Using a Sleep and Activity Monitor to Operationalize Fatigue Risk Management

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USING A SLEEP AND ACTIVITY MONITOR TO OPERATIONALIZE FATIGUE RISK MANAGEMENT

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
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by

Vanessa Bégat Seitz
B.S., University of Florida, 2009
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ABSTRACT

When a person continues to work despite being fatigued, an accident may occur or productivity may decrease. Reducing fatigue related accidents is complicated due to the subjective nature and pervasiveness of the feeling of fatigue. Because finding one universal definition or measure of fatigue is problematic, fatigue is typically measured by a combination of factors such as amount of sleep obtained, physical or cognitive work performed, or sleepiness which can then be related back to a measure of performance.

Until recently, sleep measurement was restricted to a lab setting; however, with the emergence of actigraph devices, it is now possible to measure sleep in a person’s natural environment. Therefore, the purpose of this research is to determine if operator performance on a given day can be predicted based on the amount of sleep obtained the previous night as measured on an actigraph.

To do this, the researchers used the Consensus Sleep Diary (CSD) and the Basis Band (BB) actigraph to subjectively and objectively measure the Total Sleep Time (TST), Sleep Efficiency (SE), and Number of Awakenings (NOW) recorded over three nights. Then, performance was measured using the ten-minute Psychomotor Vigilance Self-Test (PVT) within one to three hours of waking up and prior to performing any significant activities (Basner & Dinges, 2011). The two measures from the PVT are 1/RT (RT=mean reaction time) and Number of Lapses (NOL) (Basner & Dinges, 2011) which were correlated against the three sleep measures. Additionally, the three sleep measures were correlated to a subjective rating of a person’s feeling of fatigue using the Stanford Sleepiness Scale (SSS).

The Total Sleep Time and Number of Awakenings as measured on the Basis Band were significantly different from the same measures reported using the Consensus Sleep Diary. When the sleep measures were correlated against the performance measures, the only two statistically significant results were the correlation between the Total Sleep Time (on both the BB and CSD) to the Number of Lapses (\(p=-.1919, p=.0446\) and \(p=-.2168, p=.0229\), respectively) and the Total Sleep Time (on both the
BB and CSD) to the Stanford Sleepiness Scale rating ($\rho = -0.2059$, $p = 0.0309$ and $\rho = -0.2702$, $p = 0.0043$, respectively). These results indicate that the Basis Band and the PVT are not sensitive enough to be used as predictors of operator performance.
CHAPTER 1: INTRODUCTION

“I think you should ride the line between fatigue and chaos. The chaos keeps the energy level and the spontaneity maximized while the fatigue is just over the edge, and you should avoid it.”

Ted Nugent

1.1 Motivation

The adjective fatigued describes a feeling of weariness that can diminish a person’s energy and mental capacity, and it is sometimes used synonymously with the more commonly used word tired, a common phenomenon in the daily life of many working people in modern society. Types of fatigue include overexertion induced physical fatigue, mental fatigue associated with stress, and medical related fatigue. When a person continues to work despite being fatigued, an accident may occur or productivity may decrease, and either situation may have a deleterious effect on the bottom line of a business enterprise. Reducing fatigue related accidents is complicated due to the subjective nature and pervasiveness of the feeling of fatigue. Because finding one universal definition or measure of fatigue is problematic, fatigue is typically measured by a combination of factors such as amount of sleep obtained, physical or cognitive work performed, or sleepiness. Despite the difficulty in defining fatigue, a study by Leger (1994) put a dollar figure on fatigue related accidents between $43.15 billion and $56.02 billion in 1988. Ricci, Chee, Lorandeau, and Berger (2007) identify a cost of $136.4 billion annually in lost production time associated with workers who reported being fatigued. With pressure to increase output by operating a facility 24 hours a day and with the increase in automation making sustained vigilance more challenging, lost production time and accidents due to fatigue need to be addressed and mitigated through a fatigue risk management system (FRMS). A FRMS is a multi-faceted approach to reduce the risk of fatigue related accidents at the employee, manager and governmental level by creating regulations to mitigate the effect from some of the underlying causes of fatigue (Lerman et al., 2012).
1.2 Significance

Quantitatively measuring the subjective feeling of fatigue is not always an exact science since it manifests itself in different ways and has many underlying root causes. Therefore, when a researcher is measuring “fatigue” what he/she is typically doing is controlling, measuring, and manipulating a specific objectively measurable attribute that contributes to the feeling of fatigue. One of the most common factors that contribute to the feeling of fatigue is the amount of sleep a person obtains in a night, and this factor is fairly easy to measure. Therefore, most research related to the effect of fatigue on performance aims to control and measure the amount of sleep obtained by a person and then correlate those results to some objective measure of performance. Beginning with one of the first scientific investigations of fatigue by Patrick and Gilbert (1896), studies show that generally the more sleep deprived a person is, the worse he or she will perform on a given performance test, whether it be physical or cognitive, with performance declining even further when the tasks are especially long or uninteresting (Wilkinson, 1965).

Using the results from fatigue-performance studies, companies try to incorporate different rules and regulations in an FRMS to reduce the risk of fatigue related accidents. One of the most commonly made changes in a company’s FRMS is to modify the acceptable hours of service (HOS) in order to ensure that employees are given adequate time off to rest between shifts (Dawson & McCulloch, 2005). Although HOS regulations are an important component of a FRMS, these regulations only address the first level of fatigue risk mitigation because HOS can only be manipulated to a certain point before the benefit is negligible. The second level, which is rarely addressed or studied, focuses on ensuring that employees are actually obtaining the appropriate amount of rest during their allotted time off (Dawson & McCulloch, 2005). This is much more difficult to enforce or monitor as it takes place outside of the work environment. However, understanding a person’s rest patterns may possibly be the most crucial step in fatigue mitigation.
One of the challenges of measuring the amount of sleep obtained by a person in a day-to-day operational setting is that methods for collecting accurate sleep data such as the Multiple Sleep Latency Testing (MSLT), polysomnogramy (PSG), and EEG’s are very cumbersome, expensive, and fail to capture sleep data in a person’s natural environment or for extended periods of time. However, the recent emergence of commercially available inexpensive sleep measurement actigraph watches, such as the Basis Band (Intel; San Francisco, California), allow for employees to self-monitor sleep in order to mitigate some risk of fatigue as part of a FRMS and for researchers to more accurately investigate the relationship between the amount of sleep a person gets and his/her feeling of fatigue.

Therefore, the purpose of this research is to determine if operator performance on a given day can be predicted based on the amount of sleep obtained the previous night as measured on an actigraph. To do this, the researchers will use the Consensus Sleep Diary (CSD) and the Basis Band actigraph to subjectively and objectively measure the amount of sleep obtained in a night. The three sleep measures that will be collected from both the actigraph and the sleep diary are Total Sleep Time (TST), Sleep Efficiency (SE), and Number of Awakenings (NOW) (Basner & Dinges, 2011). The three measures from the BB will then be tested against the same measures from the CSD using a Wilcoxon Signed Rank Test to determine if they are significantly different from one another. Then, in order to isolate the effect of the previous night of sleep from other potential causes of fatigue, researchers will measure performance using the ten minute Psychomotor Vigilance Self-Test (PVT) within one to three hours of waking up and prior to performing any significant activities. The two measures from the PVT are $1/RT$ (RT=mean reaction time) and Number of Lapses (NOL) (Basner & Dinges, 2011). Measuring performance within one to three hours of waking up simulates the performance of a person just arriving to work after a night of sleep. The three sleep measures will then be correlated with the two performance measures using Spearman Correlation analysis to determine if there is a significant relationship between sleep as measured on the actigraph and performance on the PVT. Additionally,
the three sleep measures will also be correlated to a subjective rating of a person’s feeling of fatigue using the Stanford Sleepiness Scale to determine if the amount of sleep obtained is reflected in a person’s subjective feeling of fatigue. A summary table of abbreviations can be found below.

If the correlation between sleep measured on the actigraph and performance measured on the PVT is significant and has the potential to predict operator performance, one of the main obstacles with operationalizing sleep monitoring as part of an FRMS has to do with privacy. Currently companies cannot require employees to actually sleep during the provided time off. Even if a company could require it, there are no hard and fast rules to establish an acceptable amount of sleep since it varies from person to person. Therefore, as an introduction to possible future research, an exit questionnaire was developed to determine how the participants felt about wearing the actigraph and potentially sharing their sleep data with an employer.

Table 1: Summary of Abbreviations

<table>
<thead>
<tr>
<th>Basis Band</th>
<th>BB</th>
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<tr>
<td>Consensus Sleep Diary</td>
<td>CSD</td>
</tr>
<tr>
<td>Total Sleep Time</td>
<td>TST</td>
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<tr>
<td>Sleep Efficiency</td>
<td>SE</td>
</tr>
<tr>
<td>Number of Awakenings</td>
<td>NOW</td>
</tr>
<tr>
<td>1/(mean reaction time)</td>
<td>1/RT</td>
</tr>
<tr>
<td>Number of Lapses</td>
<td>NOL</td>
</tr>
<tr>
<td>Stanford Sleepiness Scale</td>
<td>SSS</td>
</tr>
</tbody>
</table>
CHAPTER 2: LITERATURE REVIEW

2.1 Defining Fatigue

As mentioned previously, defining fatigue is not simple since it is one of the most common symptoms patients mention during a primary healthcare visit; it can manifest itself in different ways and has many underlying causes (Aaronson et al., 1999). In fact, Eidelman (1979, p. 340) stated, “The absence of an overall definition of fatigue preempts any scientific basis for measuring the condition, because logically, that which cannot be defined cannot be measured, and is not understood”. More than 30 years after Eidelman’s assertion, a single definition of fatigue still does not exist and probably never will; however, by using subjective and objectives measures of various underlying causes of fatigue, an association between a particular cause and the resulting effect on performance can help regulating agencies, employers, and employees to better understand fatigue and mitigate its effects in the workplace. Because fatigue is increasingly identified as a cause of accidents, having a better understanding of it can help reduce unsafe situations in the workplace due to slowed reaction time, decrease in vigilance, poor judgment and decision making ability, distraction, and loss of situational awareness (Lerman et al., 2012).

Fatigue is not only associated with most acute and chronic illnesses, but also with normal functioning and everyday life (Aaronson et al., 1999). Often, fatigue is thought to be the same thing as sleepiness, but they are in fact subtly different. Sleepiness is the tendency to fall asleep, whereas fatigue is a response produced by the body when it has been subjected to physical or mental exertion (Lerman et al., 2012). The effects of fatigue can sometimes be mitigated by providing periods of rest, whereas periods of rest tend to exacerbate the feeling of sleepiness. Fatigue is also different than exhaustion, a state from which periods of rest cannot restore function (Aaronson et al., 1999). and everyday life (Aaronson et al., 1999). In this case, the researchers will be measuring the amount of sleep obtained in a night which is related to both the feeling of sleepiness and fatigue.
One definition of fatigue as it relates to humans is defined by Brown (1994) as the disinclination to perform a task, including a decline in efficiency if work is continued after the person becomes fatigued. While this is certainly a very broad way to look at fatigue, other definitions of fatigue attempt to capture different facets. Piper et al. (1989) distinguishes between acute fatigue and chronic fatigue; acute fatigue typically occurs in normal people, has quick onset, and is alleviated quickly through rest, diet, and stress management. Chronic fatigue on the other hand is normally excessive, long lasting, having an unknown cause and purpose, and greatly affects a person’s quality of life as it is generally not relieved through standard recuperative measures (Piper et al., 1989).

Another way of defining fatigue is from a purely physiological perspective and is the one of the more commonly studied type of fatigue since it is more easily observable. One physiological definition by P. Berger, McCutcheon, Soust, Walker, and Wilkinson (1991) defines fatigue as failure of organ function, which is often associated with some medical condition. Alternatively, physiological fatigue can also be caused by muscle overuse when a job requires high level of physical exertion such as construction work or by a repeated motion of posture which results in the failure of a muscle to maintain the required force (Edwards, 1981). This type of fatigue can be paralleled with another common use of the term fatigue as it metaphorically relates to structural pipeline failures. Often times, failures occur when pipelines undergo a slow progression of structural change resulting in stresses and strains which then causes cracks or fractures in the pipe leading to a potential safety issue (F. C. Campbell, 2012), and a similar process can occur in humans.

The final type of fatigue is psychological, or cognitive, fatigue. This type of fatigue is often overlooked in favor of the physiological type and is not often considered when designing jobs or work stations. Brown (1994) notes that due to an increase in automation, jobs that used to require physical effort now required more cognitive effort and sustained vigilance which makes psychological fatigue important to study and understand. Psychological fatigue can be defined as “a subjective state of
weariness related to reduced motivation, prolonged mental activity, or boredom that occurs in situations such as chronic stress, anxiety, or depression” (Lee, Hicks, & Nino-Murcia, 1991, p. 291). This type of fatigue results when internal and external demands exceed a person’s personal resources. This can result in both a feeling of drowsiness as well as difficulty concentrating (Yoshitake, 1978).

Another way to look at fatigue is to distinguish between the feelings of fatigue and the symptoms of fatigue (Yoshitake, 1978). The subjective feeling of fatigue, or an overall unpleasantness experienced by a worker ranked on a scale from 1-9, is not exactly the same as symptoms of fatigue, which consist of more objective measures relating to physical or mental characteristics of a person (Yoshitake, 1978). These symptoms of fatigue are grouped into dull or drowsy factors such as feeling strained in the eyes, decline in working motivation, inability to concentrate attention, and projection of fatigue to some part of the body which may, for example, cause a headache (Yoshitake, 1978). In an experiment using mental workers as opposed to physical workers, there was a high correlation between the feeling of fatigue and the symptoms, but the degree of the feeling of fatigue was different for each of the three groups of symptoms and the interaction between, or combination of, groups of symptoms (Yoshitake, 1978).

