Sleep Deprivation and Its Consequences in Construction Workers

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Abstract: Sleep deprivation contributes to fatigue, which can have a profound effect on an individual's wellbeing, work performance, and safety. To investigate this phenomenon, a study was conducted on a sample of construction workers on a large construction project in Vancouver, Canada. This paper reports on the results from the workers wearing an actigraph 24 h/day for a full week to precisely measure their sleep and rest. The results enabled sleep efficiency and mental effectiveness levels to be determined by correlating them to blood alcohol concentration levels. This allowed determination of increased risk due to inadequate sleep. It was found that workers fell well under recommended sleep requirement guidelines of 8-h sleep per night, which resulted in an increase in risk of accident of 9%. Although further work is needed to better understand the coping mechanisms of fatigue and how the resulting fatigue factor could be measured and managed, this study indicates that workers in the construction industry suffer decrements in performance and are at higher risk of accident at home and work solely due to inadequate sleep.

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Introduction

Sleep deprivation is pervasive in modern society. It contributes to fatigue, which can have a profound effect on an individual's wellbeing, work performance, and safety. Not all but some commercial sectors recognize this relationship and have conducted studies to apply some of the general knowledge of fatigue and sleep to their operational settings. In several instances the resulting guidelines and improved operational practices have helped reduce losses and improved worker wellness and safety.

Fatigue has been defined (Strauss 2003) as "a nonpathological state resulting in a decreased ability to maintain function or workload due to mental or physical stress." Associated with fatigue are two key physiological factors, loss of sleep and disruption of the circadian cycle, which is the physiological process controlling many bodily functions such as sleeping, digestion, hormone secretion, body temperature, and alertness. Regardless of how one enters into a fatigued state, adequate sleep is the only naturally occurring cure.

Inadequate sleep has been associated with numerous major work-related accidents, but a common problem is that individuals do not either understand their state of fatigue or its consequences or both. Over the past 40 years, researchers have developed a much better understanding of sleep, circadian rhythms, and performance effects associated with these. For several decades, researchers (Levine et al. 1988; Wehr et al. 1993; Dinges et al. 1996; Rosekind et al. 2000; Van Dongen et al. 2003; Russo 2005; Roth 2006) have found an average sleep requirement for adults of 8 h per 24-h period for fully restorative results, but most get less than 7 h resulting in a sleep deficit (Dinges et al. 1997). Any amount of sleep less than that required by an individual for full restoration results in sleep deprivation. Severe or chronic sleep deprivation can be very serious and dangerous not only to the individual but also to others who may be impacted by actions of the sleep deprived.

Many researchers and institutions such as Transport Canada (2007) and the U.S. National Transportation Safety Board (2007) report that fatigue has been cited as contributing to or causing some of the world's most visible accidents including the grounding of the Exxon Valdez (National Transportation Safety Board 1990), the Three Mile Island and Chernobyl nuclear accidents, and the BHP Texas oil refinery disaster. (U.S. Chemical Safety and Hazard Investigation Board 2007).

Sleep deprivation can result from many factors including life style, stress, poor sleep habits, and sleep disorders such as sleep apnea and restless legs' syndrome. Regardless of its origin, inadequate sleep and sleep deprivation can reduce workers' performance and put themselves and others at higher risk of accidents. Dawson and Reid (1997) made a breakthrough with research, which correlated various levels of sleep deprivation with blood alcohol concentration (BAC) levels. Impairment was known to result from inadequate sleep but until Dawson and Reid's (1997) research, which correlated cognitive and motor skill decline from sleep deprivation with equivalent declines from alcohol consumption, there were no effective measurements for fatigue impairment from sleep deprivation. Follow-on research (Lamond and Dawson 1999; Fletcher et al. 2003) has validated these findings and assisted other researchers (Hursh 2005) to develop sleep and performance models such as the sleep, activity, fatigue, and task

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effectiveness (SAFTE) model. This model correlates measured sleep levels with an equivalent BAC to make declarations about lowered individual performance, reduced mental alertness, and resulting risk from these states as found with alcohol impairment. This applies to all individuals in all walks of life. Within the construction industry, there was no known measurement of worker sleep habits, which underpins this model. Coupled with technological advances in actigraphy, which uses three-axis accelerometers to capture limb movement of subjects and record wake and sleep activity to feed the model, estimates (Hursh et al. 2006) of worker impairment equivalency and resulting risk can be made from measured sleep levels and activity.

