, sleep data collected from Actiwatch participants found an average sleep time of 5:07 (SD = :49, N = 25). The Actiwatch data also indicates that 84% of the participants slept less than an average of 6 hours per day. It is important to note that the questionnaire data and the Actiwatch data were collected from two different groups of maintenance workers. This difference in data, between Actiwatch and questionnaire, may be attributable to numerous factors. First, the respondents may be over reporting their sleep. Secondly, the Actiwatch is very accurate and does not count the initial "tossing and turning" as sleep. Thus there is a likely difference between time spent in bed versus actual sleep time. In any case, the combination of the Actiwatch data with the questionnaire data and with the previous fatigue questionnaire (Sian & Watson, 1998) strongly suggests that maintenance personnel are not fully aware of their sleep duration and the possible fatigue that may result.

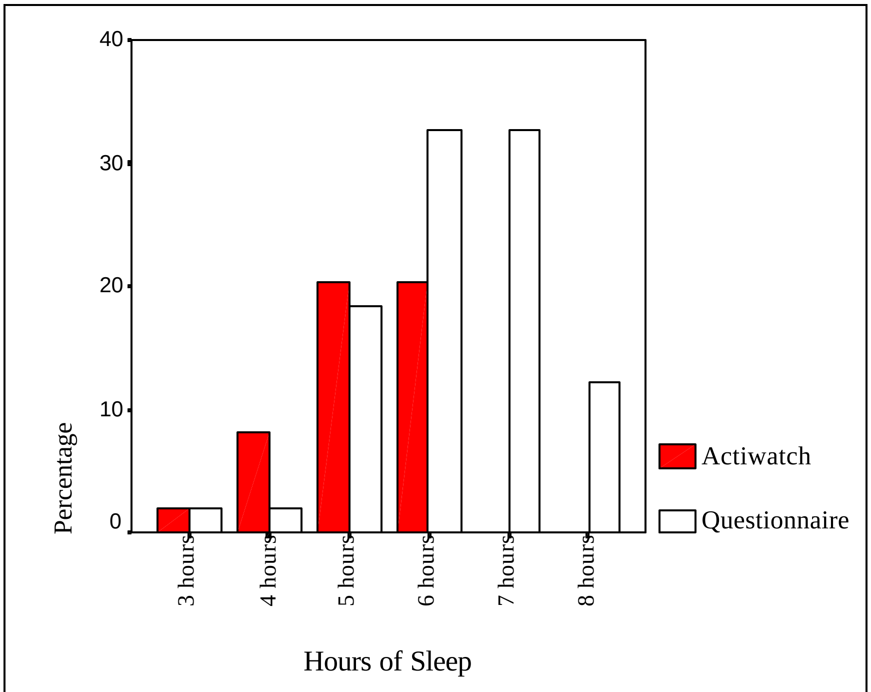

Figure 6. Questionnaire and Actiwatch measures of Average Sleep Per Night

The sleep data can be examined further by comparing the average amount of sleep reported across the three shifts worked. As can be seen in Table 4, the night shift participants reported fewer hours of sleep per day as compared to the day and afternoon shift participants. Statistical analysis indicated that the night shift participants reported significantly less sleep than the afternoon shift participants, but the other group differences were not statistically significant. While there are statically significant differences across shifts in self-reported estimates of sleep, the Actiwatch data discussed previously shows a similar trend, but does not follow suit. This could be because of a much smaller sample size for the Actiwatch data, thus limiting the statistical power of any analyses performed on those data.

Table 4: Average Actual Sleep by Shift

Shift	N	Mean	Standard Deviation
Day	12	6:38	:51
Afternoon	10	6:51	:49
Night	26	5:52	:59
All	48	6:16	1:00

3.3.4 Safety Related Issues

Several safety-related questions were asked of the participants. Specifically, items 10 – 12 and item 14 addressed several work related safety issues.

3.3.4.1 Water Consumption

Item 10 instructed participants to indicate how many times they drank water during an average work shift. The mean response was 7.2 times per shift with about 79% of the responses falling between zero and five times per shift. This is not to say that the participants do not drink other forms of fluids such as coffee, soda, tea, etc. during the course of their shifts. This questionnaire did not inquire about quantity of liquids per day. That would be an excellent question for subsequent questionnaires.

3.3.4.2 Ear Protection

Participants were also asked about whether or not they wear ear protection. Over 97% of the participants agreed or strongly agreed that they "almost always wear" their ear protection (see Figure 7).

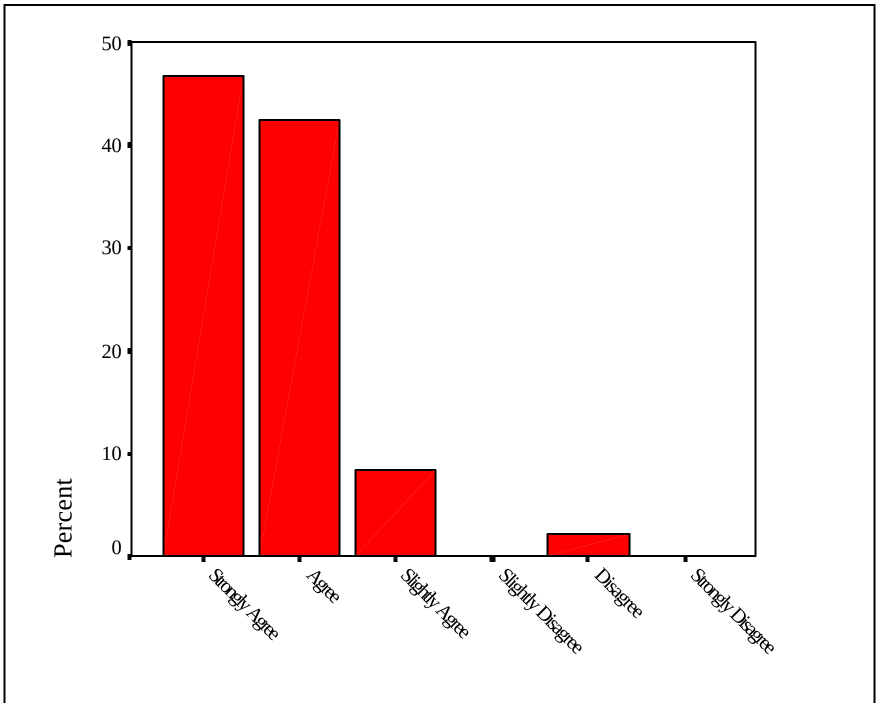

Figure 7. Participant Responses to "I almost always wear my ear protection as required by regulations"

3.3.4.3 Warning Signs

Finally, participants were asked about warning signs on the job designed to keep employees safe. This would include signs like the following: Slippery When Wet, Wear Safety Glasses with This Tool, and such warnings. Almost all employees (95.7%) indicated that they agreed that warning signs were posted in the job place (see Figure 8). The survey did not try to assess the perceived or the actual value of the warning signs.