While all of these definitions define different aspects of fatigue, the North American Nursing Diagnosis Association attempted to bring them all together to form one universal definition of fatigue integrating both the physiological and psychological aspects. The resulting definition of fatigue is “The self-recognized state in which an individual experiences an overwhelming sustained sense of exhaustion and decreased capacity for physical and mental work that is not relieved by rest” (Carpenito-Moyet, 2006, p. 306). This definition has strengths and weaknesses for the purposes of this research. One strength of this definition of fatigue is that it is a self-recognized state, and it results in a decrease in a person’s capacity to perform work. However, exhaustion is not the same as fatigue, which can in fact be relieved by rest.
Therefore, the definition presented by (Aaronson et al., 1999, p. 46) is more suited to the purpose of this research which defines fatigue as: “The awareness of a decreased capacity for physical and/or mental activity due to an imbalance in the availability, utilization and/or restoration of resources needed to perform activity.” While this definition adequately identifies the key aspects of fatigue in relation to this research, it does not provide any direct way to measure fatigue. Rather, it is through a combination of subjective and objective measures related to an underlying cause of fatigue, in this case the amount of sleep obtained in a night, from which conclusions about fatigue can be drawn.

2.2 Why Does Fatigue Matter?

2.2.1 Petrochemical

The petrochemical industry is a 24-hour a day industry, and thus at very high risk for having employees who feel fatigued and could potentially make mistakes as a result. Not only must the plants run for 24 hours, including night shifts, but they also have scheduled “turnarounds” which also increase working hours. In a “turnaround,” a piece of equipment is scheduled to be shut down for maintenance for a period of time, usually between one and five weeks. Since it usually costs the company money to have any machine shut down, employees will commonly work 12 hour shifts for the duration of the “turnaround” with no breaks. As these employees become mentally and physically fatigued, the chance of an accident related to fatigue increases. In fact, fatigue has been identified in several major accidents, including the BP Texas City refinery accident. The accident occurred around the end of a major “turnaround” where the Day Board Operator had worked 29 consecutive 12-hour shifts, and the Night Lead Operator had worked 33 consecutive 12-hour shifts. (MacKenzie, Holmstrom, & Kaszniak, 2007). Additionally, BP did not have a fatigue prevention policy restricting the number of consecutive days a person could work or the maximum number of hours per week. In fact, at the time of the accident, BP did not have any corporate or site-specific regulations concerning fatigue prevention; the
nuclear, aviation, and motor transportation industries have implemented some regulations (MacKenzie et al., 2007) regarding the fatigue issue but the chemical industry is lagging behind.

2.2.2 Healthcare

Healthcare is another 24-hour a day industry where fatigue plays an important role and can be dangerous if it is not understood and mitigated. Not only does acute and chronic fatigue as a result of working long hours contribute to poor health in the physicians, but it also can result in a decrease in patient safety (Jha, Duncan, & Bates, 2001). According to the IOM, 98,000 Americans die each year due to preventable medical errors, some of which can be attributed to fatigue related errors (Kohn, Corrigan, & Donaldson, 2000). In one study of more than 600 nurses, results showed that nurses who worked a rotating shift including nights were almost twice as likely to report committing a medication error than nurses who primarily worked day shifts (Gold et al., 1992). In another study performed by Barger et al. (2006), findings showed that compared to months with no extended-duration shifts, the odds ratio of a resident reporting at least one fatigue-related significant medical error for months in which one to four extended duration shifts were worked was 3.5 (95% CI, 3.3-3.7); in months where five or more extended duration shifts were worked, the odds ratio was 7.5 (95% CI, 7.2-7.8). While human error will never be eradicated from any field, including the medical profession, a systems approach such as a Fatigue Risk Management System (FRMS) can limit the potential for human error or help reduce the impact if an error is made (Lerman et al., 2012).

2.2.3 Aviation

While not a 24-hour a day hour type operation, aviation allows for its own kind of fatigue due to inconsistent schedules, increase automation, and jetlag. Roske-Hofstrand (1995) report that according to the Aviation Safety Reporting System (ASRS), 21% of all accidents reported by pilots and controllers are fatigue related. Part 121 of the Federal Aviation Regulations limits pilots to 30 hours of flight within 7 consecutive days, and crew members must get at least 24 hours of continuous rest each week.
However, even with these regulations in place, NASA’s Aviation Safety Reporting system reported that from 1994 to 1998 there were 227 schedule related fatigue incidents, most of them occurring between midnight and 6 AM when the circadian rhythm was desynchronized (Goode, 2003). The circadian rhythm is defined as the body’s natural routine of regulating the body’s temperature, cortisol and activity based approximately on a 24 hour day (Czeisler & Gooley, 2007).

Additionally, due to an increase in automation in the field of aviation, research has shown that pilots and co-pilots on long flights can see a decrease in alertness due to the fact that the task is very monotonous when the plane is flying itself in auto-pilot (Speyer et al., 2003). Although jet lag and fatigue are rarely cited as official causes of pilot error, research indicates that traveling across time zones impairs performance thus increasing the potential for error (Samel, Wegmann, & Vejvoda, 1995). Jet lag occurs as a result of traveling across multiple time zones which sometimes requires night flights and long working hours; therefore, crewmember fatigue caused by a disruption in the circadian rhythm is often linked to scheduling and workload issues (Samel et al., 1995). Mitigating fatigue caused by irregular schedules and continuous workload can be addressed through a properly designed FRMS, which will be discussed in subsequent sections.

2.2.4 Transportation

The ground transportation industry, both road and rail travel, is probably the most researched field in regard to fatigue and its impact on performance and safety. In one study performed by Härmä, Sallinen, Ranta, Mutanen, and Müller (2002), fifty percent of the night shift railway traffic controls workers reported severe sleepiness based on the Karolinska Sleepiness Scale. Looking at the odds ratio means the night shift was 6-14 times higher in risk for severe sleepiness than the day shift. Decreased vigilance due to excessive signals or due to the monotonous nature of the task can also contribute to fatigue and accidents. For example, in one study performed by Edkins and Pollock (1997) looking at accidents related to fatigue within an Australian public railway authority from 1990 to 1994, failing to
stop at a signal (known as Signals Passed At Danger, or SPADs) was the most frequently occurring incident at 39% which results in crashes 6% of the time and near misses 3% of the time.

In terms of driving, both casual drivers and professional drivers are at risk for fatigue, although professional drivers have an increased risk because they have less control over their work schedules and number of hours on the road than do casual drivers (Brown, 1994). Showing similar results to those seen in many other professions, one study found nearly twice as many truck accidents happen in the second half of a trip regardless of duration and about twice as many accidents happen between midnight and 8 AM when the circadian rhythm is at its lowest (Harris, 1977).

2.3 Fatigue Risk Management System (FRMS)

In the past, safety has typically been looked at from a retrospective point of view; incidents occur, like the ones reviewed above, and then are reviewed to determine the root causes. Often times, the solution proposed after review is a new set of hours of service (HOS) restrictions in order to limit the number of hours worked by an individual or increase the number of mandatory breaks in order to allow a person to have enough time to recover (Dawson & McCulloch, 2005). While this type of management has a role to play in fatigue mitigation, it really only addresses whether or not a person is given adequate time to obtain enough sleep while failing to address whether or not a person actually gets enough sleep during that time (Dawson & McCulloch, 2005). Instead, a new proactive means of preventing fatigue related incidents should be incorporated into safety policies through a Safety Management System of which a Fatigue Risk Management System (FRMS) is an important component (Dawson & McCulloch, 2005). An FRMS is “a scientifically based, data-driven addition or alternative to prescriptive hours of work limitations which manages employee fatigue in a flexible manner appropriate to the level of risk exposure and the nature of the operation” (Lerman et al., 2012, p. 234). A FRMS system would help mitigate fatigue at levels one, two, and three, to potentially avoid levels four and five of the fatigue-risk trajectory identified by Dawson and McCulloch (2005) and shown in Figure 1 below.
Previous fatigue mitigation techniques such as updated HOS and fatigue modeling really only address level one in the FRMS.

![Diagram of Five Levels of Fatigue Risk](image)

**Figure 1**: Five Levels of Fatigue Risk (Dawson & McCulloch, 2005)

Before looking at the specifics regarding the components of an FRMS, it is important to understand that successful implementation of an FRMS depends on its acceptance on three levels: regulatory, company/organizational, and individual (Gander et al., 2011). The regulatory level consists of laws and enforcement agencies that currently focus on enforcing a set of universal HOS guidelines to reduce fatigue but whose role Dawson and McCulloch (2005) argue needs to shift towards the more holistic view of simply defining the basic components needed in an FRMS but leaving the details up to
each company. Currently, regulatory agencies such as the Federal Motor Carrier Safety Administration (FMCSA) have specific HOS guidelines. For example, commercial property-carrying vehicles “a driver may not drive without first taking 10 consecutive hours off duty” (FMCSA, 49 CFR 395.3.1). However, a shift needs to be made so that the regulatory level of the FRMS would legislate based on a desired outcome (reduction in fatigue related incidents) leaving the specifics of the FRMS up to an individual company (Dawson & McCulloch, 2005). From a company responsibility level, this regulation regarding rest prior to beginning a shift must be incorporated into their fatigue risk management system; the company culture should be one that encourages compliance with this regulation and emphasizes the importance of safety (Gander et al., 2011). Finally, looking at the individual level component of fatigue risk management in the case of the FMCSA regulation example, employees are responsible for using those ten consecutive hours of off time to get adequate rest, so that they are refreshed for their next shift.

While those three levels of responsibility are essential to the successful implementation of a FRMS, Moore-Ede (2009) defines eight key characteristics that must be included in all FRMS’s to facilitate the acceptance by the three levels of responsibility. They must be science based, data-driven, cooperatively accepted, fully implemented, integrated, continuously improved, budgeted, and owned (Moore-Ede, 2009). The goal of creating this system in conjunction with a safety management system (SMS) is to create multiple levels of defense against fatigue in order to decrease hazards and loss (Lerman et al., 2012). These five levels of defense are discussed in detail below.

2.3.1 Sleep Quality and Workload

A major contributing factor of fatigue is the number of hours worked, which can also be considered as a component of workload (Lerman et al., 2012). Working long hours is not a new concept and, as in previous generations, is a major component of modern life. Additionally, some industries such as doctors, firemen and plant operators are required to be “on call”. This means that although they
aren’t specifically working 24-hours a day 7 days, they could potentially be called into work to perform specific duties regardless of their level of fatigue. Some regulatory agencies have put into place laws or guidelines limiting the maximum number of hours one can be required to actually work within a given period of time. However, despite shift limitation regulations, physicians are often required to work shifts of more than 24 hours with only a few hours of sleep. A study by Lockley et al. (2004) showed these physicians working 24 hours or more while getting little sleep made more serious medical errors than when their shift was limited to 16 hours. As a result of long working hours, these workers suffered lack of sleep resulting in fatigue which then reduced their performance and increased the number of errors.

Another cause of working long hours is a result of poor staffing or understaffing. The effect of understaffing or poor scheduling is a big contributor to fatigue but is often overlooked when compared to studying how shiftwork is impacted through different manipulations (12 hour versus 8 hour shifts, clockwise rotating versus counterclockwise etc) (Lerman et al., 2012). A company can spend time, money, and effort to get a shift schedule to be as optimal as possible given all of the research in a particular field, but it may be undermined if staffing is not taken into consideration. For example, if a worker doesn’t show up for a shift, or an employee is asked to extend their shift to meet the excess demand during the holidays, or if someone changes jobs and their shifts need to be covered until someone new is hired, that “perfect” schedule has become merely an ideal, and the reality is that employees are working overtime with less time off, resulting in fatigue (Lerman et al., 2012).

One reason that staffing is rarely looked at is because, in order to reduce overtime and fatigue, companies generally must hire more staff, which increases fixed costs. In contrast, reorganizing shift work into a more efficient manner may cost less and can essentially be an inexpensive way to improve efficiency and reduce fatigue. However, Lerman et al. (2012) point out that the perceived cost of hiring additional people is often over estimated by managers and that the cost of having someone work
overtime is underestimated; because of this, companies shy away from new hires in favor of current employees working overtime when in reality there appears to be little actual cost savings to using overtime instead of additional staff.

Regardless of the reason for the long working hours, the extra work and reduced time off cause workers to suffer from lack of sleep or poor quality of sleep (Lerman et al., 2012). Sleep consists of five basic stages combining into a 90 minute cycle with the 5th stage representing the only stage with rapid eye movement, or REM, sleep (Weitzman et al., 1974) Stages 1 and 2 are generally considered light sleep and stages three and four are considered deep sleep (Weitzman et al., 1974). During the six to ten hours of sleep typically required by most humans to perform at normal levels, people will go through several of these cycles each night but will feel fatigued if the cycle is cut short or if certain stages, such as REM, are eliminated (Weitzman et al., 1974)). The importance of REM sleep was first discovered by Dement (1960) when he studied the effect of depriving participants of the REM cycle of sleep, awakening them at the precise moment that they entered this stage.

On the other end of the spectrum, psychosocial factors associated with low stimulation or low workload can also affect fatigue. In a study performed by Finkelman (1994), 3705 temporary employees in clerical and light-industrial assignments who reported fatigue were surveyed to study the factors associated with work-induced fatigue. The results showed that a higher incidence of job fatigue was significantly associated with low information processing demands, poor supervision, low job control, poor job performance, and low pay; interestingly, sleep deprivation was minimally associated with fatigue (Finkelman, 1994).

A FRMS can help mitigate the effect of long hours and understaffing by preventing these problems through better scheduling or by alerting management to the need for additional employees. An FRMS will not automatically suggest that new employees be hired to help with understaffing but instead put into place the necessary framework to analyze workload and current staffing in order to
determine the next steps towards improvement (Lerman et al., 2012). It can also help implement job rotation or job enrichment policies to avoid fatigue due to low job stimulation.