Why Study Construction Workers?

The construction sector can be a difficult place to work. It is prone to safety incidents and accidents. The National Institute for Occupational Safety and Health (2007) reported "Construction is a high hazard occupation. In the United States during the period from 1980 to 1995, at least 17,000 construction workers died from injuries suffered on the job. Construction lost more workers to traumatic injury death than any other major industrial sector during this time period. Construction has the third highest rate of death by injury: 15.2 deaths per 100,000 workers. Only mining and agriculture experience higher rates."

In British Columbia, WorkSafeBC administer the Workers' Compensation Act on behalf of the British Columbia government. WorkSafeBC's (2006) statistics show 389,911 lost work days with an average weekly wage of $789 or a total annual productive loss of approximately $44 million.

Risks on construction sites may be heightened due to inclement weather and mobile equipment, and different work sites necessitating travel coupled with changing and demanding schedules requiring additional work hours. All possibly increase stress and fatigue. Factors such as these challenge human physiology and can result in performance-impairing fatigue leading to higher worker risk. Continuous improvement of worker performance, productivity, and safety is possible but starts by acknowledging and managing these factors. Rosekind et al. (1996, p. 157) noted, ignoring them "…can lead to decrements in performance and capability as well as the potential for incidents and accidents that can result in tremendous societal and individual costs."

It is possible that fatigue via sleep deprivation is a key component of the risk profile facing construction workers of British Columbia, but it has not been investigated in British Columbia or any other regions while other industrial sectors have recognized that fatigue is a key component of workplace safety and employee wellness and therefore a factor that must be managed. The aviation industry (Graeber et al. 1986; Gander et al. 1993; Rosekind et al. 1995; Dinges et al. 1996) and the transportation industry (Transport Canada 1996; National Transportation Safety Board 1999) were early promoters of research to better understand fatigue's impact on performance, accidents, and its management. The construction industry has many elements found in other sectors, which have studied fatigue including operation of heavy equipment, shift work (Akerstedt 1988; Dijk and Czeisler 1995; Monk et al. 1996), and long hours (Spengler et al. 2004; Dong 2005), making it a logical concern after consideration of the findings from other sectors. Understanding fatigue levels in the construction industry, as well as any companion risk associated with accidents introduced by workers from this factor, was the driver of this study.

Methodology

Workers wore an actigraph for 7 days (a session) to capture their actual wake and sleep activity to feed the Hursh SAFTE model (Hursh et al. 2006) for estimated worker accident risk and performance decrements due to their measured sleep. This is done via determining a BAC equivalency to sleep deprivation. To verify the measured sleep data, the workers kept sleep logs. For further validation the measurements were compared to results from a separate survey where workers of the same project estimated their sleep. The study was conducted in August and September of 2007. One hundred thirteen sessions were conducted where 95 different participants wore an actigraph after which the collected data were analyzed with the fatigue software model SAFTE.

Study Participants

The construction workers in this study were from one of British Columbia's megaprojects called the Canada Line project (SNC-Lavalin Inc. 2007b), which was building an 18-km automated rapid transit system in the metropolitan Vancouver area. The opportunity was unique in that most trades of the sector's workers were represented. Additionally, all professional, clerical, and other office personnel were available in addition to field workers for this study. Further, there were segments of the project, which operated around the clock and provided a unique opportunity to study the sleep of construction workers on this shift pattern.

The project is further unique in that it is a public private partnership, which brought together several major construction organizations with different skills, backgrounds, cultures, procedures, and training practices. This included joint ventures, contractors, as well as the primary party all operating from common sites.

Actigraphy, Sleep, Activity, Fatigue, and Task Effectiveness

Actigraphy was used extensively for this research to identify sleep patterns by collecting data 24 h/day for a 7-day period per participant. An actigraph, as shown in Fig. 1, is a small device worn around the wrist to record motion of the wearer. These devices are able to digitally and precisely record the movement of the limb they are worn on, which is then translated into an estimate of sleep quantity and quality.