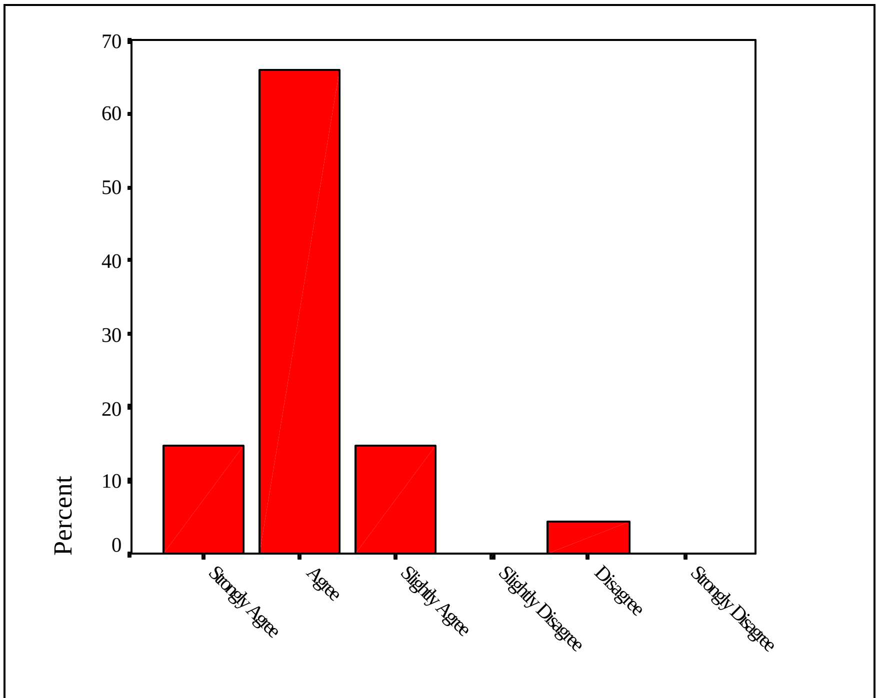

Figure 8. Participant Responses to "There are warning signs posted to keep employees safe"

3.3.5 Factors Affecting Work Performance: Light, Temperature, Noise, Sleep and Alertness

Most of the second half of the survey was designed to measure perceived problems with work lighting, temperature levels on the job, noise levels on the job, sleep habits, and level of alertness on the job. Six-point Likert-type items were used to assess each of the five factors. Some of the items were negatively worded to avoid response sets. Reversing the order of the questions encourages the respondent to read each question carefully. The items were designed to assess the extent to which each factor is problematic. For example, participants were asked about the adequacy of lighting on the job as well as whether or not they felt their job performance suffered due to sub-optimal lighting conditions. The items were reverse scored when appropriate and combined to form five sub-scale composite scores with possible values ranging from 1 to 6. The scoring was done so that sub-scale values towards 1 indicate that the factor is not problematic, while sub-scale values towards 6 indicate that the factor is perceived to be problematic. Sub-scale scores should be viewed as a relative index in that the absolute values of the scale scores are not of primary interest. Scores can also be compared across groups (e.g. shift worked) or across scales (i.e. sleep vs. light vs. noise, etc.). These scores can also be used as an indicator of which factors the participants view as the most problematic, therefore giving some guidance as to which factors should be given the most attention by airline management.

3.3.5.1 Light

A total of four items were presented regarding lighting conditions on the job (Items 16, 19, 22, & 25). Items 19 and 22 addressed whether or not participants think there is enough light on the job while items 16 and 25 addressed the extent to which participant felt their job performance was negatively impacted by lighting conditions. The overall lighting sub-scale score was 3.2 with a standard deviation of 1.1 (see Table 5). As can also be seen in the table, the day shift participants had the lowest mean score (2.75) followed by afternoon (3.11) and evening shift participants (3.42), but these differences were not statistically significant. Additionally, response patterns to each of the items seem to indicate that lighting is not perceived as a problem on the job and that work performance is not seriously affected by work place lighting (see Appendix B). These findings are consistent with the survey data and actual MiniLogger data collected during 2000 (Johnson et al., 2001).

Table 5: Mean Light Sub-scale Scores by Shift Worked

Shift	N	Mean	Standard Deviation
Day	12	2.75	1.00
Afternoon	9	3.11	1.35
Night	26	3.42	1.03
All	47	3.19	1.10

3.3.5.2 Temperature

Two questionnaire items were presented regarding the impact of extreme temperature on job performance (Items 13 & 20). The first of these items addressed the direct impact of temperature on job performance while the second of these items is directed towards fatigue as a result of working in extreme temperatures. The responses to these two items were reverse scored and combined to form a composite score. As can be seen in Table 6, the overall average score was 4.31, with the afternoon shift having the highest average score of 5.11. The differences in scores across shifts were not statistically significant. Examining the response patterns to items 13 and 20 reveals that over 64% of participants either “Agreed” or “Strongly Agreed” that working in extreme temperatures hurts their job performance, but responses were much more mixed with regard to the impact of extreme temperature on fatigue (see Appendix B).

Table 6: Mean Temperature Sub-scale Scores by Shift Worked

Shift	N	Mean	Standard Deviation
Day	12	4.17	1.27
Afternoon	9	5.11	.78
Night	26	4.10	1.06
All	47	4.31	1.12

3.5.5.3 Noise

Four items (17, 21, 24, & 29) were presented regarding noise on the job. Three of the items addressed the possibility that noise on the job may reduce work performance (Items 17, 21, &

24) while item 29 addressed the possibility that increased noise levels may lead to fatigue. The overall average scale score for noise was 2.60 with a standard deviation of 1.11. Scale scores differed very little across shifts (see Table 7). These data indicate that noise on the job is not perceived as a problem. This is not surprising given the fact that the vast majority of participants indicated that they use ear protection as required by regulations (see Figure 7). Again, this finding is consistent with the perceived and actual data collected in 2000.