2.3.2 Shift Work and the Circadian Rhythm

Shift work, common in many industries, is yet another factor that can cause varying levels of fatigue among workers. Shift work as defined by Åkerstedt (1990) refers to using two or more groups of workers, or shifts, to extend the hours of operation of a business. A typical two-group rotation shift schedule would have workers work 12 hour shifts; for example the first shift would start at 5 AM and end at 5 PM and the second shift would start at 5 PM and end at 5 AM. Alternatively, three-group shifts are also common, with each shift working 8 hours typically early morning, afternoon, and night shifts. In the two-group rotation, those workers on the second shift are working primarily at night, which is exactly opposite from their natural body clock, or the circadian rhythm.

As previously mentioned, the circadian rhythm is defined as the body’s natural routine of regulating the body’s temperature, cortisol and activity based approximately on a 24 hour day (Czeisler & Gooley, 2007) and regulates the timing, structure and consolidation of sleep (Dijk, Shanahan, Duffy, Ronda, & Czeisler, 1997). Circadian rhythms occurs when suprachiasmatic nuclei produce a cyclic oscillation over a roughly 24 hour time period (Åkerstedt, 2003). Additionally, this rhythm is self-sustaining and persists even in the absence of external environmental cues (Czeisler & Gooley, 2007). When workers are trying to perform their job out of sync with their natural circadian rhythm, their sleep efficiency is greatly reduced, which in turn increases the feeling and symptoms of fatigue (Dijk et al., 1997).

Because the body is working against its natural sleep pattern, the amount of sleep obtained by night shift workers has been found to be between one and four hours less than workers generally following the circadian rhythm (Åkerstedt, 1990). These missing hours of sleep are generally taken from stage 2 and from REM sleep, which, as discussed above, is an important factor in the quality of the sleep.
obtained (Åkerstedt, 1990). The accumulated loss of sleep combined with the natural tendency to feel sleepy in the early morning hours when the circadian rhythm is naturally telling the body to go to sleep may cause workers to feel fatigued. The feeling of fatigue will be displayed through common symptoms of fatigue such as reduced performance, lowered ability to concentrate, and may even result in falling asleep on the job (Åkerstedt, 1990).

In a previously mentioned study performed by Lockley et al. (2004), results indicate that physicians working 24 hour shifts made two times as many attentional errors while working at night than they did during the daytime hours. Other industries also report signs of reduced performance as a result of fatigue linked to shift work. In a study performed by (Bjerner, Holm, & Swensson, 1955) of meter readers from a gasworks plant in Sweden over a period of more than 40 years, results indicate that more errors were made during the night shift which coincided with the workers reports of being naturally fatigued in the early morning hours between midnight and 3 AM. Another study with airplane simulators shows that a pilot’s ability to “fly” a plane during a simulation at night is similar to being under the influence of alcohol to a .05% level (Klein et al., 1970).

In addition to poor job performance, shift work has been linked to medical issues such as cardiovascular disease and gastrointestinal disease (Åkerstedt, 2003). Additionally, shift work impairs a person’s social life which has underlying consequences related to one’s health (J Mitchell & Williamson, 2000). Moreover, having these health conditions could lead a worker to take medication or to suffer mental stress, thus increasing his/her fatigue level both physiologically and psychologically.

Unfortunately, studies have shown that because of the circadian rhythm present in humans, workers rarely adjust to night shift work to any significant degree (Åkerstedt, 2003). In a study performed by Paley and Tepas (1994), firefighters working a two week long shift rotating between morning, afternoon, and night shifts were unable to adapt to a regular sleep schedule. However, some people adjust better than others due to their level of morningness or eveningness. Horne and Ostberg
developed the Morningness-Eveningness Questionnaire (MEQ) in 1976 which presents the worker with 19 preferentially framed questions aimed at determining the person’s natural inclination for activity during a 24 hour day (Sack et al., 2007). Each question is scored from 0-6 with a total range up to 86 possible points; participants with lower scores generally tend to be eveningness oriented. A second questionnaire aimed at obtaining similar information is the Munich Chronotype Questionnaire (Sack et al., 2007). Sack et al. (2007) reviewed the literature and found 14 studies that used the MEQ along with objective circadian rhythm measures such as core body temperature. In all studies, there was a negative correlation between the circadian measures and the MEQ score meaning people who had a lower score (eveningness oriented) generally had a later circadian phase and were better able to adjust to night shifts. While morningness and eveningness are traits can be determined humans, they are not the only factors involved in deciding whether an employee will be more or less fatigued at any given point, and therefore cannot be relied upon by companies as the sole indicator of a person’s potential for fatigue related incidents.

Given the abundant research concerning circadian rhythm and its impact on shift workers, a FRMS can provide employers with the tools to manipulate certain aspects of shift work, such as shift rotation, shift handover, and shift length, to dampen the negative effect of being awake at odd times. Regarding shift rotation direction, there is no robust research to support a clockwise rotation (morning-afternoon-night) over a counterclockwise rotation. However, the clockwise rotation does allow for a longer rest period between shifts, thus providing the maximum opportunity for sleep, and has been shown in one study to result in better work-life balance and better sleep quality (van Ame & Kant, 2004). Shift handover relates to the time that shifts start and end and this concept can be maximized through an analysis of the FRMS. For example, having the morning shift come in at 3 AM instead of 6 AM may cause more fatigue in the morning shift, but could reduce fatigue in the night shift employees since they are able to go to sleep when it is still dark outside, and their circadian rhythm is still sending signals to go
to sleep (Lerman et al., 2012). Finally, an FRMS can help determine the suitable shift length for a particular company. Long shifts might increase the hours since the worker last slept but they also involve fewer handovers which might mean less potential for information loss between different employees. On the other hand, short shifts allow more opportunity for sleep, but shorter shifts increase handovers during which some information might be lost.

2.3.3 Training and Education

Another critical part of an FRMS is training and education for employees and management. In an FRMS, responsibility for managing fatigue is shared by the employees and management; management must schedule staff shifts appropriately and employees must use their off time to get adequate sleep (Dinges, 1995). In a study performed by Dinges, Maislin, Brewster, Krueger, and Carroll (2005) related to fatigue management techniques, truck drivers in both the control group and test group were provided with a three-hour course developed by Krueger through sponsorship by the Federal Motor Carrier Safety Administration and the American Transportation Research Institute. Although the course was not a response variable, the researchers thought that the training increased the acceptance of the fatigue management technologies (Dinges et al., 2005).

Lerman et al. (2012) identify a number of topics that should be covered in an educational training course pertaining to fatigue. These topics include the following:

- Hazards associated with working while fatigued
- Impact of chronic fatigue on general life satisfaction
- Understanding that fatigue is a manageable condition
- Basics of sleep physiology, circadian rhythm, and the difference between quality and quantity of sleep
- Basic understanding of sleep disorders and how to identify if a worker has one
- The importance of factors outside of sleep, such as activity, diet, and stress management, that can affect the feeling and symptoms of sleep
- Signs of fatigue in oneself and others
- Simple strategies to use at work to stay alert such as drinking caffeine or taking short breaks
- Communication of the efforts being made by management to reduce the potential for fatigue such as scheduling of shifts
Incorporating basic training for employees and supplementary training for managers is imperative for an effective FRMS. Periodic reinforcement or retraining is also a key aspect.

2.3.4 Work Environment

Another component of an effective FRMS is to develop a work environment that is conducive to promoting alertness. Creating a mindful work environment takes into account the physical environment, employee activity, and the actual task parameters (Lerman et al., 2012). By manipulating a few aspects of the environment, companies may counteract some of the effects of fatigue. However, while minor changes may offer some benefit, their effect is often temporary. Therefore, modifications of the work environment should be part of an overall plan to mitigate fatigue but should not be considered as solutions by themselves.

Ballard (1996) states that light, temperature, and noise are aspects of the physical work environment that can be controlled or modified to create an atmosphere to help counteract some of the natural fatigue encountered when an employee works a night shift or when an employee comes to work without a proper night’s sleep. In regard to light, workspaces for daytime workers should be well lit and avoid glare and eye strain. However, lighting of workspaces for night time workers is more complicated. There are three ways that lighting during the night can affect workers: phased resetting of the circadian clock (Czeisler et al., 1990), increased level of alertness and cognitive performance due to stimulation (S. S. Campbell & Dawson, 1990), and increased health risks as a result of nighttime light exposure on the neuroendocrine system such as suppression of melatonin and elevation of cortisol (Scheer & Buijs, 1999). In the past, companies have opted for bright lighting in night shifts to gain the benefit of increased alertness. However, the negative effects of brightly lit nighttime environments have been robustly shown through numerous research studies, and these results have caused companies to rethink the idea of using bright light as a way to increase alertness during night shifts. Research is now emerging that shows the negative effects from the bright lighting are actually
associated with a particular wave length of the light; thus filtering the light can allow for the increased alertness without phase resetting of the circadian clock or the health risks (Rahman, Marcu, Shapiro, Brown, & Casper, 2011).

Research on temperature and humidity are fairly contradictory or inconclusive. Lerman et al. (2012) suggests that the low end of the comfortable temperature range (around 68 degrees F) is generally preferred since warm environments are more conducive to feelings of drowsiness. Rolling down a window while driving is another common technique to increase driver alertness but this is often a short term solution (Schwarz et al., 2012). Noise is another way that workers try to increase vigilance. The benefits of noise or music depend on the type of noise; monotonous music may cause a sedating effect whereas more varied noises can be stimulating (Bonnefond, Tassi, Roge, & Muzet, 2004). However, just like rolling down a window while driving, the effect is temporary and should not be used as a means of controlling fatigue (Schwarz et al., 2012).

Finally, an FRMS can help management determine how to vary the actual task or general employee activity in order to mitigate feelings of fatigue. Monotonous work can lead to increased feelings of fatigue but performing critical tasks while fatigued may result in reduced performance (Lerman et al., 2012). Therefore, it is important for management to be aware of the potential for fatigue in each task and implement countermeasures such as using two or more employees for high-risk or critical tasks, implementing checklists, varying the task through job rotation, allowing for naps, or enforcing mandatory breaks (Lerman et al., 2012).

2.3.5 Fatigue Monitoring

The final component of a FRMS is fatigue monitoring by both the employee and the employer (Lerman et al., 2012). Workload, shift work scheduling, training, and work environment are similar in that they are all to a large degree controlled by company or government regulations. In contrast, fatigue monitoring falls into the realm of personal responsibility and probably plays one of the largest
roles in successful fatigue mitigation. However, it is one of the least studied aspects of fatigue mitigation due to the difficulty in defining fatigue and in collecting data. Since fatigue is difficult, if not impossible, to quantifiably measure due to its subjective nature, objectively measurable causes of fatigue to measure and monitor must be used. One quantifiable contributing factor to fatigue is the amount of sleep obtained in a night. In the past, the only way to capture sleep data was in a laboratory setting and that is reflected in much of the sleep research cited in the previous sections. For example, in the previously cited study of night shift railworkers, the researchers required two years to collect the data because participants had to visit a sleep lab twice, separated by a three week interval and could only be investigated in couplets (Härmä et al., 2002). However, in the last ten years, the emergence of actigraphs has opened the possibility of capturing fairly accurate sleep data without the need for participants to sleep in a lab. While the amount of sleep obtained by a worker is not a direct measure of fatigue and is certainly not the only contributing factor of fatigue, when used in combination with other objective and subjective measures discussed below, it can raise the employees awareness of a potential cause of fatigue which they can then mitigate by getting more sleep if needed.

2.4 Fatigue Measures

As discussed in the previous sections, fatigue has many underlying causes; thus there are multiple ways of measuring it. For example, when planning an experiment, researchers must first select a particular underlying cause of fatigue to study, and then determine the appropriate measures in order to isolate the effect of that causing factor (Matthews, Hancock, Desmond, & Neubauer, 2012). In order to have a well-balanced research approach, the chart and subsequent definitions table below showing a taxonomy of constructs was used to select the following tools: objective measure of performance, subjective measure of the feeling of sleepiness or fatigue, and subjective and objective measure of sleep. A detailed review of those four tools must take into consideration attributes such as the relative sensitivity, reliability, validity, and intrusiveness of each tool.
Figure 2: A Taxonomy of Constructs Adapted from Matthews et al. (2012)
Table 2: Definition of Taxonomy of Constructs Adapted from Matthews et al. (2012)

<table>
<thead>
<tr>
<th>Construct</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjective</td>
<td>Reflect conscious processes.</td>
</tr>
<tr>
<td>Objective</td>
<td>Reflect unconscious processes.</td>
</tr>
<tr>
<td>Psychophysiological</td>
<td>Relationship between the physiological events and brain responses.</td>
</tr>
<tr>
<td>Behavioral</td>
<td>Actions or reactions to stimuli.</td>
</tr>
<tr>
<td>Physical</td>
<td>Physiological processes; muscle discomfort, headache; loss of function due to prolonged use.</td>
</tr>
<tr>
<td>Sleepiness</td>
<td>Falling asleep; difficulty staying awake.</td>
</tr>
<tr>
<td>Compensatory</td>
<td>Dimensions of coping; snacking, drinking, pacing.</td>
</tr>
<tr>
<td>Affective</td>
<td>Mood; Arousal; Tension.</td>
</tr>
<tr>
<td>Cognitive</td>
<td>Self-focus; Concentration; Distractibility.</td>
</tr>
<tr>
<td>Motivational</td>
<td>Interest; Effort; Determination.</td>
</tr>
<tr>
<td>Obtrusive</td>
<td>Interference with the work environment.</td>
</tr>
<tr>
<td>Non-Obtrusive</td>
<td>No interference or disruption to operator.</td>
</tr>
</tbody>
</table>

2.4.1 Objective Measures

Objectively measuring fatigue in an operational setting is of increasing importance given the prevalence of accidents linked to fatigue. However, as previously discussed, there are no direct objective measures of fatigue. Therefore, it is important to find measurable underlying causes of fatigue which can then be controlled and mitigated. For the purpose of this research, the amount of sleep obtained in a night is the objective contributing factor of fatigue that will be measured.