Collected data from the actigraph are an activity record as shown in Fig. 2, which illustrates a subject's motion during sleep and wake periods. Poor sleep is illustrated by a short sleep duration coupled with much activity during the sleep.

The actigraph data fed the Cole-Kripke algorithm (Cole et al. 1992), in the Hursh sleep model SAFTE. Hursh (2005), who led the development of the SAFTE model based on research conducted for the Department of Defense in the United States, applied knowledge of circadian rhythms and fatigue then operationally validated and "tuned" the model to predict standard levels of performance, which individual results may be viewed against. The model validation and calibration of Hursh et al. (2006) resulted from a large field-based project associated with railway accidents.

The data of Fig. 2 are analyzed by the model for an assessment of worker mental effectiveness, as shown in Fig. 3. Morgenthaler et al. (2007) recently reviewed evidence from 108 research projects using actigraphy in sleep studies. Morgenthaler et al. (2007, p. 519) concluded that "actigraphy provides an acceptably accurate estimate of sleep patterns in normal, healthy adult popu-

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Fig. 1. SleepPerformance Inc. actigraph worn on the wrist

lations and inpatients suspected of certain sleep disorders." Table 1 shows a typical conversion by the SAFTE model of the measured sleep data into values associated with the mental effectiveness of the worker and their increased risk of accident.

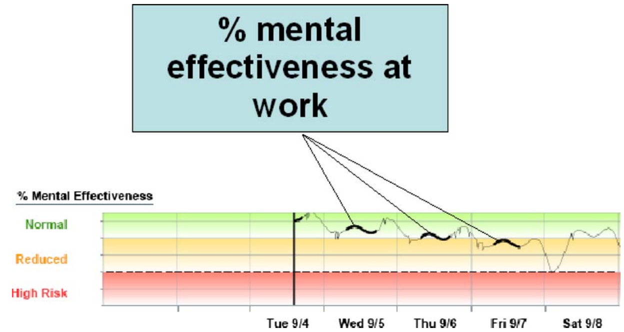

Fig. 3. Interpreted worker effectiveness from actigraph data, Session No. 32428 (Powell 2007, with permission)

Findings

Measured sleep performance for the participant construction workers ranged from an average of 4.5 to 8.9 h/day. Mean sleep values for 1 week were determined for participants and averaged 6.7 h/night, as shown in Table 2, which also shows the comparison data from the sleep logs they kept and from the estimated sleep of workers from a separate survey. As shown in Table 2, the averages of the survey and measured sleep were in very close agreement (6.6; 6.7-h sleep per night). The log average was 7.2 h, suggesting that participants believed they were getting a half hour more sleep per night than measured.

Only 16% of the participants measured met the recommended guidelines of 8 h of sleep per night, as shown in Table 3. The actigraphs were worn by 17 female workers and 96 male workers, and 46 sessions were with participants who had an office and 67 were workers who did not have an office. The latter were classi-