Table 7: Mean Sound Sub-scale Scores by Shift

Shift	N	Mean	Standard Deviation
Day	12	2.54	1.28
Afternoon	9	2.61	1.23
Night	26	2.62	1.02
All	47	2.60	1.11

3.3.5.4 Sleep

In addition to item 8, which asked participants to indicate the average amount of sleep they get in a day, four Likert-type items were presented regarding participant sleep habits (Items 15, 18, 23, & 26). Specifically, these items assessed the extent to which participants felt they obtained both the quality and quantity of sleep they need to function properly. Overall, the average score for the sleep sub-scale was 3.59 with a standard deviation of 1.32, but there were significant differences in sub-scale scores as a function of shift worked (see Table 8). Statistical analysis indicated that night shift participant scores were significantly higher than the day shift scores, indicating that the night shift participants feel that they do not obtain as much or as good of sleep as their day shift peers. The afternoon shift scores were not statistically different from the day or night shift scores.

Table 8: Sleep Sub-scale Scores by Shift

Shift	N	Mean	Standard Deviation
Day	12	2.79*	1.27
Afternoon	9	3.22	1.28
Night	26	4.08*	1.17
All	47	3.59	1.32

**Significantly different from each other (p<.05).*

3.3.5.5 Alertness

Two items (27 & 28) were used to assess the extent to which participants felt alert and awake on the job, and responses to these items were combined to form a sub-scale score. The overall average sub-scale score was 3.23 with a standard deviation of 0.97. Scores across shifts did not vary much (see Table 9). Additionally, examination of the responses to these items indicates that most participants generally feel alert on the job even though they may sometimes feel a little bit tired on the job (see items 27 and 28, Appendix B, respectively).

Table 9: Alertness Sub-scale Scores by Shift

Shift	N	Mean	Standard Deviation
Day	12	3.17	1.09
Afternoon	9	2.94	.73
Night	26	3.37	.99
All	47	3.23	.97

3.3.6 Implications of the Survey Data

3.3.6.1 Quality and Representativeness of the Data

The quality of the data collected by this survey appears to be high. For the most part, participants answered all of the items. Furthermore, participants appear to have read all of the items as response patterns across items in a sub-scale were consistent even though some of the items were negatively worded. That is, it is not unusual to have participants simply circle the same response for all items; this was not a problem in the current data set. Additionally, factor analysis of the Likert-type items, comprising the sub-scales, confirmed that the attitudinal part of the survey was indeed measuring five separate factors as planned. These factors correspond to the light, noise, temperature, sleep, and fatigue sub-scales discussed above.

A limitation of the current data set is that only 48 surveys were completed and returned, and all of these surveys came from one facility and one geographic location. Response trends may vary across different facilities or different geographic regions. Furthermore, participants were not selected in a random fashion, limiting the statistical argument for the generalizability of these results to some broader aviation maintenance population. These limitations do not imply that the survey results have no merit; only that caution must be used when trying to generalize the findings.

3.3.6.2 Rank-Ordering Perceived Problems

As previously discussed, the sub-scale scores should be interpreted relative to one another or should be compared across groups. Figure 9 shows the sub-scale scores across the five factors measured. Lower scores indicate less of a perceived problem with that factor while higher scores indicate more of a perceived problem. Statistical analysis indicated that Temperature was the most problematic and Noise was the least problematic, while the other sub-scales were statistically equivalent.

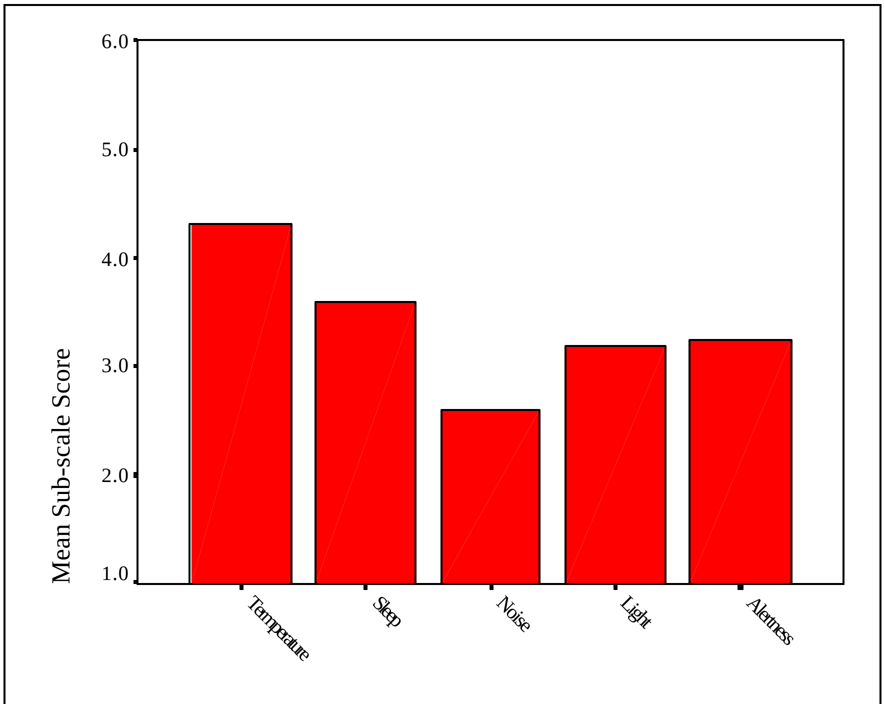

Figure 9. Average Scores for Each of the Sub-scales

If these data are broken down across shift worked, an interesting data pattern emerges. As can be seen in Figure 10, opinions about which factors are most important differ as a function of shift worked. Sub-scales scores for noise are almost identical across shifts, but sub-scale scores for temperature and sleep differ across shifts. The afternoon shift workers appear to have the most problems with temperature, while the night shift workers see temperature and sleep as equally problematic. In general, sleep is viewed as more problematic moving from day, to afternoon, to evening shifts. This is consistent with the notion that shift work often disrupts sleep patterns. It is very interesting that alertness scores do not follow the same pattern. This may suggest that proper use of caffeine, combined with adequate lighting, may contribute to alertness even on the nighttime shifts.