The problem that arises with measuring sleep, and the reason for this study, is that the most highly praised way of capturing sleep data is the multiple sleep latency test (MSLT) (Carskadon et al., 1986; Johns, 1991; Richardson et al., 1978) but it is not practical in an operational environment due to the obtrusiveness (Balkin et al., 2004). Other methods of capturing sleep data such as polysomnography (Rupp & Balkin, 2011; Veauthier et al., 2011) or Electroencephalography (Åkerstedt, Kecklund, & Knutsson, 1991; Caldwell, Prazinko, & Caldwell, 2003; Eoh, Chung, & Kim, 2005) also suffer from being cumbersome. However, the recent development of somewhat accurate actigraphs used to measure activity and sleep-wakefulness has allowed researchers to study sleep in participants without having to utilize a lab setting, thereby making the potential fatigue monitoring more operationalizable.
Actigraphy is “the continuous recording of the body (often wrist) movement by means of a body-worn device that detects movement (usually acceleration) and stores the information for days, weeks, or months, along with the times it was measured” (Pollak, Tryon, Nagaraja, & Dzwonczyk, 2001, p. 957). Whereas a PSG will typically only provide a snapshot of data, an actigraph can provide data over a longer period of time (Pollak et al., 2001). However, it is important to review the accuracy and validity of the actigraph as compared to the polysomnograph output.

In a review article of objective measurements of sleep by Van De Water, Holmes, and Hurley (2011), results show that the accuracy of actigraph monitors compared with PSG depended on four things: the population being studied, the specific sleep variable of interest, the algorithm and wakefulness threshold used, and finally the make of the device (Actiwatch, Mini-Motionlogger basic, Sleepwatch, Vivago Wristcare, CSA Model 7164 Activity Monitor, and IM Acti-Trac were used in the study by Van De Water et al). Overall, the actigraphs studied tended to overestimate total sleep time and sleep efficiency, generally due to low sleep specificity in differentiating between wakefulness while lying down and sleep (Paquet, Kawinska, & Carrier, 2007). In another study conducted by Weiss, Johnson, Berger, and Redline (2010), the Sleepwatch, Actiwatch and Actical actigraphs were compared against the output of the PSG; findings show that the total sleep time (TST) of the three wrist devices produce reliable measures relative to the PSG, but that the sleep efficiency measure is not as reliable due to the aforementioned low specificity.

Unfortunately, many of the studies were carried out using actigraphs that are not commercially available or that cost thousands of dollars; furthermore, for those that are available, the research has not yet caught up to the claims made by the manufacturers. According to a review article by Kelly, Strecker, and Bianchi (2012), very few, if any, validation studies exist for the motion-based actigraph monitors available in the $100 to $200 range. Several devices claim to track deep sleep and light sleep or provide a “sleep quality index” but there are no published validation reports to support those claims.
It is also difficult, if not impossible due to proprietary issues, to obtain the algorithms used by the developers in the determination of sleep and wakefulness.

Given the qualification and acceptance that the sleep data provided by the less expensive actigraph may lack some degree of validation, the aim of this study was to select the tool that was most operationalizable in the workplace; thus the actigraph was the chosen method for capturing sleep data and a number of inexpensive actigraphs were evaluated for the purposes of this study. Many models of actigraphs were investigated by the researchers to determine the one that was best suited to this application, the main goal being to extract information regarding TST, SE, and NOW. Once a fairly comprehensive list was compiled, the most promising actigraphs were tested by the researchers for usability and accuracy of data. Table 3 shows the key attributes of each actigraph that was evaluated in the initial stages of the research. The Basis Band was selected for this research because it allowed for automatic sleep detection, long battery life, and its ability to be used in the shower. All of these attributes made the device the most unobtrusive and would be the most operationalizable, which will be discussed in greater detail in subsequent sections.

**Table 3: List of Common Actigraphs**

<table>
<thead>
<tr>
<th>Objective Sleep Measures</th>
<th>Water-proofing</th>
<th>Battery Life</th>
<th>Sleep Detection</th>
<th>Reason not Selected/Selected</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Fitbit Flex</td>
<td>Shower, No Swimming</td>
<td>5 Days</td>
<td>Manual</td>
<td>Manual Sleep Detection</td>
</tr>
<tr>
<td>2 Fitbit Force</td>
<td>No</td>
<td>7-10 Days</td>
<td>Manual</td>
<td>Manual Sleep Detection</td>
</tr>
<tr>
<td>4 BodyMedia Fit Core</td>
<td>No</td>
<td>4-6 Days</td>
<td>Automatic</td>
<td>Obtrusive (Worn on arm, instead of wrist)</td>
</tr>
<tr>
<td>5 BodyMedia Fit Link</td>
<td>No</td>
<td>2-4 Days</td>
<td>Automatic</td>
<td>Obtrusive (Worn on arm, instead of wrist)</td>
</tr>
<tr>
<td>6 Lifetrak Zone C410</td>
<td>Yes</td>
<td>1 year +</td>
<td>Automatic</td>
<td>No detailed sleep analysis</td>
</tr>
<tr>
<td>7 Basis Band*</td>
<td>Shower, No Swimming</td>
<td>4 Days</td>
<td>Automatic</td>
<td><strong>Selected: Auto sleep detection, unobtrusive, detailed sleep analysis (TST, SE, NOW)</strong></td>
</tr>
</tbody>
</table>
The second objective measure required for this research addressed the measurement of performance. After collecting sleep data, the researchers needed to be able to measure performance to see if any correlations exist between the amount of sleep obtained as recorded by the actigraph and performance. In relation to objective performance measures, the criteria of sensitivity, reliability, and obtrusiveness were used to evaluate a variety of performance tests. Sensitivity relates to the ability of the measure to show the effect of sleep loss (Balkin et al., 2004). Reliability looks at whether a measure is repeatable and not subject to a learning effect (Balkin et al., 2004). Finally, obtrusiveness deals with the ability to obtain the measure passively or without disrupting the performance of the primary task (Balkin et al., 2004). There are a number of objective performance measures available, but not all of them are suitable for needs of this research. Table 4 provides a summary of some of the available objective performance measures and the reason why the measure was not selected. The Psychomotor Vigilance Self Test was selected for this experiment due to its high sensitivity to sleep loss, which will be discussed in greater detail in subsequent sections.

**Table 4: List of Common Objective Measures of Performance**

<table>
<thead>
<tr>
<th>Objective Performance Measures</th>
<th>Research Support</th>
<th>Reason Selected/not Selected</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Eye-tracking devices – Blinking</td>
<td>(Ji, Zhu, and Lan (2004); Saito (1992); Saravanakumar and Selvaraju (2010))</td>
<td>Intrusive, low sensitivity to sleep loss</td>
</tr>
<tr>
<td>2 Eyelid Closure (PERCLOS)</td>
<td>(Dinges and Grace (1998); Golz, Sommer, Trutschel, Sirois, and Edwards (2010))</td>
<td>Intrusive, low sensitivity to sleep loss</td>
</tr>
<tr>
<td>3 Fatigue Scale and Fatigue Observation Checklist</td>
<td>(Rhoten (1982))</td>
<td>Low sensitivity to sleep loss, low reliability</td>
</tr>
<tr>
<td>4 Finger tapping/Thumb pressing</td>
<td>(Fleminger (1992); LaChapelle and Finlayson (1998))</td>
<td>Low sensitivity to sleep loss</td>
</tr>
<tr>
<td>5 Posturography</td>
<td>(Avni et al. (2006); Morad et al. (2007))</td>
<td>Low sensitivity to sleep loss</td>
</tr>
<tr>
<td>6 Psychomotor Vigilance Self-Test (PVT)*</td>
<td>(Basner, Mollicone, and Dinges (2011); Dinges (1995))</td>
<td>Selected: High sensitivity to sleep loss, unobtrusive, easy to use</td>
</tr>
</tbody>
</table>
2.4.2 Subjective Measures

Since fatigue is not universally defined or quantifiable by any one measure, subjective measures necessarily play a big role in understanding fatigue. Subjective measures by themselves are prone to bias, but when used in conjunction with objective measures, they can provide a more rounded analysis than a compilation of only objective data. Based on an experiment looking at the correlation between PSG data and an actigraph, Kushida et al. (2001) recommends that the use of subjective data regarding total sleep time and sleep efficiency be collected in addition to the objective data obtained from the PSG and actigraph. In regards to fatigue in terms of sleep obtained and feeling of sleepiness, there are two types of subjective measures that will be used in this research. The first is keeping a sleep diary to record the hours spent sleeping. The second is a visual analog scale for fatigue aimed at understanding a person’s feeling of fatigue. Within these two subjective measures, many options and tools are available.

Until the recent developments in technology related to electronic sleep measurement, sleep diaries were the only way to determine how much sleep a person got each night. Since there is no standard defining the substance of what needs to be collected, it is difficult to compare results from different experiments and to validate the various diaries (Carney et al., 2012). Some differences in sleep diaries have been identified such as the number of questions asked, the definition of common sleep parameters, the time of day the respondents should complete the diary, and whether the diaries should elicit quantitative or qualitative responses (Carney et al., 2012). The format and content of the currently available diaries were fairly extensive and diverse based on the objective of the research. In fact, there are only a few universally recognized diaries, which are listed below; the rest of insomnia research was conducted using diaries that were specifically developed for a unique experiment. Table 5 shows the most commonly used sleep diaries. The Consensus Sleep Diary was chosen due to its high construct
validity and the ability of the actigraph to provide the same output sleep values so that the two can be compared, which will be discussed in greater detail in subsequent sections.

**Table 5: List of Common Sleep Diaries**

<table>
<thead>
<tr>
<th>Subjective Sleep Diaries</th>
<th>Research Support</th>
<th>Reason Selected/not Selected</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Pittsburgh Sleep Diary</td>
<td>Monk, Buysse, Rose, Hall, and Kupfer (2000)</td>
<td>Includes more questions than were needed for comparison to Basis Band output</td>
</tr>
<tr>
<td>2 Karolinska Sleep Diary</td>
<td>Akerstedt, Hume, Minors, and Waterhouse (1994)</td>
<td>Does not capture TST or SE</td>
</tr>
<tr>
<td>3 Morin Sleep Diary</td>
<td>Sloan et al. (1993); A. M. Berger and Higginbotham (2000); Morin and Barlow (1993)</td>
<td>Includes more questions than were needed for comparison to Basis Band output</td>
</tr>
<tr>
<td>4 Consensus Sleep Diary*</td>
<td>Carney et al. (2012)</td>
<td>Selected: comprehensive yet simple, high construct validity</td>
</tr>
</tbody>
</table>

Fatigue questionnaires or scales are the second type of subjective measure of sleepiness. As shown above, the study of sleep is not standardized, and sleep questionnaires are no exception. These questionnaires or scale can range from a simple 10 question, like the Fatigue Feeling Tone Checklist (Pearson & Byars, 1956) up to the multi-dimensional detailed questionnaire developed by Piper et al. (1989). Depending on the application of the questionnaires or scale, a shorter or longer version may be more appropriate. For the purposes of this experiment, the researchers were looking for a questionnaire that would produce a single output rating of the current feeling of fatigue which could then be correlated to the amount of sleep obtained by a person. After briefly reviewing each of these scales as it relates to this experiment,

**Table 6** shows a summary of common questionnaires used for the subjective rating of fatigue; the Stanford Sleepiness Scale was the one chose for this experiment due to its ease of use in an operational setting, which will be discussed in greater detail in subsequent sections.
### Table 6: List of Common Subjective Questionnaires

<table>
<thead>
<tr>
<th>Subjective Fatigue Questionnaire</th>
<th>Research Support</th>
<th>Reason Selected/not Selected</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Epworth Sleepiness Scale (ESS)</td>
<td>(Johns, 1991)</td>
<td>Does not produce a single output rating</td>
</tr>
<tr>
<td>2 Fatigue Assessment Scale (FAS)</td>
<td>(Michielsen, De Vries, &amp; Van Heck, 2003)</td>
<td>Deals too much with physical fatigue</td>
</tr>
<tr>
<td>3 Fatigue Descriptive Scale (FDS)</td>
<td>(Dittner, Wessely, &amp; Brown, 2004; Iriarte, Katsamakis, &amp; De Castro, 1999)</td>
<td>Deals with severity and frequency of fatigue</td>
</tr>
<tr>
<td>4 Fatigue Feeling Tone Checklist</td>
<td>(Pearson &amp; Byars, 1956)</td>
<td>Does not produce a single output rating</td>
</tr>
<tr>
<td>5 Fatigue Impact Scale (FIS) - healthcare</td>
<td>(Fisk et al., 1994; LaChapelle &amp; Finlayson, 1998)</td>
<td>Concerned with the impact of fatigue rather than the current feeling of fatigue</td>
</tr>
<tr>
<td>6 Fatigue Scale</td>
<td>(Yoshitake, 1978)</td>
<td>Concerned with the symptoms of fatigue rather than the current feeling of fatigue</td>
</tr>
<tr>
<td>7 Chalder Fatigue Scale</td>
<td>(Chalder et al., 1993)</td>
<td>Too many measures of fatigue both physical and mental</td>
</tr>
<tr>
<td>8 Fatigue Self-Report Scale</td>
<td>(Piper et al., 1989)</td>
<td>Too many measures of fatigue both physical and mental</td>
</tr>
<tr>
<td>9 Fatigue Severity Scale (FSS)</td>
<td>(Krupp, LaRocca, Muir-Nash, &amp; Steinberg, 1989)</td>
<td>Concerned with the impact of fatigue rather than the current feeling of fatigue</td>
</tr>
<tr>
<td>10 NASA-Task Load Index (TLX)</td>
<td>(Hart &amp; Staveland, 1988; Selcon, Taylor, &amp; Koritsas, 1991)</td>
<td>Too many non-fatigue related questions</td>
</tr>
<tr>
<td>11 Visual Analog Scale for Fatigue (VAS-F)</td>
<td>Lee et al. (1991); Johns (1991); LaChapelle (1998); Blesch (1991)</td>
<td>Concerned with energy and fatigue but too many scales</td>
</tr>
<tr>
<td>12 Stanford Sleepiness Scale (SSS)*</td>
<td>Johns (1991); Hoddes et al. (1972; 1973).</td>
<td>Sensitive to sleep loss, easy to use</td>
</tr>
</tbody>
</table>
CHAPTER 3: A MODEL TO OPERATIONALIZE FATIGUE MEASURES FOR INDUSTRY

As discussed in the introduction, the most currently implemented operational fatigue techniques only address the first level of fatigue management. For example, rules are established regarding Hours of Service (HOS) so that the company allows adequate time off for employees to recover and sleep. The aim of this research is to identify a way of quantifying the second level of fatigue management, which is to ensure that employees are using that time off in an effective manner by getting adequate sleep.