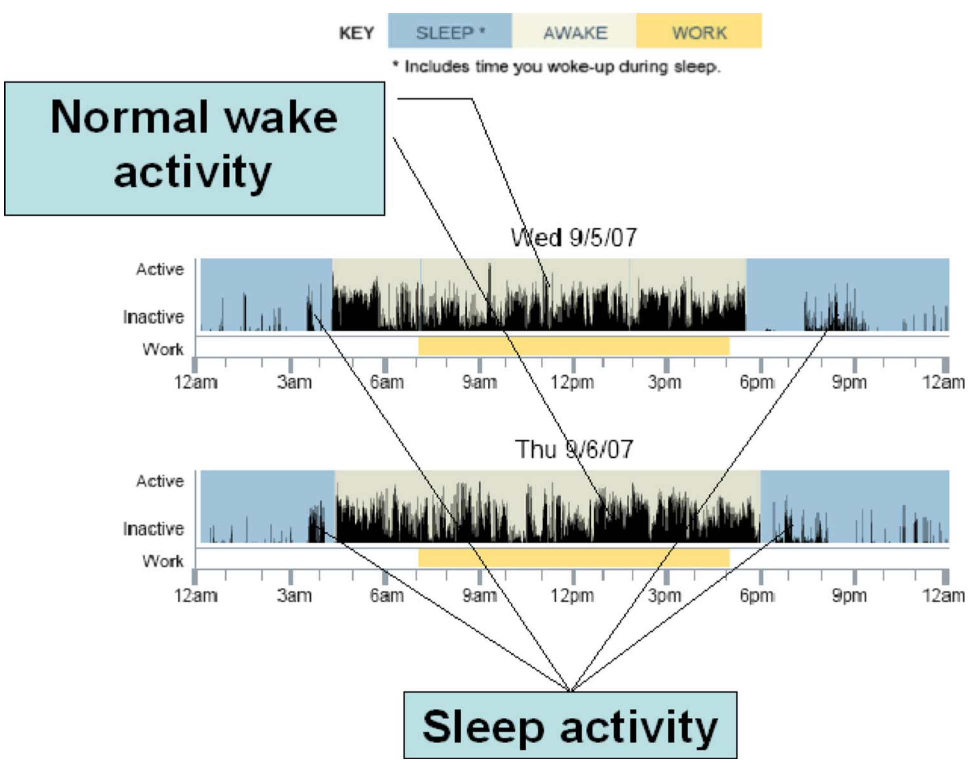

Fig. 2. Actual actigraph data collected from a construction worker, Session No. 32428 (Powell 2007, with permission)

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Table 1. Actual Fatigue Analysis from Actigraph Data; Session No. 32428 (Powell 2007, with Permission)

Mental effectiveness (%)	Average equivalent BAC	Increased accident risk (%)	While at work		While awake	
			h	% time	h	% time
90–100	0.0	0	11	25	25	30
80–90	0.03	+27	32	75	57	67
70–80	0.05	+27	0	0	2	2
60–70	0.09	+31	0	0	0	0
0–60	>0.11	+46	0	0	0	0
Average increased accident risk			18.7%		18.1%	

fied as field workers. Office workers included personnel such as supervisors, support staff, engineers, and others who were "field based" but had an office there.

Sleep activity levels, wake periods, sleep efficiency, and mental effectiveness levels were determined correlating to BAC levels to estimate increased risk for the workers due to inadequate sleep. The percent mental effectiveness levels were determined for each participant based on research, which correlated reduced mental effectiveness levels and increased reaction times from fatigue to a BAC level, as illustrated in Table 4. Reduced mental effectiveness greater than 10% is taken by the SAFTE model as outside a normal range. Average increased accident risk was 8.9% for all participants: 7.4% for all office workers and 10.1% for all field workers solely due to inadequate sleep.

To put this in perspective, 432 work hours were measured at a BAC equivalency of 0.05%, a level considered unsafe for operating motor vehicles in most parts of Europe. In North America 0.08% BAC is considered legally impaired. Another 133 h were measured at an equivalent BAC of 0.09% and 38 h were measured at an equivalent BAC of over 0.11%. For the entire group the estimated average increased accident risk levels ranged from 0.7 to 23.3% solely due to inadequate sleep. While the source of impairment was not alcohol, the effects of inadequate sleep are similar resulting in a more risky work environment for workers and their coworkers.

Additional Focus on Construction Shift Workers

Six workers who were shift workers in a tunneling operation agreed to wear an actigraph for 3 straight weeks or 1 full shift rotation of work around the clock. The "day shift" of 0600 to 1400 averaged the lowest sleep of the participants at 6.7 h, which was significantly different from the 1400 to 2200 shift of 7.7 h ($p=0.04$). Data failure prevented a comparative statement with significance regarding the 2200 to 0600 shift but it averaged 7.1 h of sleep, as shown in Table 5.

This result is unexpected as workers believed that a standard day shift gave them the most sleep. In fact, the early morning start on this shift negated quality sleep resulting in higher risk values for the workers on this day shift compared to later starts where more quality sleep was obtained.