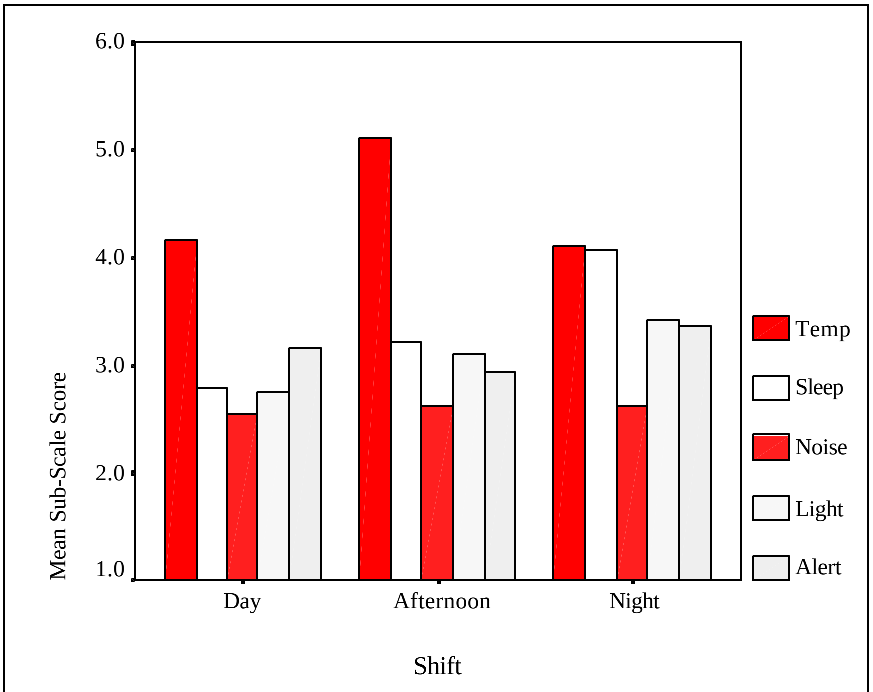

Figure 10. Average Scores for Each of the Sub-scales

3.3.6.3 Setting Priorities

These data indicate that many workers view temperature as being a problematic environmental factor on the job, while noise is viewed as least problematic. This perspective seems to hold overall and across the different shifts worked. Therefore, it seems that airline management should strive to mitigate the impact of extreme temperature with portable cooling, and other such measures.

3.3.6.4 Interpreting the Findings: The Sleep Data

Two different parts of the survey addressed the issue of sleep. First, participants were asked to estimate the amount of sleep per day they obtained. Second, a series of Likert-type items were presented to assess participant attitudes about the quality and quantity of their sleep. Average estimated time slept per night, which is probably optimistic, was 6.26 hours. This is well below the recommended 8 hours of sleep per day. Realistically, participants probably overestimated the amount of time they sleep on average, making the situation even worse. Furthermore, results from the attitudinal items also indicate that the participants generally see sleep as a problem. When the results are broken out by shift worked, night shift participants report fewer hours slept and tend to view sleep as more problematic than their peers.

4.0 RECOMMENDATIONS

This section shall emphasize the areas where the observed data are outside of the recommended limits. Phase 3 of this research program shall contain extensive information to mitigate fatigue, lighting, sound, and temperature extremes.

4.1 Sleep

Table 10 shows summary Actiwatch data and the recommendations for sleep. Most researchers advocate an average sleep requirement for adults is 7.5-8.0 hours per day.

Table 10: Actual Sleep vs. Recommended Sleep

Mean Overall Sleep Experienced by Participants	**Recommended Levels by Carskadon & Dement as cited in Battelle, 1998**
Mean : 5:07 sleep per night	7:30 to 8:00 sleep per night

The data clearly show that airline maintenance personnel sleep about 5 hours per day. All sleep experts agree that 5 hours is not enough sleep (Battelle, 1998). The experts would argue that the population of maintenance personnel is acquiring a daily "sleep debt" of, at least, 2 hours. Since the Actiwatch was worn 7 days a week for the two-week data collection period it does not appear that maintenance personnel are repaying the sleep debt. However, the questionnaire data, reported in Section 3.3, does not reflect a population that perceives chronic fatigue or tiredness. The data collected from the Actiwatch strongly suggests that the population of aviation maintenance workers has a sleep deficiency problem and has not yet acknowledged that potential problem.

Changing the culture of aviation maintenance personnel to sleep more hours is likely to be difficult. It may also be difficult to make management understand and appreciate the significance of this sleep pattern. In most cases, the managers came up through the ranks of the maintenance personnel and are likely to have the same short sleep patterns. Education may be the only way to accomplish this cultural change. During the data collection the research team observed that the personnel who wore the Actiwatch became sensitized to their sleep habits. It is likely that airline maintenance personnel are simply unaware of their sleep habits versus the recommended sleep amounts. Airlines could use equipment like Actiwatches to help technicians to understand their sleep habits and form improved habits if necessary. While this is only speculation, the productivity return on investment would quickly justify the cost of the equipment, administration personnel, and training. Subsequent phases of this research program could determine the extent of error and associated cost that can be based on worker fatigue.

Another possible manner to motivate personnel, with respect to sleep, is to initiate an education campaign related to "Fitness for Duty." While many associate "Fitness for Duty" with alcohol or drugs it can also apply to sleep. Of course, sleep deprivation is not as easy to define or measure relative to alcohol or drug use.

If personnel can recognize fatigue they can help one another to avoid the inevitable performance degradation and potential error. During 2000, the Air Transport Association (ATA, 2000) published the *Alertness Management Guide*. The document was designed for flight crews but has applicability to everyone. The ATA guide offers quick explanations of the importance of sleep as a vital physical need. It strongly endorses the importance of the 8-hour sleep requirement and the "debt" that accumulates. Among the many recommendations offered are such actions as the following: Minimize sleep loss; alter habits to acquire necessary sleep; create the right environment for sleep and; the effect of age, alcohol, diet, and exercise on sleep. This type of guideline and education program should be implemented for maintenance personnel. The labor unions, companies, or the FAA through this research program should foster such informational activity.