3.1 Operationalized Assessment Tools

To operationalize the fatigue risk management system at the second level, the Basis Band (BB) will be used in conjunction with the Consensus Sleep Diary (CSD), Psychomotor Vigilance Self-Test (PVT), and the Stanford Sleepiness Scale (SSS) to determine if a correlation exists between sleep and performance as measured on these devices.

3.1.1 Basis Band Actigraph - Measuring TST, SE, NOW

Since sensitivity and reliability have not been scientifically validated for any commercially available inexpensive devices, and the obtrusiveness of most of the actigraph devices is minimal, the selection of the band was based on the four aspects that (Gartenberg, 2012) identifies as critical for widespread use of actigraphs: technology must be imbedded in everyday interactions, cost must be low and benefits high, the social community must be engaged, and the data must be scientifically validated. Although several actigraphs track sleep, the Basis was chosen as the best option for this current research due to the embedded nature of the technology and the high benefit cost ratio. Several of the actigraphs on the market, such as the Jawbone Up, require the user to push a button in order to activate the sleep tracking function whereas sleep detection is automatic in the Basis, meaning that everyday patterns are not disrupted. Additionally, the Basis is a fully functional water resistant watch with an external display allowing it to be worn all the time and allowing the user to track his or her progress.
throughout the day. Several other devices, such as the Fitbit, do not include an external display meaning that the data is only available when the device is synced with a phone or computer. The drawback to the Basis and many of the actigraphs currently available is that it must be charged regularly; in the case of the Basis, the battery lasts approximately four to five days and will not need to be charged during the duration of the experiment.

Although the Basis is one of the more expensive models currently on the market, it provides a large variety of upgrades such as heart rate monitoring, perspiration levels, and skin temperature that also help automatically detect sleep. In terms of sleep data, the Basis provides a detailed analysis including total sleep time, sleep efficiency, and number of awakenings. Additionally, the online web program offers users the option to create “habits” or goals for each week, thus increasing the benefit of the watch and software. Figure 3 is an image of the output from one night of sleep. TST is calculated as the time the user fell asleep, in this case 1:29 AM, until the time he/she awoke, in this case 9:19 AM. Therefore, TST for this example is 7 hours 50 minutes or 470 minutes. The sleep time displayed at the top of the image, 7 hours 44 minutes or 464 minutes, is the amount of time actually spent sleeping excluding the six minute long interruption that occurred around 6:30 AM. Therefore, sleep efficiency is calculated as \( \frac{464}{470} \times 100 = 98.7\% \). \( NOW \) is the number of interruptions, in this case one. Number of tosses and turns, sleep score, and differentiation in sleep stages were not used for analysis.
Two areas that are lacking for the Basis Band are social community involvement and scientific validation. As mentioned previously, scientific validation is currently missing for all of the inexpensive commercially available actigraphs and is certainly an area for further research. In terms of social community involvement, the Basis is lacking when compared to other models like the Fitbit which can sync with the MyFitnessPal app. Currently the Basis Band has its own application and its own software that can be used to view data, but it cannot link to other existing applications that may track data like caloric intake or that may offer the feature to be able to “compete” against a friend who may be using a different device. These features may limit widespread use of this watch for users who want to share sleep and fitness successes or align activity with calorie intake. However, for the purposes of this study, community involvement is not crucial and thus was not considered as a concern for use in this research.
3.1.2 Consensus Sleep Diary - Measuring TST, SE, NOW

Although the Consensus Sleep Diary (CSD) was developed relatively recently, it is the first diary that attempts to create a unified diary that can be used primarily for insomnia research but is also general enough to be used for other clinical and research applications (Carney et al., 2012). The CSD was developed using both an expert panel and focus groups. The panel consisted of seven insomnia experts who attended the 2005 Insomnia Assessment Conference, where it was originally decided that a standard needed to be established. These experts asked all 25 members of the original Pittsburgh Assessment Conference to submit sleep diaries; of the 22 diaries submitted, 16 of them were found to be unique. The questions from these 16 diaries were then grouped based on the item content, such as grouping all questions that relate to how long it took a participant to fall asleep into one category. The seven expert members then reviewed all of the questions and rated their top three choices for the wording of each question, with the option to rewrite the question if none of the given options were suitable. A draft of the diary was submitted to twenty clinicians, seven of whom responded, giving feedback concerning the content and format of the diary. Focus groups of patients with and without sleep disorders were then provided with both the core and the expanded sleep diaries; they provided additional feedback regarding the content, format, and usability of the CSD. Final versions of the core and expanded CSD’s were then developed.

Due to the high construct validity of the development of the CSD and its comprehensive yet brief format, it was chosen for use in this experiment. The CSD has a core component that can fit on a single 8.5” x 11” page with the option for an expansion that would fit on the front and back of a single page. Since sleep will also be measured using the actigraph described above, the core version is suitable for this experiment. Additionally, Kushida et al. (2001) identified the number of awakenings, total sleep time, and sleep efficiency as three sleep parameters that define sleep, all three of which are captured on the CSD. A full copy of the CSD can be found in Appendix7.5.
3.1.3 PVT- Measuring 1/RT and NOL

Based on the study performed by Balkin et al. (2004), the PVT test had the second highest sensitivity index after the MSLT which indicates that it is very good at detecting loss of sleep. However, the PVT was selected over the MSLT since it was significantly less obtrusive. The standard PVT test is a ten minute sustained attention test whereby participants are presented a visual stimulus on a computer using the PVT-192 software and must click on a response button as soon as the image appears in order to measure response time (Basner & Dinges, 2011). It is different from a standard reaction time test because the stimuli appear randomly (within a certain inter-stimulus interval) and continue to appear for a prolonged period of time, usually 10 minutes. Additionally, the software used for standard reaction time tests performed on general computers does not control for various sources of delay, such as mouse delay, that could greatly affect the true reaction time (Khitrov et al., 2013). Since the PVT measures vigilance not sleepiness, it can be used when fatigue is caused by either lack of sleep or by prolonged task duration, both of which are applicable in an operational setting (Basner & Dinges, 2011).

Results from the PVT been shown to have very high correlation to sleep loss. Basner and Dinges (2011) conducted a study to determine the best output metrics for a PVT that would optimally discern between fatigued participants and alert participants. Due to the enhanced statistical properties and high sensitivity to sleep loss, the two measures that should be used for analysis are 1/RT (mean reaction time) and number of lapses (NOL). A lapse is when a participant fails to react to the stimulus within 500 ms. Mean RT or median RT are prone to skewness due to outliers and should not be used for analysis of performance.

In terms of reliability, the PVT has been broadly validated in numerous laboratory studies over the last four decades, and the results have shown the repeatability of the measure (Basner & Dinges, 2011). Additionally, in a study performed by Balkin et al. (2004), no significant effect was found for the
PVT in regard to a learning effect; better performance on the PVT did not occur with practice when compared to the baseline.

Finally, the intrusiveness of this test is minimal when compared to other methods, such as the MSLT. In the research conducted by Basner and Dinges (2011), the standardized recommended test length was set at ten minutes, which for the purposes of this experiment is not considered to be overly obtrusive. There is a three minute PVT-B test that was validated by Basner et al. (2011) that could be useful in field applications where ten minutes may be considered too long.

3.1.4 Stanford Sleepiness Scale – Measuring Subjective Rating of Sleepiness

The scale that was chosen for this experiment is the Stanford Sleepiness Scale (SSS) developed by Hoddes, Zarcone, Smythe, Phillips, and Dement (1973). The measurement is based on a seven point scale whereby the participant selects his or her subjective feeling of sleepiness at a given time. Hoddes et al. (1973) define the seven statements and corresponding scale values as:

1 – Feeling active and vital; alert; wide awake
2 – Functioning at a high level, but not at peak; able to concentrate
3 – Relaxed; awake, not at full alertness; responsive
4 – A little foggy; not at peak; let down
5 – Fogginess; beginning to lose interest in remaining awake; slowed down
6 – Sleepiness; prefer to be lying down; fighting sleep; woozy
7 – Almost in a reverie; sleep onset soon; lost struggle to remain awake

In the study performed by Hoddes et al. (1973), the SSS scores from the experiment were found to be sensitive to sleep loss. Additionally, higher scores on the SSS were found to be cross-validated with a lower performance on mental tasks. In addition to being sensitive and reliable, this scale requires very little time and effort for the participants to respond, and this quality was also consider significant in making the decision to use it for the present experiment.

3.2 Hypotheses

Total sleep time (TST), sleep efficiency (SE) and number of awakenings (NOW) are the three continuous independent variables that can help quantify user fatigue and will be measured using the BB
and the CSD. TST is measured as the total number of hours and minutes the participant spends sleeping, including any time spent awake during an awakening in the middle of the sleeping period. SE is the percentage of total sleep time actually spent sleeping (i.e. time spent awake for awakenings is subtracted). NOW is the number of times that a participant has been awakened during his or her sleep period. The first hypothesis states that there will be no significant difference in the TST, SE, and NOW recorded by the Basis Band and the Consensus Sleep Diary. The subsequent hypotheses state that these three variables will be significantly correlated against three continuous dependent variables: the subjective feeling of fatigue according to the SSS, the objective performance as measured using the PVT results of 1/RT (Mean Reaction Time), and the number of lapses.

Therefore, the three main hypotheses and two sub hypotheses can be seen in the block diagram and subsequent descriptions below.

![Hypothesis Block Diagram](image)

**Figure 4: Hypothesis Block Diagram**

**Hypothesis 1:** For all nights of sleep, the Total Sleep Time (TST), Sleep Efficiency (SE), and Number of awakenings (NOW) values for the Basis Band (BB) and the Consensus Sleep Diary will not be significantly different from one another using the Wilcoxon Signed Rank Test.
**Hypothesis 2:** For all nights of sleep, the Total Sleep Time (TST) and Sleep Efficiency (SE) as measured on the Basis Band (BB) will have a Spearman Correlation Coefficient ($\rho$) value that is positively correlated with $1/RT$ and negatively correlated with the number of lapses as measured by the PVT test. The Number of awakenings (NOW) value will have a Spearman Correlation Coefficient ($\rho$) value that is negatively correlated with $1/RT$ and positively correlated with the number of lapses (NOL) as measured by the PVT test. Essentially, as total sleep time and quality increases, performance will improve.

**Hypothesis 3** (Only if Hypothesis 1 is rejected): For all three nights of testing per participant, Total Sleep Time (TST) and Sleep Efficiency (SE) as measured on the Consensus Sleep Diary (CSD) will have a Spearman Correlation Coefficient ($\rho$) value that is positively correlated with $1/RT$ and negatively correlated with the number of lapses as measured by the PVT test. The Number of awakenings (NOW) value will have a Spearman Correlation Coefficient ($\rho$) value that is negatively correlated with $1/RT$ and positively correlated with the number of lapses (NOL) as measured by the PVT test. Essentially, as total sleep time and quality increases, performance will improve.

**Hypothesis 4:** For all three nights of testing per participant, the Total Sleep Time (TST) and Sleep Efficiency (SE) as measured on the Basis Band will have a Spearman Correlation Coefficient ($\rho$) value that is negatively correlated with the subjective feeling of fatigue as measured on the Stanford Sleepiness Scale (SSS). The Number of awakenings (NOW) value will have a Spearman Correlation Coefficient ($\rho$) value that is positively correlated with the subjective feeling of fatigue as measured on the Stanford Sleepiness Scale. Essentially, as total sleep time and quality increases, users report feeling more awake.

**Hypothesis 5** (Only if Hypothesis 1 is rejected): For all three nights of testing per participant, Total Sleep Time (TST) and Sleep Efficiency (SE) as measured in the Consensus Sleep Diary (CSD) will have a Spearman Correlation Coefficient ($\rho$) value that is negatively correlated with the subjective feeling of fatigue as measured on the Stanford Sleepiness Scale (SSS). The Number of awakenings (NOW) value will have a Spearman Correlation Coefficient ($\rho$) value that is positively correlated with the subjective feeling
of fatigue as measured on the Stanford Sleepiness Scale (SSS). Essentially, as total sleep time and quality increases, users report feeling more awake.

CHAPTER 4: METHODS

4.1 Experiment Design

Total sleep time (TST), sleep efficiency (SE) and number of awakenings (NOW) are the three continuous independent variables that can help quantify user fatigue and will be measured using the BB and the CSD. TST is measured as the total number of hours and minutes the participant spends sleeping, including any time spent awake during an awakening in the middle of the sleeping period. SE is the percentage of total sleep time actually spent sleeping (i.e. time spent awake for awakenings is subtracted). NOW is the number of times that a participant has been awakened during his or her sleep period. These three sleep variables will be correlated against the three continuous dependent variables: the subjective feeling of fatigue according to the SSS, the objective performance as measured using the PVT results of 1/RT (Mean Reaction Time) and the number of lapses.

One assumption made to evaluate the data is that each night of sleep and the resulting performance and subjective feeling of fatigue rating are independent of each other. For example, the amount of sleep obtained on Night 1 does not have any effect on the amount of sleep obtained on Night 3, nor does it have any effect on the performance on the PVT test after Night 3. Therefore, all nights of data were evaluated as individual data points and the six variables collected for each night were compared within one night.