Table 3. Distribution of Hours Slept per 24-h Period

Hours sleep each day	Percent (survey)	Percent (log)	Percent (measured)
8+ h	8.2	21.4	15.7
7–8 h	34.5	38.8	27.0
6–7 h	29.1	30.6	37.1
5–6 h	18.2	7.1	15.7
<5 h	10.0	2.0	4.5

Age, Sleep Obtained, and Accident Rates

Averaged accident claims from 2000 to 2006 (WorkSafeBC 2006) show that almost 60% came from workers under the age of 40. Workers under the age of 40 recorded less average sleep than workers over 40 (6.6 ± 1.9 h versus 6.9 ± 1 h) with implications that less sleep may be a factor but the statistical significance is weak ($p=0.22$; CL=95%). More data samples were needed in some of the age categories to allow significant comparisons. Fig. 4 illustrates the distribution of the average sleep per 24-h period by age group as well as the distribution of the samples ages. The added trend line clearly shows the younger the worker, the less sleep obtained.

Sleep Log Data

Workers wearing the actigraph were also requested to keep a sleep log and record daily their time sleeping and working. The logs did validate a low amount of sleep per participant averaging 7.2-h sleep per night. Interestingly, companion sleep logs did not have strong correlation with individuals' measured sleep ($r^2=0.07$), suggesting that the participants were not good at recording their actual sleep. The higher sleep value is most probably explained as individuals recording their time in bed as an estimate of their sleep. However, all separate levels of average sleep per night shown in Table 2 are significantly under the recommended average of 8 h/night for fully restorative sleep. It was possible to compare the work-week sleep with the weekend sleep using the log data.

Sleep Survey

A survey independent of the sleep log and the actigraph wearers was distributed to a larger group of the Canada Line workers. One hundred twenty-five responses were received from a distribution of about 500 surveys. The two relevant questions for comparison were as follows:

1. How long do you usually spend sleeping each night during the week?
2. How long do you usually spend sleeping each night on the weekend?

The results are those shown in Tables 2 and 3. The survey gave close agreement on sleep (6.6; 6.7 h) per night and standard deviation (1.2 h) as the measured values. The log data averaged

Table 2. Average Sleep Values from Survey, Log, and Actigraph Measurements in Hours per 24-h Period

Survey sleep		Log sleep		Survey sleep full week	Log sleep full week	Actigraph-measured sleep full week
Week	Weekend	Week	Weekend			
6.2	7.5	7.0	7.7	6.6	7.2	6.7

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Table 4. Actigraph-Measured Values and SAFTE Results

Results from actigraph measurement	Measured average sleep	10–20% mental decrement		20–30% mental decrement		30–40% mental decrement		40–100% mental decrement	
		h	%	h	%	h	%	h	%
All workers	6.7	1,648	21.1	432	5.5	133	1.7	38	0.5
Office	6.8	503	14	166	4.6	30	0.8	33	0.9
Field	6.7	1,145	26.7	266	6.2	103	2.4	5	0.1
BAC equivalent		0.03%		0.05%		0.09%		>0.11%	

7.2 ± 1.1 h. From the survey it is expected that 49.4–66.2% of the workers would report sleeping less than 7 h/night (CL =95%).

A key indicator of sleep deprivation is associated with sleeping more when unconstrained by work schedule. Sleep deprivation can simply be due to the schedules kept during the week; schedules which prevent adequate sleep resulting in sleep debt heading into the weekend. To repay the debt individuals sleep longer on weekends than during the work week when free from schedule to do so (Brown et al. 2002). With statistically significant difference in sleep patterns, one can conclude that there is fatigue via sleep deprivation during the work week, which is being reduced over the weekend by sleeping longer.

Fig. 5 shows a statistically significant shift (p-value =0.0000000001) in the hours slept during weekends indicating a sleep debt coming out of the work week. The log data agreed with this result (p-value=0.000007), further confirming inadequate sleep among the workers.