4.2 Environmental Factors

The bulk of the data suggest that low light, temperature extremes, and high noise levels in the work place impact technicians. However, the industry employs a variety of excellent measures to mitigate the potentially adverse conditions. Obviously, very little can be done to radically change the nature of the workplace. For example rivet tools are loud and the inside of engine nacelles are dark. Thus aviation workplace management must provide the training and the tools to overcome the conditions. The data collection demonstrated that the companies are doing a very good job to mitigate the negative work conditions. The research team does not recommend that it is necessary to conduct further research on environmental conditions. The team recommends that the *Human Factors Guide for Aviation Maintenance* be reviewed and modified to provide adequate information on these topics.

5.0 USING ENVIRONMENTAL AND FATIGUE DATA TO PREDICT ERROR

5.1 Status of Fatigue and Environment Data Collection in Current Incident Investigation Forms

Boeing's maintenance error Decision Aid (MEDA) incident procedures and the US Navy's Human Factors Classification System (HFACS) collects no quantitative data on fatigue, heat, light, or sound. The Boeing system (see Figure 11), specifically Sections F and G of the MEDA form merely allows a check box for Fatigue, Noise, Lighting, Hot, and Cold. Investigators can add specific data regarding any of these factors, however that is seldom done with respect to these investigations. A study by Johnson and Watson (2001) reviewed numerous MEDA investigations and the environmental factors were the lowest category of contributing factors. When fatigue is checked as a factor, it is seldom quantified. One airline said they had a rare incident investigation where they found that the technician who erred was just completing a double twelve-hour shift. That airline readily reported to the research team that such information is seldom discovered or reported regarding an incident. Instead, the contributing factor may be "failure to use the proper tools and equipment." In reality, the technician was too tired to go a get the manual and/or tools and chose to proceed with the available information and tools.

The research team contemplated creation of a detailed MEDA-like form for collection of very specific data related to environmental and rest data. Those checklist/forms would include the kind of data reported in Section 3 of this report. After considerable discussion, the team surmised that such a form would be an academic exercise and not likely to find widespread use at this time. This is based on the fact that, generally, the industry is not very good at collecting the high-level MEDA data much less the details associated with environmental conditions and perceived fatigue. If the airlines, or the FAA, decides to include such data as part of the Continuous Analysis and Surveillance System (CASS) the data could include such information as the following: amount of overtime worked in the week of incident, number of consecutive shifts worked at the time of the incident, temperature, humidity, lighting conditions, noise levels, and such factors.

N/A __

F. Individual Factors

__ 1.	Physical health (including hearing and sight)	__ 6.	Body size/strength
__ 2.	Fatigue	__ 7.	Personal event (e.g., family problem, car accident)
__ 3.	Time Constraints	__ 8.	Workplace distractions/ interruptions during task performance
__ 4.	Peer Pressure	__ 9.	Other (explain below)
__ 5.	Complacency		

Describe specifically how the selected <u>factors affecting individual performance</u> contributed to the error.

N/A __

G. Environmental/Facilities

__ 1.	High noise levels	__ 6.	Snow	__ 11.	Hazardous/toxic substances
__ 2.	Hot	__ 7.	Lighting	__ 12.	Power sources
__ 3.	Cold	__ 8.	Wind	__ 13.	Inadequate ventilation
__ 4.	Humidity	__ 9.	Vibrations	__ 14.	Other (explain below)
__ 5.	Rain	__10.	Cleanliness		

Describe specifically how the selected <u>environment/facilities</u> factor(s) contributed to the error.

Figure 11. Environmental and Fatigue Sections of MEDA

5.2 Model-Based Approaches to Error Prediction

Models are typically used to predict future occurrences of events. For example, weather forecasting relies on mathematical forecasting models to predict what the weather will be like on a given day. Insurance companies use actuarial models to minimize risk and loss. Universities use selection models to predict student success based on Scholastic Aptitude Test scores and high school Grade Point Averages. Models use information about past events to predict future events. Models predict what is *likely* to occur with some specified level of probability.

Models usually begin life as a conception of how certain variables are related. For example, one may hypothesize that technician fatigue and ambient temperature/humidity is linked with maintenance error. Variables used to predict some outcome are labeled "predictor variables" and variables that represent some outcome are labeled "criterion variables." Moving the model from the conceptual stage to the applied stage requires recording multiple measures of both predictor and criterion variables. These data are then used to assess the nature of the relationship between the predictor and criterion variables. If a relationship exists, a mathematical formula is derived to predict the value of the criterion variable given specific values for the predictor variables. The user can input specific values for the predictor variables and obtain an estimated value for the criterion variable. That is, a single value for the predictor variable can be put into the formula to produce an estimated value for the criterion variable. Once the equation has been established, the criterion value can be estimated using predictor variable information.

The more information we have about someone or something, the more accurately we can predict things about that person or object. For example, suppose that we want to predict how much a person weighs. Without knowing anything about that person (i.e. height, gender, etc.), the mean weight of the overall population is the best estimate of the weight of that particular person. In this example, the average weight for humans is 164.5 pounds according to tables in the *FAA Human Factors Guide for Maintenance and Inspection* (FAA, 1998). Suppose we are asked to give a weight range within which we are 95% confident the person in question will fall. That range would be 96 pounds to 238 pounds and is based on the mean weight +/- 1.96 standard deviations. Several issues come to light. First, our estimate of this person's weight looks reasonable but the weight range that we have supplied to meet the 95% confidence criteria is so broad that it makes our estimate of 164.5 pounds virtually useless. Second, we could substantially improve the accuracy of our prediction by knowing something about the person in question: something related to weight. For example, if we knew that the person in question was male, we would estimate his weight to be 183 pounds and we would be 95% confident that he is somewhere between 129 and 238 pounds. We could further whittle down our confidence interval by gathering more and more information until our estimate of the person's weight did not change with the addition of more information. In some situations, such as predicting student success in college, this point of diminishing returns is reached with as few as two or three predictor variables. Other situations will require more predictor variables to meet that same point of diminishing returns. Similarly, models will only improve if predictor variables that are related to the criterion variable are added. In some cases, using one variable that is strongly associated with the outcome can provide better results than using several variables that are not as directly related to the outcome.