4.2 Participants

Forty students from the undergraduate and graduate engineering student population at Louisiana State University (LSU) participated in this research. Students were asked their current work status (full time, part time, days or night) but were not excluded from the study based on their work status.
status. Participants were also asked if they have a diagnosed sleep disorder and if they are currently taking medication. Participants who have a diagnosed sleep disorder but who are not taking medication were excluded from the results due to the potential for outliers. Therefore, 39 participants were used in the final analysis. Below is a breakdown of demographic information of the participants.

Table 7: Summary demographic information

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Male: 29 (74%)</td>
</tr>
<tr>
<td></td>
<td>Female: 10 (26%)</td>
</tr>
<tr>
<td>Age</td>
<td>18-24: 30 (77%)</td>
</tr>
<tr>
<td></td>
<td>25-34: 8 (21%)</td>
</tr>
<tr>
<td></td>
<td>34-44: 1 (3%)</td>
</tr>
<tr>
<td>Status in School</td>
<td>Freshman: 1 (3%)</td>
</tr>
<tr>
<td></td>
<td>Sophomore: 14 (36%)</td>
</tr>
<tr>
<td></td>
<td>Junior: 15 (38%)</td>
</tr>
<tr>
<td></td>
<td>Senior: 2 (5%)</td>
</tr>
<tr>
<td></td>
<td>Graduate Student: 7 (18%)</td>
</tr>
<tr>
<td>Job Status</td>
<td>No job: 15 (38%)</td>
</tr>
<tr>
<td></td>
<td>Part time days: 19 (49%)</td>
</tr>
<tr>
<td></td>
<td>Part time nights: 1 (3%)</td>
</tr>
<tr>
<td></td>
<td>Part time nights/days: 3 (8%)</td>
</tr>
<tr>
<td></td>
<td>Full time nights/days: 1 (3%)</td>
</tr>
<tr>
<td>Diagnosed Sleep Condition</td>
<td>Yes: 2 (1 meds, 1 no meds – excluded from study) (5%)</td>
</tr>
<tr>
<td></td>
<td>No: 38 (95%)</td>
</tr>
</tbody>
</table>

4.3 Procedure

Due to the limited availability of the Basis watches, up to nine participants were studied at a time, capturing three nights of sleep for each participant. Sleep and performance studies performed previously have varied in length from one night (Paquet et al., 2007) up to weeks or months (Dinges et al., 1997; Krystal et al., 2003). The duration of this study is based on a previous study done by (Basner and Dinges (2011)) who used four nights of sleep with the first night being used only to establish whether or not the participant had a sleep disorder. By choosing to measure sleep on Monday, Tuesday
and Wednesday nights, the potential for variability in a sleep schedule on the weekends is reduced while still allowing three nights of data collection.

On Monday of each week, the participants for that week were asked to participate in an information session, lasting approximately thirty minutes in which they were asked to complete a demographic and informational questionnaire and to sign an informed consent form. After completing the questionnaire, participants were asked to take the ten-minute PVT test in order to familiarize themselves with the equipment. Each participant was then briefed regarding the requirements of the Consensus Sleep Diary as well as the functionality of the Basis Band. Participants were shown how to use the Stanford Sleepiness Scale. Finally, participants were asked to get six to ten hours of sleep each night, which is the recommended amount of sleep for most humans. Getting that amount of sleep was not a requirement for inclusion in the study since real world employees may or may not get the recommended amount of sleep. However, all employees are generally asked to come to work well rested thus the reason for the request to the participants. Additionally, participants were instructed continue with their normal routines including use of caffeine, over the counter medication, and daily exercise.

After participating in the information session, each participant was instructed to do three things: wear the watch constantly until Thursday morning, come to the research lab each morning within one to three hours of waking up in order to take the ten minute PVT, complete the Stanford Sleepiness Scale, and complete the Consensus Sleep Diary. Since this research aims to isolate the amount of sleep obtained as the main contributing factor to fatigue, this timeframe was selected since this is generally the time between waking and coming to work for employees. Additionally, by measuring performance on a vigilance test in the morning, the study hopes to isolate the effect of the sleep from the previous night from the effect of general fatigue that would be accumulated through the day.
Finally, upon coming into the research lab on Thursday, participants were asked to return the watches, take the three normal tasks (PVT test, SSS questionnaire, and CSD entry) and complete an exit questionnaire. The exit questionnaire contains questions related to the likelihood that the participant would wear a similar watch regularly, whether the felt it was an invasion of privacy, and if they felt that it made them likely to get more sleep. A full copy of the questionnaire can be found in Appendix 7.5.

4.4 Data Analysis

First, a test for normality will be performed using the Shairo Wilkes normality test. Significance will be set at alpha = .05. The first hypothesis stating that the Total Sleep Time, Sleep Efficiency, and Number of Awakenings as measured on the Basis Band will not be significantly different from the same measures recorded by the Consensus Sleep Diary will be tested using the Wilcoxon Signed Rank Test with alpha set at .05. All subsequent hypotheses will be tested using Spearman’s Correlational analysis with alpha set at .05. The p-value for hypothesis one is two tailed. All other p-values are one-tailed with the direction of the tail being established in the hypothesis.
CHAPTER 5: RESULTS

Forty students participated in this research resulting in 120 nights of data collection. Only the participant who had a diagnosed sleep condition who was not taking medication was completely eliminated from the study. Additionally, several participants had missing nights of data due to failure to wear the Basis Band. In the end, 110 nights of sleep were available for analysis. General summary statistics are listed in Table 8 followed by the results for each hypothesis.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>TST – BB</td>
<td>408.93 minutes (6.81 hrs)</td>
<td>135.56 minutes</td>
</tr>
<tr>
<td>TST – CSD</td>
<td>385.22 minutes (6.42 hrs)</td>
<td>125.24 minutes</td>
</tr>
<tr>
<td>SE – CSD</td>
<td>97.96%</td>
<td>3.67%</td>
</tr>
<tr>
<td>SE – BB</td>
<td>95.79%</td>
<td>8.09%</td>
</tr>
<tr>
<td>NOW – BB</td>
<td>.918 times/night</td>
<td>1.07 times</td>
</tr>
<tr>
<td>NOW – CSD</td>
<td>1.45 times/night</td>
<td>1.35 times</td>
</tr>
<tr>
<td>Time to sleep - BB</td>
<td>12:58 AM</td>
<td>-</td>
</tr>
<tr>
<td>Time to sleep - CSD</td>
<td>1:14 AM</td>
<td>-</td>
</tr>
<tr>
<td>Time at wake - BB</td>
<td>7:47 AM</td>
<td>-</td>
</tr>
<tr>
<td>Time at wake - CSD</td>
<td>7:39 AM</td>
<td>-</td>
</tr>
<tr>
<td>1/RT</td>
<td>3.51</td>
<td>.4775</td>
</tr>
<tr>
<td>NOL</td>
<td>2.45</td>
<td>2.74</td>
</tr>
<tr>
<td>SSS</td>
<td>3.28</td>
<td>1.53</td>
</tr>
</tbody>
</table>

After the data was collected, a normality assessment was conducted using the Shapiro-Wilk test on TST, SE, and NOW for both the BB and the CSD. TST, SE and NOW for both the BB and the CSD did not have a normal distribution with p-values <.0001 for all six measures. Additionally a normality assessment was conducted on 1/RT, NOL, and SSS ratings. 1/RT did have a normal distribution (p = .4743), but NOL and SSS did not (p-value <.0001).

Because the majority of the data wasn’t normal and because there are a large number of data points, a Wilcoxon Signed Rank Test, which does not rely on normality of data, was selected to test for a difference in means between the TST, SE, and NOW for the Basis Band and the CSD. A Spearman
correlation analysis, which also does not rely on normality of data, was then used to correlate the TST, SE, and NOW to 1/RT, NOL, and SSS rating.

**Hypothesis 1:** For all nights of sleep, the Total Sleep Time (TST), Sleep Efficiency (SE), and Number of awakenings (NOW) values for the Basis Band (BB) and the Consensus Sleep Diary (CSD) will not be significantly different from one another using the Wilcoxon Signed Rank Test.

a. As hypothesized in hypothesis 1, SE for the BB and the CSD were not significantly different from each other.

b. Contrary to hypothesis 1, the NOW for the BB and the CSD were significantly different from each other. Also, the TST for the BB and the CSD were significantly different from each other. Due to the potential of irregularity of sleep patterns during Spring Break and finals week, the same analysis was run excluding the data for those two weeks (new n=76). The Wilcoxon Signed Rank Test still found there to be a significant difference between the TST of the CSD and the BB.

As a follow up to this, the researchers were interested to see if the difference in TST recorded by the BB and the CSD tended to occur due to a difference in the time that the participant fell asleep or when he/she awoke or both. Results showed that there was a significant difference (p<.0001) in the time that participants reported falling asleep using the CSD and the time that the BB recorded that a participant fell asleep. Results regarding the time participants awoke also showed a significant difference (p<.001). Therefore, overestimation of sleep time on the BB was significant on both ends of the period of sleep but the BB tended to be more aligned with the CSD in determining the time the participant awoke than in determining when the participant fell asleep. A summary of results can be seen in Table 9 below.

<table>
<thead>
<tr>
<th></th>
<th>Difference in Means</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>TST – BB:CSD</td>
<td>23.7182 minutes</td>
<td>&lt;.0001*</td>
</tr>
<tr>
<td>SE – BB:CSD</td>
<td>2.15%</td>
<td>.4220</td>
</tr>
<tr>
<td>NOW – BB:CSD</td>
<td>.5145 times</td>
<td>.0001*</td>
</tr>
</tbody>
</table>

* significant at alpha = .05
Hypothesis 2: For all nights of sleep, the Total Sleep Time (TST) and Sleep Efficiency (SE) as measured on the Basis Band (BB) will have a Spearman Correlation Coefficient (ρ) value that is positively correlated with 1/RT and negatively correlated with the number of lapses as measured by the PVT test. The Number of awakenings (NOW) value will have a Spearman Correlation Coefficient (ρ) value that is negatively correlated with 1/RT and positively correlated with the number of lapses (NOL) as measured by the PVT test. Essentially, as total sleep time and quality increases, performance will improve.

a. As hypothesized in hypothesis 2, the TST as recorded on the BB is significantly correlated with NOL, meaning that the more sleep a participant received, the fewer lapses occurred on the PVT.

b. Contrary to hypothesis 2, the TST as recorded on the BB does not have a significant correlation with 1/RT. As a follow up to the initial hypothesis, the researchers were interested to see if there was any effect on performance based on whether or not the participant had a job. Therefore the analysis was run a second time separating out participants who reported having no job (n=46) and participants who reported having either a full time or part time job (n=65). Results showed that there was no significant correlation between TST and 1/RT for either group, ρ = .06 for those with no job and ρ = .15 for those with jobs.

Also contrary to hypothesis 2, the SE as recorded on the BB is not significantly correlated with 1/RT. Interestingly, SE as recorded on the BB is significantly positively correlated with NOL meaning that the higher the sleep efficiency, the more lapses occurred which is contrary to the initial hypothesis which predicted a negative correlation between the two measures.

Additionally, the NOW as recorded on the BB is significantly negatively correlated with NOL, meaning that the more times a participant woke up in the night, the fewer lapses they recorded on the PVT which is contrary to the initial prediction.

Hypothesis 3: For all three nights of testing per participant, Total Sleep Time (TST) and Sleep Efficiency (SE) as measured on the Consensus Sleep Diary (CSD) will have a Spearman Correlation Coefficient (p)
value that is positively correlated with $1/RT$ and negatively correlated with the number of lapses (NOL) as measured by the PVT test. The Number of awakenings (NOW) value will have a Spearman Correlation Coefficient ($\rho$) value that is negatively correlated with $1/RT$ and positively correlated with the number of lapses (NOL) as measured by the PVT test. Essentially, as total sleep time and quality increases, performance will improve.

a. As hypothesized in hypothesis 3, the TST as recorded on the CSD is significantly correlated with NOL confirming that the more sleep a participant received, the fewer lapses occurred.

b. Contrary to hypothesis 3, the TST, SE and NOW as recorded on the CSD are not significantly correlated with $1/RT$. The NOW as recorded on the CSD is also not significantly correlated with NOL. Additionally, contrary to hypothesis 3 which hypothesized a negative correlation, the SE as recorded on the CSD is significantly positively correlated with NOL meaning that the better the sleep efficiency, the more lapses occurred. A summary is shown below in Table 10. Certain correlations, such as TST and NOW, are not correlated with each other as these values have no meaning when correlated. The total amount of time you sleep does has no bearing on many times you wake up during a night of sleep. Therefore, these values are indicated with a dash in the summary table below.

**Table 10: Summary of Hypothesis 2 and 3**

<table>
<thead>
<tr>
<th></th>
<th>TST - CSD</th>
<th>TST - BB</th>
<th>NOW - CSD</th>
<th>NOW - BB</th>
<th>SE - CSD</th>
<th>SE - BB</th>
<th>1/RT</th>
<th>NOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>TST - CSD</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TST - BB</td>
<td>-</td>
<td>1</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOW - CSD</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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<td>NOW - BB</td>
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<tr>
<td>SE - CSD</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SE - BB</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/RT</td>
<td>0.1842 (.0541)</td>
<td>0.1232 (.1998)</td>
<td>0.0175 (.8560)</td>
<td>0.1107 (.2495)</td>
<td>-0.1208 (.2089)</td>
<td>-0.1101 (.2521)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>NOL</td>
<td>-0.2168 (.0229*)</td>
<td>-0.1919 (.0446*)</td>
<td>-0.0816 (.3967)</td>
<td>-0.2063 (.306**)</td>
<td>0.2077 (.0295**)</td>
<td>0.2469 (.0093**)</td>
<td>-</td>
<td>1</td>
</tr>
</tbody>
</table>

Spearman Correlation Coefficient (p-value)

* significant at alpha = .05, ** significant at alpha = .05 but opposite direction of hypothesis
**Hypothesis 4:** For all three nights of testing per participant, the Total Sleep Time (TST) and Sleep Efficiency (SE) as measured on the Basis Band will have a Spearman Correlation Coefficient (ρ) value that is negatively correlated with the subjective feeling of fatigue as measured on the Stanford Sleepiness Scale (SSS). The Number of awakenings (NOW) value will have a Spearman Correlation Coefficient (ρ) value that is positively correlated with the subjective feeling of fatigue as measured on the Stanford Sleepiness Scale. Essentially, as total sleep time and quality increases, users report feeling more awake.

a. As hypothesized in hypothesis 4, the TST as recorded on the BB is significantly correlated with the SSS rating of sleepiness meaning that as TST increased, SSS rating showed that participants reported being more alert.

b. Contrary to hypothesis 4, the SE and NOW as recorded on the BB are not significantly correlated with the SSS rating.