Discussion

Without the actual measurements from this study, it was only possible to speculate about the sleep habits of the construction workers. The findings from this study are significant. Three separate measurements illustrated that this group was not getting recommended sleep levels. From this, as a group, it is estimated that the participants increased risk of accident by almost 9% solely due to inadequate sleep. If this is projected onto the 1,500 workers of the Canada Line project, it means higher work risk for all, underperformance, and potential productivity loss in a year. It is interesting to note that the Canada Line project was not performing poorly when it comes to accidents. Through the month of August for the year 2007, the project was under industry averages for both frequency and severity of accidents (SNC-Lavalin Inc. 2007a). This is not necessarily a contradiction of the findings herein. As reported by Hursh et al. (2006, p. 6), "...a fatigue model can predict an increase in fatigue-associated risk, not the specific occurrence of an accident.... Wide variations exist in individual sensitivity to the factors that cause fatigue, so, again, fatigue models can only predict an increased risk of fatigue, not a specific individual person's level of fatigue or performance."

There is also a possible understatement of the amount of sleep deprivation driving fatigue among these workers due to timing of the study. The study spanned 2 months during which there were two statutory holidays, which added an extra day off to a weekend. The workers wearing the actigraph during these "long" weekends were able to sleep longer and effectively had another day of sleep debt repayment. This study did not invalidate these data but took it as representative of what would occur naturally over the course of 1 year.

This study found the following:

1. Averaging 6.7 h of sleep per night, only 16% of the construction worker participants measured, met the recommended guidelines of 8 h of sleep per night for healthy adult populations.
2. Construction workers are fatigued due to sleep deprivation, resulting in significant performance decrements above 10%. Only 71% of all the wake hours were recorded as "normal" mental effectiveness. 21% showed that mental effectiveness degraded 10–20%, 6% showed 20–30%, and 2% more than 30%.
3. This fatigue is derived from poor sleeping habits as recorded by actigraph, sleep logs, and survey, which also illustrated the practice of sleeping longer on weekends than during the work week.
4. The estimated average increased accident risk was about 9%, supporting concern that fatigue via sleep deprivation may be correlated to accident rates in the sector. Thirty-five participants had an estimated increased risk of accident in the range 10–23%. More accidents and less sleep by age show a trend but this study cannot state that it is statistically significant.

Creating worker awareness of sleep requirements and the impact of too little sleep should be undertaken in construction. Many treat sleep or the lack of sleep as a "fact of life" in the 21st century without regard to what it may mean. It cannot only increase risk of accident at home and in the workplace, but can also be a factor degrading personal health. Organizations need to be aware of the potential decrements in performance due to inadequate sleep and promoting individual awareness on this issue and promoting good sleep habits as preventive to losses.

The results from the workers who wore the actigraph for a 6-week period illustrated that their worst sleep occurred alongside

Table 5. Average Weekly Measured Sleep of Workers in a Tunneling Operation (Powell 2007, with Permission)

Average sleep by shift	Worker A	Worker B	Worker C	Worker D	Worker E	Worker F	Average of six workers
0600–1400	7.5	7.2	5.8	Data failure	5.9	6.9	6.7
1400–2200	8.0	7.7	8.6	7.2	Data failure	7.2	7.7
2200–0600	7.8	Data failure	6.5	Data failure	5.3	8.8	7.1
Worker average	7.8	7.3	7.0	7.0	6.3	7.6	7.2

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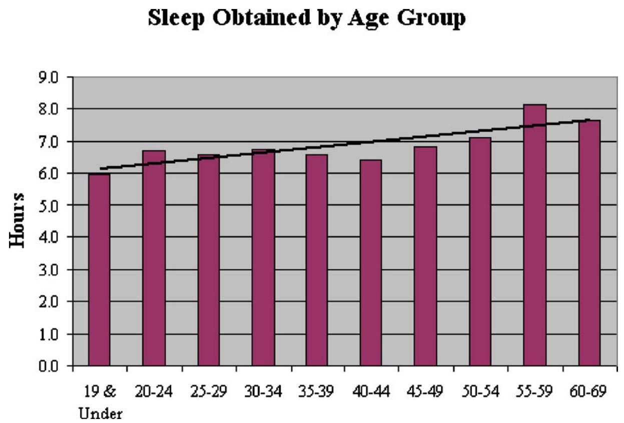

Fig. 4. Measured sleep values by age category

their day shift. A key element of this was the starting time of the day shift at 0600. To get to work for this shift, these workers were disrupting their sleep during the lowest point of their circadian cycle and not compensating with additional rest after work. To protect from this problem, the shift schedules, allowing for commute times, should not impose disruption of workers' sleep during the lowest dip of the circadian cycle.