In most situations, predictor variables can be used to improve criterion estimates above and beyond using the overall mean alone. In some situations, even small improvements are beneficial. The amount of benefit must be weighed against the cost of model development, use, and maintenance. In some cases, a model may improve criterion estimates slightly, but the cost associated with obtaining the improved estimate may outweigh its benefit.

Model accuracy is also influenced by the measurement quality of the input data. The old saying, "Garbage In, Garbage out" definitely applies here. Inaccurate input data will reduce the usefulness of the model by enlarging the confidence interval around the criterion variable estimate.

Developing an accurate model is not an easy task for this project. Model construction begins at the theoretical stage and requires data collection and analysis to determine the validity of the model. That is, data must be collected on both the predictor and criterion variables before the model can be used to make outcome predictions. Analysis of the data is used to determine the degree to which each predictor variable improves the predictive performance of the model. Predictor variables that fail to help the model are removed and mathematical weights are assigned to the remaining predictor variables. More data are collected to verify that the model will accurately predict outcomes on a new data set. In some situations, models developed with one data set will not accurately predict outcomes of a new data set. Models that fail to accurately predict outcomes across data sets should be substantively modified to improve their overall performance.

A common question regarding model construction is "how much data are needed to build and validate a model?" A good rule of thumb is to have 50 cases for each predictor variable. For example, suppose that we want to build a model to predict whether or not a maintenance error will occur using light, temperature, sound pressure, and fatigue as predictor variables. A good start would be to obtain measures for the five variables (light, temperature, sound pressure, fatigue, and whether or not an error occurred) from 200 different maintenance events. Two hundred events are needed because there are four predictor variables. Additionally, the distribution of values for each of the variables should be varied and normally distributed across the range of interest. Technically speaking, predictor variables outside the range of values collected during model validation cannot be input into the model. Therefore, the flexibility of the model partially depends on the range of predictor variable scores used to create the model. Similarly, the model should not be used to predict criterion variable values that fall outside the range of criterion values collected during the model construction process. More information regarding regression-based models and prediction can be found in Pedhazur (1997).

5.3 Modeling for Maintenance Incidents

The report section deals with constructing a model to predict the probability of a maintenance error occurring given environmental (light, temperature, and sound) data and employee sleep quantity information. The outcome of the model would be a number representing the percent likelihood that an error will occur under specific environmental and fatigue conditions. Such a model has several prerequisites. First, the predictor and criterion variables must be operationally defined by creating a thorough description of how to measure the variables. Second, the model users must establish a data collection process that will address logistical issues related to valid and reliable data collection and recording. Third, the user must collect data in such a way to ensure that a range of values for the environmental and fatigue variables are represented to include activities when there is an error as well as activities when there is not an error. This last requirement is the most demanding. It requires an airline to continuously collect environmental and fatigue data related to maintenance events (ex. tire replacement, specific inspection task, etc.) regardless of whether or not an error occurred during that event. In other words, environmental and fatigue data must be collected for some number of maintenance activities regardless of whether or not an error occurred.

5.3.1 Assuming the Data is Collected

While the above issues must be addressed and represent a difficult task, they are possible to resolve. Consider the case were a model is constructed, validated, and deemed to improve the accuracy of prediction above and beyond using mean values as estimates of the criterion variable. Such a model may look like this:

$$P_{(Error)} = -.002(Temp)^2 + .005(Sound) - .0005(Light) + .025(Fatigue) + .50$$

Where $P_{(Error)}$ is the probability of an error occurring.

Assuming that the above model is accurate, how can the predicted error rate be used to achieve some organizational objective? That is, suppose that at a given point in time a supervisor collects the above predictor information and computes the estimated probability that an error is likely to occur. What action will the supervisor take to keep an error from occurring? Even if there is a good answer to this question, three troubling facts present themselves. First, the nature of the predictor variables in the above model is that they are continually changing, requiring constant observation and measurement of the above variables. Second, it is not at all likely that a supervisor will actually have time or inclination to collect the predictor data, compute the probability of error, and intervene to keep the error from occurring. Third, it is not likely that an airline would dedicate the personnel required to address points one and two. In essence, construction and validation of an error prediction model is only a small part of the battle; implementation, usage, and maintenance of the model are overwhelming tasks. In terms of cost versus benefit, the benefit of knowing some probability of whether or not an error is *likely* to occur is outweighed by the cost of simply using and maintaining the model, much less the cost of actually developing the model. While developing such a model may be of theoretical interest, the actual use of such a model is likely impractical. This position is reinforced by the industry reluctance to properly collect and use data from the Boeing MEDA system. The information related to rest, number of hours worked, consecutive days worked, environmental conditions are more detailed than most MEDA data. The airline maintenance industry has not successfully used MEDA, mostly due to the large time commitment required. Therefore it is highly unlikely that they will use a system that requires even a higher degree of diligence, investigation, and record keeping than MEDA. This comment is driven by the reality of the industry rather than by the potential high value of such information. Ultimately, the FAA may strongly suggest, or require that such data become a part of each airline's Continuous Analysis and Surveillance System (CASS) requirements.

6.0 SUMMARY AND RECOMMENDATIONS FOR NEXT STEPS

6.1 Three Phases Completed – A Summary

The research team has now collected data in all seasons, from airlines and from repair stations. The environmental data is based on nearly 125 participants, wearing the sophisticated MiniLogger equipment for over 10,000 hours of data collection. The sleep duration data is based of over 150 participants, wearing the Actiwatches for over 50,000 hours of data collection. Since the start of this effort the research team has collected over 1000 questionnaires, from maintenance technicians, reporting on rest, fatigue, and environmental factors associated with work performance. This is a significant amount of accurate and reliable data. That means there is very high confidence in our summary statements.

Based on the data, there were no environmental conditions that seriously threaten the safety of maintenance or of maintenance personnel. There are times when the equipment measured light, temperature, and noise ranges that were out of the optimal limit for ideal human performance. However, the measurement devices could not account for the various means to mitigate the extremes. For example, the equipment did not assess that the workers were wearing hearing protection when noise levels were very high. Technicians reported that they use hearing protection under such circumstances. With respect to lighting, the equipment noted some low light conditions but was unable to always determine when ancillary lighting was applied to the specific work area. When high temperatures were recorded, the equipment was unable to measure the fact that high volume fans and plenty of appropriate hydration was available for the workforce. Even in the observed cold weather conditions, a mere absolute measurement of a very cold outside air temperature fails to measure that the work force is supplied with warm coats, hats, gloves, and even long underwear. The bottom line is that the industry is doing a reasonable job of assuring safety and safe working conditions in spite of the inevitable and occasional environmental extremes. There is always opportunity for improvement but, once again, the situation is safe and under control.