**Hypothesis 5:** For all three nights of testing per participant, Total Sleep Time (TST) and Sleep Efficiency (SE) as measured in the Consensus Sleep Diary (CSD) will have a Spearman Correlation Coefficient (ρ) value that is negatively correlated with the subjective feeling of fatigue as measured on the Stanford Sleepiness Scale (SSS). The Number of awakenings (NOW) value will have a Spearman Correlation Coefficient (ρ) value that is positively correlated with the subjective feeling of fatigue as measured on the Stanford Sleepiness Scale (SSS). Essentially, as total sleep time and quality increases, users report feeling more awake.

a. As hypothesized in hypothesis 5, the TST as recorded on the CSD is significantly correlated with the SSS rating of sleepiness.

b. Contrary to hypothesis 5, the SE and NOW as recorded on the CSD are not significantly correlated with the SSS rating. A summary of hypothesis 4 and 5 can be found in Table 11 below. Certain correlations, such as TST and NOW, are not correlated with each other as these values have no meaning when correlated. The total amount of time you sleep does has no
bearing on many times you wake up during a night of sleep. Therefore, these values are indicated with a dash in the summary table below.

**Table 11: Summary of Hypothesis 4 and 5**

<table>
<thead>
<tr>
<th></th>
<th>TST - CSD</th>
<th>TST - BB</th>
<th>NOW - CSD</th>
<th>NOW - BB</th>
<th>SE - CSD</th>
<th>SE - BB</th>
<th>SSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>TST - CSD</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TST - BB</td>
<td>-</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOW - CSD</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOW - BB</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SE - CSD</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SE - BB</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>SSS</td>
<td>-0.2702</td>
<td>0.2059</td>
<td>0.0876</td>
<td>-0.0210</td>
<td>-0.0701</td>
<td>0.0323</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>(.0043*)</td>
<td>(.0309*)</td>
<td>(.3629)</td>
<td>(.8274)</td>
<td>(.4668)</td>
<td>(.7376)</td>
<td></td>
</tr>
</tbody>
</table>

Spearman Correlation Coefficient (p-value)

* significant at alpha = .05
CHAPTER 6: DISCUSSION AND LIMITATIONS

As can be seen from the 1918 train wreck in Hammond, Indiana where a train driver fell asleep at the wheel killing over 100 people and injuring 127, fatigue accidents in the workplace are not a new concept (Lytle, 2011). However, in the past it has been difficult to identify fatigue as a contributing cause of an accident. Now advances in technology and fatigue research allow companies to be more proactive in mitigating the risk of fatigue by implementing FRMS’s. With further advances and research, the use of an actigraph to monitor sleep could be an inexpensive solution for employees to self-monitor and mitigate his or her individual risk of fatigue and fatigue related accidents.

6.1 Significant Results

Looking at the results, only a few of the initial hypotheses regarding the Basis Band turned out to be supported by the data collected. To begin the discussion, it is important to look first at the interpretation of the statistically significant results.

<table>
<thead>
<tr>
<th>Table 12: Summary of Significant Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wilcoxon Signed Rank</strong></td>
</tr>
<tr>
<td>SE – BB:CSD</td>
</tr>
<tr>
<td><strong>Spearman’s Correlation Analysis</strong></td>
</tr>
<tr>
<td>TST – BB : NOL</td>
</tr>
<tr>
<td>TST – CSD : NOL</td>
</tr>
<tr>
<td>TST – BB : SSS</td>
</tr>
<tr>
<td>TST – CSD : SSS</td>
</tr>
</tbody>
</table>

In looking at the Wilcoxon Signed Rank test, SE was the only measure to show no significant difference for the CSD and BB. Given that TST was significantly different, it may at first seem surprising that SE is not significantly different. However, SE only determines the percentage of time a person was actually sleeping during the period of sleep. Therefore, if a person did not wake at all during the period of sleep, the SE for both the CSD and the BB is 100% regardless of whether or not TST is the same using the two methods. Given that SE is not significantly different when the two methods are compared, it
can be inferred that the two devices measure periods of wakefulness during the period of sleep roughly equally.

Moving on to the Spearman Correlation Analysis, there were only four results obtained during analysis that were significantly correlated as hypothesized. TST as measured on both the BB and the CSD was negatively correlated with NOL meaning that as participants got more sleep, the performed better as measured by NOL. This implies that NOL on the performance test could potentially be a predictor of fatigue as defined by the amount of sleep obtained the previous night but additional research would have to be done to confirm this since NOL had mixed results when looking at its correlation with other sleep measures.

The final significant correlation occurred between TST for both the BB and the CSD and the SSS rating. This significant correlation is supported by research done by Hoddes et al. (1973) that found that using the SSS, people are accurately able to subjectively evaluate their level of fatigue. From an operationalizable fatigue management standpoint, keeping in mind the employees’ subjective rating of his/her feeling of fatigue is important to consider. However, due to a fear of potential repercussions in a work setting, employees may not be as truthful in reporting their subjective feeling of fatigue as they would be in a research environment.

6.2 Non-Significant Results

6.2.1 Wilcoxon Signed Rank Test

It would seem ideal to have an automated collection device in the form of a reasonably priced watch that could collect total sleep time (TST) for employees. Such a method would eliminate the need for manual sleep logs and provide industry a tool for evaluating sleep in their employees thereby helping them detect sleep deprived employees prior to putting them in control of a train, plane, or refinery. Unfortunately, in this study the Wilcoxon Signed Rank test showed that the Basis Band and the Consensus Sleep Diary were significantly different from one another for estimating TST. Essentially, this
means that the BB and the CSD reported differing TST values; the BB recorded that a participant received more sleep than was subjectively reported using the CSD. One limitation of this study is that the actual amount of sleep obtained by a person was not measured in a laboratory using a PSG or some other method to validate the data produced by the CSD or the BB. Therefore, the researchers only know that the two measures are different from one another but not which is more accurate in capturing the true amount of sleep obtained. However, in a study performed by Kushida et al. (2001) where TST, SE, and NOW measured on an actigraph (different model than the Basis Band) and subjective sleep questionnaire were compared to PSG outputs, results showed that actigraphs significantly overestimate TST and SE when compared to the PSG output whereas the subjective questionnaire did not. The reason for this overestimation of the actigraph is due to the low sensitivity in detecting the difference between sleep and wakeful lying down Kushida et al. (2001). Therefore, in the absence of the measure of actual sleep via laboratory methods and in line with the previous study by Kushida et al. (2001) the researchers conclude that it is likely that the BB overestimated the actual amount of sleep obtained by a person during the night.

Since the TST was different for the BB and the CSD, the researchers were interested to see if the difference in TST occurred at the point of falling asleep or at the point of waking up or both. Essentially, was the BB more closely matched with the CSD in detecting the moment of falling asleep or detecting the moment of waking? Therefore, additional analysis was conducted to see if there was a significant difference in the moment of falling asleep and the moment of waking using the BB and the CSD. Analysis showed that the CSD and BB were significantly different from one another for both measures. The BB measured that participants went to bed 15.68 minutes sooner than was self-reported on the CSD and that participants were asleep 8.22 minutes longer than was self-reported on the CSD. Therefore, the overestimation of sleep on the BB occurred both at the time of falling asleep and the time of waking up.
Looking at NOW, results of the Wilcoxon Signed Rank test show a significant difference between the BB and the CSD as well. When looking at this data in conjunction with the SE reported above, the interpretation is that participants using the CSD reported waking up more often but for shorter periods of time than was recorded by the BB. In the study by Kushida et al. (2001) participants were found to be significantly worse in recognizing NOW on the questionnaire than was reported by the actigraph or the PSG. Therefore, it is possible that participants in this research also overestimated the number of times he/she awoke during the period of sleep. Just like with TST and SE, this research did not validate the sleep measures in the laboratory setting, so it can only be said that the NOW between the two devices is different.

6.2.2 Spearman Correlation Coefficient

There was no significant correlation between 1/RT and TST, SE, or NOW measured on the BB. Therefore, based on those results, the amount of sleep as measured on the BB cannot be used as a predictor of performance on the PVT. Results of the SE and NOW as measured using the CSD also show no significant correlation with 1/RT, and TST shows a very small significant correlation to 1/RT (p= .0541) which, as mentioned above, was not considered by the researchers to be a strong enough correlation from which to draw conclusions. Therefore, the amount of sleep as measured on the CSD cannot be used as a predictor of performance on the PVT. This is contrary to previous research by Basner and Dinges (2011) which showed that 1/RT was sensitive to sleep loss.

One possible reason that no significant correlation was found between the sleep measures and performance despite previous research concluding the opposite could be due to the fact that amount of sleep obtained by the participants was not varied enough to be able to detect a significant difference in performance. Participants generally got an acceptable amount of sleep; therefore, the PVT was not sensitive enough to able to detect any significant difference in performance. In the study by Basner and Dinges (2011), participants were either sleep deprived for 33 consecutive hours or were limited to four
hours of sleep for five consecutive nights which could explain why the PVT was able to detect differences in performance. Since the objective of this research is for the measurement of sleep and performance to be operationalizable in the workplace in order to mitigate the risk of fatigue related accidents, it is important for the performance measure to be sensitive to even small differences in TST, SE, and NOW yet still be easy enough to use regularly.

Moving to the NOL performance measure from the PVT, the results showed that SE as measured on the BB was significantly correlated with NOL but not necessarily in the way anticipated by the researchers. Contrary to the initial hypothesis, SE was significantly positively correlated with NOL meaning that the more efficient the sleep period, the more lapses in performance occurred. This is particularly interesting because NOL was one of the only measures that was significantly correlated with TST as discussed previously. This indicates that NOL may not be a strong enough predictor of operation performance.

Also contrary to the initial hypothesis, NOW was significantly negatively correlated with NOL meaning that the more often a participant awoke in the night, the less lapses occurred. Because the number of awakenings in a night was between zero and five and the number of lapses was between 0 and 13 for all participants, it is possible that the effect of only a few awakenings wasn’t enough to show the predicted results. When looking at the sleep measures from the CSD, the same results occurred with the exception of NOW which was not significantly correlated with NOL. Since the results of SE and NOW compare to NOL were opposite of the expected result, these measures should not be used to predict operator performance.

Finally, looking at correlation in sleep measures and SSS ratings, SE and NOW were not significantly correlated with SSS. Using the CSD sleep measures instead of the BB yielded the same results. As seen from some of the other results, SE and NOW certainly are not strong enough for industry to use to predict operator performance.
6.3 Limitations

6.4.1 Study Limitations

There are three important limitations regarding the actual experiment design. First, the participants were students as opposed to full time employees. A younger student population may be able to recover more quickly from sleep deprivation than older people. Secondly, but related to the first, none of the participants worked a standard shiftwork schedule. University students are known for having odd sleep schedules due to the flexible nature of classes, so sleep patterns may not be as regular as could be expected in the working environment. However, eliminating the two weeks that had the potential for the most variability in sleep showed no difference in results.

The third limitation regarding the design of the experiment deals with the assumption about the independence of each night of sleep. It could be argued that the amount of sleep obtained two or three nights prior to taking the performance test could in fact have an effect on performance. One possible extension of this research would be to investigate the trend in performance taking into consideration the trend in sleep over the course of the experiment to see if performance declines more markedly after several consecutive nights of little sleep. These limitations must be understood in interpreting the results of this work and its application to the industry. Further work is needed before the results can be implemented within industry.

6.4.2 General Limitations

Privacy and regulatory issues with monitoring sleep in the workplace present other concerns (Lerman et al., 2012). Once technological advances make actigraphs a suitable tool to use in workplace fatigue management systems, there are definitely some obstacles related to full blown implementation in a real work setting. The question of whether fatigue testing should be voluntary or mandatory is a major limitation to consider. Unlike a research setting where participants are voluntary, an employee may not want his or her employer to have access to the amount of sleep that he or she is getting each
night. As there is currently no regulation that says that employees must get a certain number of hours of sleep each night, employees may consider the monitoring of their sleep to be an invasion of their privacy.

Another consideration is access to the sleep data. Given that many of the actigraphs, including the one used in this study, rely on internet access to track data, the fear is that this information could be accessed by a number of people, potentially including insurance companies. The lack of regulations surrounding the privacy of the data could be a concern to employees. One challenge regarding confidentiality of information is that the idea of privacy is ever changing and is also partially in the eye of the beholder (Barrows & Clayton, 1996).

One final privacy or regulatory related limitation to the implementation of actigraphs in the workplace is that the consequences or disciplinary action as a result of fatigue are yet to be defined. Currently there is no law, that dictates how much sleep is acceptable or that clearly defines a state of fatigue although Dawson and McCulloch (2005) suggests a model based on the previous 24 and 48 hour sleep-wake data to establish a prior-sleep threshold that would be acceptable for companies. The acceptable threshold level would be variable based on the task and the company itself, and to set proposed threshold, additional research is required.

If an employee is agreeable to wearing the device and the privacy of the data is ensured, then there is still a final hurdle, namely compliance in the use or wearing of the device (Gartenberg, 2012). A participant may want to use the device but Gartenberg (2012) argues that to increase compliance with use, four problems must be addressed: technology must be imbedded in everyday interactions, cost must be low and benefits high, the social community must be engaged, and the data must be scientifically validated.