Actual measured sleep did not match self-assessed subjective measures of sleep. The correlation to individuals' log books and measured sleep was not strong. This suggests that workers do not actually know how long or how well they sleep at a given point and is a flag for researchers relying on individuals' estimates of nightly sleep, even when keeping a log book.

Most participants only wore the actigraph for a specific week; therefore it is not known whether this 1 week is truly representative of the weekly average for 1 year. Different weeks might produce different results for each worker, but it is believed that the numbers sampled were large enough to help dampen variation from all of these factors. Also, individual sleep habits were not known prior to the week the actigraph was worn meaning that individuals may have come into the study already lacking sleep. The effect of this would be to lower the reported percentage mental effectiveness levels.

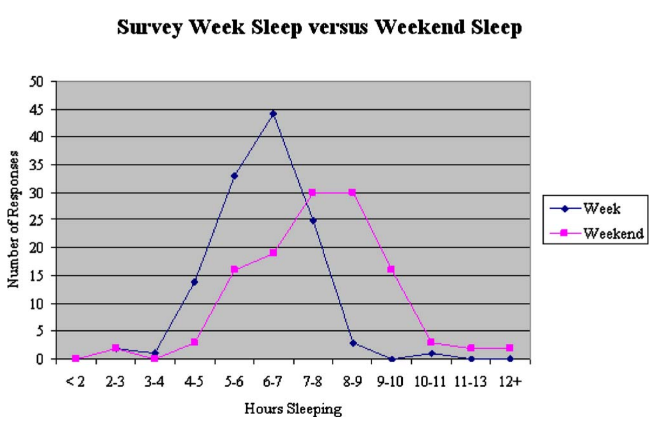

Fig. 5. Graph of sleep during week versus weekend from survey

Conclusions

Although other studies have provided valuable insights into fatigue and its operational influence in numerous other sectors, little was known of the sleep habits of construction workers despite ample reasons for concerns for poor safety records and productivity. Thus this large study in an operational setting attempted to understand whether fatigue might be a factor of concern. The value of these findings is that for the first time a beach head in the issue of fatigue impairment in construction workers has been established with insight into the human and economic impact from inadequate sleep. This work should provide foundational incentive for the industry to look deeper at this issue with its workers for opportunities for improvement.

The results of this study indicate that an average increase in risk of accident was 8.9%. For field workers it was even higher (10.1%) and when coupled with a more hazardous work environment in the field should raise the flag on fatigue for construction workers. In addition to other forms of impairment in the workplace, the indications are that fatigue impairment is a serious erosion of base productivity and makes the workplace a more risky place to work.

It is speculated that "impairment cocktails," which consist of different impairing elements, is also in play with neither a test for it nor an understanding of how the components interact relative to impairment. As no effective screen exists for the presence of excessive fatigue in the workplace, developing one must be a priority for all industries interested in improving safety and productivity. Additionally, it is important to explore what may be done to screen out fatigue-impaired workers who are not fit for working their shift.

Workers need to understand the impact of poor sleep and what they can do in their personal lives to improve their sleep. The construction industry should profile its jobs and ensure that those jobs with the highest risk receive a higher priority of training regarding this subject. Mobile equipment operators, shift workers, night workers, and workers putting in long hours at the workplace are examples of workers who should be targeted for training, monitoring, and rules. Project managers are limited in what they can do with tools currently available but are advised to raise the awareness level on the importance of sleep and its impact on impairment in the workplace. They should further develop fatigue-avoidance plans and review schedules for shifts allowing for commute times to ensure that the shifts do not start too early or end too late. Future work should try to get representative samples by age to see if there is a strong correlation between accident rates and sleep based on age category.

Analyzing the measured sleep values over a 7-day period with the assistance of a fatigue model correlated to BACs revealed that workers are putting in many hours effectively drunk. These degraded hours increase the risk of accidents and reduce productivity either directly or indirectly, and the industry needs to make fatigued workers a bigger priority. One wonders if these results had been attained due to alcohol use alone, would they be received with the same level of concern.

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