The assessment of sleep duration showed that the population of aviation maintenance technicians, throughout the industry, is sleep deprived. This is a certain finding and represents a risk to safe work performance. This statement is independent of age, experience, type of company, season of the year, etc., and it is exacerbated by shift work schedules. Based on the data, low and insufficient sleep duration appears to be a cultural characteristic of the aviation maintenance workforce. The questionnaire data strongly support the fact that this general pattern of insufficient sleep is not a result of extended work hours. Further, the combination of the measured data and the questionnaire data indicate that AMTs are not cognizant of the fact that they do not get enough rest. This is a problem, one that the industry must address.

The research team believes that there is not an immediate requirement for additional environmental data collection. The research team recommends that FAA use the data, from Phases 1-3, to address the safety risks associated with sleep duration. Issues associated with lack of rest, with likely resultant fatigue, and "Fitness for Duty" issues and should receive a high level of attention by FAA, companies, labor unions, and the individual. A number of recommendations are listed in below.

6.2 Recommendations

The first three phases of this research have shown that the area of greatest need relates to challenges associated with the sleep duration habits of AMTs. Therefore the suggestions herein are associated with changing the culture of technicians. That culture change is most likely to be successful if it combines awareness, training, behavioral modification, and on-going reporting.

The US Department of Health, the Department of Transportation, the National Sleep Foundation, and other government and private organizations prepare educational materials for education about alertness, fatigue, and sleep. The research team recommends creation, implementation, and evaluation of such programs that are specifically designed for the aviation maintenance work force.

6.2.1 Awareness

This report has discussed aviation maintenance workplace environmental factors and sleep duration habits of aviation maintenance technicians. The company and the work force reasonably mitigate the environmental conditions. However the data show that insufficient rest seems to be a cultural trait of the workforce. The research team proposes to create training and awareness materials that will inform the workforce about the dangers of working while fatigued, methods to ensure safety when fatigue is a potential threat, and ways to improve sleep duration habits.

The FAA should create materials for a sleep importance awareness campaign for the AMT workforce. These materials should include brochures, signage, and training material that is focused on the aviation maintenance workforce. While such materials can and should capitalize on existing government documents they should be designed specifically for the aviation maintenance workforce. Such materials can be used throughout the maintenance organization.

This recommendation is likely to have immediate recognition by the workforce. The FAA cannot create regulations regarding hours of sleep. Proper industry awareness, education, and motivation is the only way to begin to impact the aviation maintenance culture with regard to sleep.

6.2.2 Training

This recommendation is closely aligned with the awareness campaign above. The FAA should create the training program to make technicians aware of issues related to fatigue and alertness. This program can have a format similar to the documents created for Maintenance Resource

Management. Those materials included published guidelines, on the FAA website, a Computer-based training program, and finally an Advisory Circular. These materials, ultimately, could provide enough information to create an excellent video program, when funding is available from FAA or industry.

6.2.3 Behavioral Modification

Changing a culture will require large-scale behavior modification. This means that the research must be able to show AMTs their current behavior, show them how to change the behavior, and measure that behavioral change along the way. For this proposed task the behavioral modification treatment will be in the form of measurement, with the Actiwatch. Participants would receive frequent feedback, throughout the treatment period, regarding their sleep duration habits.

During Phases 2 and 3, many of the participants wearing the Actiwatch commented that merely wearing the watch made them a bit more conscious of their sleep duration habits. That consciousness took place without the wearer even seeing the Actiwatch data. Members of the research team also wore the watch in order to fully understand its capabilities and the nature of the resulting data. The researchers felt that the watch, with the data, had the perceived effect of altering sleep duration behavior. Because of this experience, the researchers believe that AMT sleep duration habits can be modified.

This task would run a formal experiment study to see how the Actiwatches can be used to alter sleep behavior. The experimental variable would be feedback while wearing the watch. Of course, there would be no plan to train the entire population of AMTs with the Actiwatch. However this information can show industry how to change sleep duration by making AMTs more aware of their actual sleep habits. Ultimately the solution could be as simple as creating a sleep diary for technicians. Such an intervention would merely make them aware of their sleep duration patterns.

The output from this proposed tasks are multifold. First, the experimental nature of this task can demonstrate that it is possible to modify the sleep duration behavior of AMTs. In the Phase 3 survey over 60% respondents said that they wish that they could get more sleep. This task will help those respondents. Secondly, this task will create a system that the industry can use to change behavior. The final reports will offer a specific implementation report for using the watches and other less sophisticated interventions to modify sleep duration behavior. We must mention that we expect to modify sleep duration behavioral only of participants who are not suffering from a physical or mental condition associated with sleep behavior.

6.2.4 On-going Reporting

The research team recommends the creation of a system to better track the relationship between fatigue and maintenance error. This task has many challenges. First, the industry must generate additional internal, or external, motivation to increase the quantity and quality of error investigations. The current companies that use MEDA or HFACS to their full capability would have to raise the level of their error investigation techniques with respect to fatigue. This can happen if FAA makes such data an airline requirement. It would behoove the industry to explore the value of such data in advance of FAA action. Whether it is a Continuous Analysis and Surveillance System requirement or an airline voluntary action, investigators must be trained to recognize situations were fatigue might be a contributing factor. This can be done only if the FAA and the industry make it a high priority before a serious incident or accidents brings the fatigue issue into the public eye.

7.0 ACKNOWLEDGEMENTS

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APPENDIX A: BLANK QUESTIONNAIRE

Measurement of Maintenance Work Environment Factors and Technician Rest Periods

Date:		***No name is necessary***

1. Age: ______________

2. Gender: ______ Male ______ Female

3. Please check your primary role/position.

- ❑ Airframe
- ❑ Avionics
- ❑ Machine Shop
- ❑ Component
- ❑ Powerplant
- ❑ Structure/Bond
- ❑ Mod Line
- ❑ Interiors
- ❑ Q/A Inspection
- ❑ Apprentice
- ❑ Line Maint
- ❑ Other

4. What shift do you presently work?	❑ Day ❑ Afternoon ❑ Night
5. How long have you been an aircraft mechanic/AMT?	_______________ Years
6. On average, how many hours a week do you work overtime?	_______________ Hours
7. Do you work a second job?	❑ Yes ❑ No
8. Have you taken a training course on maintenance resource management or maintenance human factors?	❑ Yes ❑ No
9. On average, how many hours of sleep do you get when you go to bed?	_______________ Hours
10. How many times do you drink water during the average work shift?	_______________ Times

Please choose the **ONE BEST** response that describes the way you feel about each statement.	**Strongly Agree**	**Agree**	**Slightly Agree**	**Slightly Disagree**	**Disagree**	**Strongly Disagree**
11. I almost always wear my ear protection as required by regulations.	1	2	3	4	5	6
12. I have received adequate safety training for this job.	1	2	3	4	5	6
13. Working in extreme temperatures hurts my job performance.	1	2	3	4	5	6
14. There are warning signs posted to keep employees safe.	1	2	3	4	5	6
15. I feel completely rested when I wake up.	1	2	3	4	5	6
16. I would do better work if the lighting were better.	1	2	3	4	5	6
17. I make mistakes because of the high noise level at work.	1	2	3	4	5	6
18. I don’t sleep very well.	1	2	3	4	5	6
19. I often work without enough light.	1	2	3	4	5	6
20. Working in extreme temperatures makes me very tired.	1	2	3	4	5	6
21. The loud noises on the job affect the quality of my work.	1	2	3	4	5	6
22. My job area is well lit.	1	2	3	4	5	6
23. I never seem to get enough sleep.	1	2	3	4	5	6
24. I would do better work if there was less noise on the job.	1	2	3	4	5	6

Please choose the **ONE BEST** response that describes the way you feel about each statement.	**Strongly Agree**	**Agree**	**Slightly Agree**	**Slightly Disagree**	**Disagree**	**Strongly Disagree**
25. I make mistakes because there isn't enough light on the job.	1	2	3	4	5	6
26. I need to get more sleep on a regular basis.	1	2	3	4	5	6
27. I am always very alert on the job.	1	2	3	4	5	6
28. I almost never feel tired on the job.	1	2	3	4	5	6
29. The noise level on the job makes me tired.	1	2	3	4	5	6

Thank you. Your input is very valuable and will help with data assessment. Nothing stated in this document will be used against any personnel. You may leave comments in this section.

APPENDIX B: QUESTIONNAIRE WITH DATA INCLUDED

Measurement of Maintenance Work Environment Factors and Technician Rest Periods

Date:		***No name is necessary***

1. Age: Mean- 39.2 Years SD- 7.86 Years

2. Gender: 95.8% Male 4.2% Female

3. Please check your primary role/position.

Airframe	0%	Mod Line	0%
Avionics	2.1%	Interiors	0%
Machine Shop	0%	Q/A Inspection	0%
Component	0%	Apprentice	0%
Powerplant	0%	Line Maint	95.2%
Structure/ Bond	0%	Other	2.1%

4. What shift do you presently work?	Day 25.0% Afternoon 20.8% Night 54.2%
5. How long have you been an aircraft mechanic/AMT?	Mean- 16.6 Years SD- 8.45 Years
6. On average, how many hours a week do you work overtime?	Mean- 3.8 Hours SD- 6.87 Hours
7. Do you work a second job?	Yes 8.5% No 91.5%
8. Have you taken a training course on maintenance resource management or maintenance human factors?	Yes 25.0% No 75.0%
9. On average, how many hours of sleep do you get when you go to bed?	Mean- 6.26 Hours SD- 1.00 Hours
10. How many times do you drink water during the average work shift?	Mean- 7.2 Times SD- 15.4 Times

Please choose the **ONE BEST** response that describes the way you feel about each statement.	Strongly Agree	Agree	Slightly Agree	Slightly Disagree	Disagree	Strongly Disagree
11. I almost always wear my ear protection as required by regulations.	45.8	41.7	8.3	0	2.1	0
12. I have received adequate safety training for this job.	20.8	56.5	15.2	6.5	0	0
13. Working in extreme temperatures hurts my job performance.	37.5	27.1	16.7	8.3	4.2	4.2
14. There are warning signs posted to keep employees safe.	14.6	64.6	14.6	0	4.2	0
15. I feel completely rested when I wake up.	4.2	22.9	18.8	25.0	16.7	10.4
16. I would do better work if the lighting were better.	14.6	16.7	29.2	10.4	16.7	10.4
17. I make mistakes because of the high noise level at work.	0	2.1	20.8	18.8	35.4	20.8
18. I don’t sleep very well.	10.4	12.5	25.0	14.6	29.2	6.3
19. I often work without enough light.	2.1	35.4	14.6	16.7	18.8	10.4
20. Working in extreme temperatures makes me very tired.	14.6	20.8	18.8	25.0	12.5	4.2
21. The loud noises on the job affect the quality of my work.	2.1	8.3	18.8	20.8	27.1	20.8
22. My job area is well lit.	8.3	33.3	18.8	18.8	6.3	12.5

Please choose the **ONE BEST** response that describes the way you feel about each statement.	Strongly Agree	Agree	Slightly Agree	Slightly Disagree	Disagree	Strongly Disagree
23. I never seem to get enough sleep.	8.3	16.7	22.9	18.8	27.1	4.2
24. I would do better work if there was less noise on the job.	0	6.3	25.0	18.8	22.9	20.8
25. I make mistakes because there isn't enough light on the job.	2.1	0	14.6	22.9	31.3	27.1
26. I need to get more sleep on a regular basis.	20.8	18.8	18.8	12.5	20.8	6.3
27. I am always very alert on the job.	8.3	41.7	33.3	10.4	2.1	2.1
28. I almost never feel tired on the job.	2.1	10.4	27.1	29.2	18.8	10.4
29. The noise level on the job makes me tired.	0	6.3	14.6	18.8	31.3	27.1

NOTE: *Data represented in percent of sample. Not all rows will add up to 100% due to missing data.*