In order to see general perception regarding the general limitations of widespread implementation of using actigraphs to monitor performance, researchers compiled an exit questionnaire
to determine addressing some of the concerns listed above. Looking at the exit questionnaire data, results showed that generally participants did not find the watch to be intrusive and that he or she would generally be willing to wear the actigraph if there was an incentive based program offered by an employer. In looking at the answer to the first two questions, results show that although people don’t care one way or the other if the employer has access to their sleep data, they are also not opposed to having to take a vigilance test prior to beginning a shirt. Results were measured using a five point Likert scale with 1 representing “strongly agree” and 5 representing “strongly disagree”. Table 13 shows a summary of the median values of the exit questionnaire.

**Table 13: Summary of Exit Questionnaire Data**

<table>
<thead>
<tr>
<th>Statement</th>
<th>Median Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Employers should not have access to my sleep data.</td>
<td>Neutral</td>
</tr>
<tr>
<td>Employers should be allowed to require employees to take a vigilance test, such as the PVT, prior to beginning a shift.</td>
<td>Neutral</td>
</tr>
<tr>
<td>I would wear a sleep/activity monitor, such as the Basis Band, if there was an incentive from my employer.</td>
<td>Strongly Agree</td>
</tr>
<tr>
<td>I would wear a sleep/activity monitor, such as the Basis Band, in my daily life.</td>
<td>Agree</td>
</tr>
<tr>
<td>I felt that wearing the Basis Band was inconvenient and disrupted my daily activities.</td>
<td>Disagree</td>
</tr>
<tr>
<td>Wearing the Basis Band motivated me to get more sleep each night.</td>
<td>Neutral</td>
</tr>
</tbody>
</table>

Given the lack of significant correlation between the BB and the PVT outputs, the study limitations, and the general limitations of widespread actigraph implementation, further research is needed before
operator performance can be predicted using an actigraph to measure sleep obtained the previous night.

### 6.4 Conclusions

Taking all of these pairwise comparisons and correlations into consideration, the observation of the researchers is twofold. First, results showed that Total Sleep Time and Number of Awakenings measured on the Basis Band were significantly different from the same measure recorded by the Consensus Sleep Diary but there was nothing in the experiment that allowed the researchers to determine which was more the more accurate measure of sleep. Since the objective of this research was to see if the watch was able to be used in an operational setting, it would be beneficial if the manufacturers of the BB conducted additional testing in a laboratory setting in order to validate the sleep outputs from the device. However, this type of reliability testing of the Basis Band is not available in published research.

The second observation is that the performance measure used to evaluate the effect of sleep on a person’s performance was not sensitive enough to detect relatively minor differences in the TST, SE, and NOW. Previous studies using the PVT to measure performance were based on the participants being subjected to substantial sleep deprivation whereas this experiment asked participants to get a normal amount of sleep each night in order to simulate a real work environment. In order to continue further research in the use of sleep and performance testing in an operational setting, a performance measurement device that is sensitive enough to detect small differences in sleep must be found. Therefore, the conclusion of the research is that the PVT and the BB are not adequate tools for predicting operator performance and measuring the amount sleep obtained the previous night without further investigation.

Given these two conclusions, the ability of these tools to accurately measure sleep and performance is in question but the BB could still have some value. Many companies provide
pedometers to employees in conjunction with 10,000 step/day programs to encourage their employees to be more active. The objective of the pedometers and the step programs are to raise awareness of health and fitness; the same thing could be done with raising awareness of proper sleep using the Basis Band. Self-awareness of sleep is an important part of a Fatigue Risk Management System and even though the results of this study could not quantifiably correlate performance and sleep, the Basis Band or other actigraph could still prove to be a critical component in mitigating the risk of fatigue.
REFERENCES


Krystal, A. D., Walsh, J. K., Laska, E., Caron, J., Amato, D. A., Wessel, T. C., & Roth, T. (2003). Sustained efficacy of eszopiclone over 6 months of nightly treatment: results of a randomized, double-
blind, placebo-controlled study in adults with chronic insomnia. SLEEP-NEW YORK THEN WESTCHESTER, 26(7), 793-800.


APPENDIX

7.1 Informed Consent From

Consent Form for non-clinical study

1. Study title: Using sleep Tracking Activity Monitors to Mitigate Risk of Fatigue
2. Performance Site: Louisiana State University
3. Investigators: The following investigators are available for questions about this study,
   a. Vanessa Seitz, vseitz1@tigers.lsu.edu
   b. Dr. Craig Harvey, Harvey@lsu.edu
4. Purpose of Study: The purpose of this research project is to determine whether there is an
   association between the amount of sleep obtained by a participant as recorded on the
   Basis Band Activity Monitor and performance on a vigilance test.
5. Subject Inclusion: Individuals between the ages of 18 and 65 who do not report psychological
   or neurological conditions
6. Number of subjects: 30
7. Study Procedures: This study will consist of four components. Participants will be required to
   (1) wear a Basis Band Activity Monitor beginning on Monday and concluding on
   Thursday. During this same time, they will be asked to (2) keep a sleep diary recording
   their total sleep time, number of awakenings, and sleep efficiency. On Tuesday, 
   Wednesday, and Thursday morning, participants will be asked to (3) report to the lab
   within one to three hours of waking up in order to take a ten minute psychomotor
   vigilance task test before which they will complete (4) a subjective visual analog scale
   rating of their subjective feeling of fatigue.
8. Benefits: This study may yield valuable information concerning the potential to use of
   inexpensive activity monitors to self-monitor sleep and reduce accidents related to
   fatigue
9. Risks: The only study risk is the inadvertent release of sleep data and vigilance testing results.
   However, every effort will be made to maintain the confidentiality of your study
   records. File will be kept in a secure cabinet to which only the investigator has access.
10. Right to Refuse: Subjects may choose not to participate or to withdraw from the study at any
    time without penalty or loss of any benefit to which they might otherwise be entitled.
11. Privacy: Results of the study may be published, but no names or identifying information will be
    included in the publication. Subject identity will remain confidential unless disclosure is
    required by law.
12. Signatures: The study has been discussed with me and all my questions have been answered. I may direct additional questions
    regarding study specifics to the investigators. If I have questions about subjects’ rights or other concerns, I can
    contact Robert C. Matthews, Institutional Review Board, (225) 578-8692, irb@lsu.edu, www.lsu.edu/irb. I agree to
    participate in the study described above and acknowledge the investigator’s obligation to provide me with a signed
    copy of this consent form.

Subject Signature: _____________________________ Date: __________________
7.2 Preliminary Questionnaire

http://www.123contactform.com/form-891901/Preliminary-Questionnaire

Name *

How old are you? *
- Under 18
- 18-24
- 25-34
- 35-44
- 45-54
- 55-64
- 65 or over

Gender *
- Male
- Female

What is your current field of study? *
- Engineering
- Other

What is your current status? *
- Freshman
- Sophomore
- Junior
- Senior
- Graduate Student

Do you have a job? *
- Full time = 20+ hrs/wk; Part time = <20 hrs/wk; Night Shift = Beginning after 5 PM and Ending by 5 AM; Day Shift = Beginning by 5 AM and Ending by 7 PM
- Yes, Full Time, Day shifts only
- Yes, Full Time, Night shifts only
- Yes, Full Time, Day and Night shifts
- Yes, Part Time, Day shifts only
- Yes, Part Time, Night shifts only
- Yes, Part Time, Day and Night shifts
- No, I do not have a job

Do you have a diagnosed sleep disorder? *
- Yes, I take medication to treat it
- Yes, I do not take medication to treat it
- No, I do not have a diagnosed sleep disorder
How many naps do you take on a typical week day? *

- 0
- 1
- 2
- 3
- More than 3

If you take naps, how long does each one typically last? *

- I do not take naps during the week
- 0 to 30 minutes
- 30 minutes to 1 hour
- 1 hour to 2 hours
- More than 2 hours
7.3 Sleepiness Scale Questionnaire

http://www.123contactform.com/form-900776/Stanford-Sleepiness-Scale

Using the Stanford Sleepiness Scale, how did you feel when you woke up this morning? *

- 1 – Feeling active and vital; alert; wide awake
- 2 – Functioning at a high level, but not at peak; able to concentrate
- 3 – Relaxed; awake, not at full alertness; responsive
- 4 – A little foggy; not at peak; let down
- 5 – Fogginess; beginning to lose interest in remaining awake; slowed down
- 6 – Sleepiness; prefer to be lying down; fighting sleep; woozy
- 7 – Almost in a reverie; sleep onset soon; lost struggle to remain awake.
7.4 Exit Questionnaire

http://www.123contactform.com/form-891930/Exit-Questionnaire

**Name** *

---

**How much do you agree with the following statements?**

<table>
<thead>
<tr>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
</table>

Wearing the Basis Band motivated me to get more sleep each night. *

I felt that wearing the Basis Band was inconvenient and disrupted my daily activities. *

I would wear a sleep/activity monitor, such as the Basis Band, in my daily life. *

I would wear a sleep/activity monitor, such as the Basis Band, if there was an incentive from my employer. *

Employers should be allowed to require employees to take a vigilance test, such as the PVT, prior to beginning a shift. *

Employers should not have access to my sleep data. *
7.5 **Consensus Sleep Diary**

Instructions from Carney et al. (2012)

**General Instructions**

What is a Sleep Diary? A sleep diary is designed to gather information about your daily sleep pattern.

How often and when do I fill out the sleep diary? It is necessary for you to complete your sleep diary every day. If possible, the sleep diary should be completed within one hour of getting out of bed in the morning.

What should I do if I miss a day? If you forget to fill in the diary or are unable to finish it, leave the diary blank for that day.

What if something unusual affects my sleep or how I feel in the daytime? If your sleep or daytime functioning is affected by some unusual event (such as an illness, or an emergency) you may make brief notes on your diary.

What do the words “bed” and “day” mean on the diary? This diary can be used for people who are awake or asleep at unusual times. In the sleep diary, the word “day” is the time when you choose or are required to be awake. The term “bed” means the place where you usually sleep.

Will answering these questions about my sleep keep me awake? This is not usually a problem. You should not worry about giving exact times, and you should not watch the clock. Just give your best estimate.

**Item Instructions**

Use the guide below to clarify what is being asked for each item of the Sleep Diary.

**Date**: Write the date of the morning you are filling out the diary.

1. **What time did you get into bed?** Write the time that you got into bed. This may not be the time that you began “trying” to fall asleep.

2. **What time did you try to go to sleep?** Record the time that you began “trying” to fall asleep.

3. **How long did it take you to fall asleep?** Beginning at the time you wrote in question 2, how long did it take you to fall asleep.

4. **How many times did you wake up, not counting your final awakening?** How many times did you wake up between the time you first fell asleep and your final awakening?

5. **In total, how long did these awakenings last?** What was the total time you were awake between the time you first fell asleep and your final awakening. For example, if you woke 3 times for 20 minutes, 35 minutes, and 15 minutes, add them all up (20+35+15= 70 min or 1 hr and 10 min).

6. **What time was your final awakening?** Record the last time you woke up in the morning.

7. **What time did you get out of bed for the day?** What time did you get out of bed with no further attempt at sleeping? This may be different from your final awakening time (e.g., you may have woken up at 6:35 a.m. but did not get out of bed to start your day until 7:20 a.m.)

8. **How would you rate the quality of your sleep?** “Sleep Quality” is your sense of whether your sleep was good or poor.

9. **Comments:** If you have anything that you would like to say that is relevant to your sleep feel free to write it here.

*Figure 1—Sleep Diary Instructions: Core*
Name *

1. What time did you get into bed? *

2. What time did you try to go to sleep? *

3. How long did it take you to fall asleep? *

4. How many times did you wake up, not counting your final awakening? *

5. In total, how long did these awakenings last? *

6. What time was your final awakening? *

7. What time did you get out of bed for the day? *

8. How would you rate your quality of sleep?  
   - Very Poor  
   - Poor  
   - Fair  
   - Good  
   - Very Good

9. Comments (if applicable)
Application for Exemption from Institutional Oversight

Applicant, please fill out the application in its entirety and include the completed application as well as parts A.1, A.2, and B.1 below, which outlining the IRB. Once the application is completed, please return the completed application to the Institutional Review Board (IRB) office or to a member of the Human Subjects Screening Committee. Members of this committee can be found at https://hsbc.lsu.edu.

A. Complete application includes all of the following:
(A) A copy of this completed form and a copy of part A.1 below.
(B) A copy of the research proposal (submittable by telephone or mailed to the Review Board) and all research materials.
(C) Documentation of all recruitment and consent procedures.

B. The purpose of the study outlined below was: to study [insert purpose of study].

C. Study Subjects: [insert details about study subjects].

D. Budget: [insert budget details].

E. IRB Approval:

F. Exemption:

G. Exemption Expires: [insert expiration date].

H. Signature:

I. Date:

J. Signature:

K. Date:

L. IRB Approval:

M. Exemption:

N. Exemption Expires: [insert expiration date].

O. Signature:

P. Date:

Q. Signature:

R. Date:

S. Signature:

T. Date:

U. Signature:

V. Date:

W. Signature:

X. Date:

Y. Signature:

Z. Date:

LSU

Institutional Review Board

Dr. Robert C. Mathews, Chair

130 David Boyd Hall

P. 225-578-8692

F. 225-578-5835

Email: hsb@lsu.edu

Human Subjects Committee:

Date: [insert date]

Exemption Expires: [insert expiration date]
Consent Form for Non-clinical Study

1. Study Title: Using sleep tracking activity monitors to mitigate risk of fatigue

2. Performance Site: Louisiana State University

3. Investigators: The following investigators are available for questions about this study,
   a. Vanessa Seitz, vseitz1@tigers.lsu.edu
   b. Dr. Craig Harvey, harvey@lsu.edu

4. Purpose of Study: The purpose of this research project is to determine whether there is an
   association between the amount of sleep obtained by a participant as recorded on the
   Basis Band Activity Monitor and performance on a vigilance test.

5. Subject Inclusion: Individuals between the ages of 18 and 85 who do not report psychological
   or neurological conditions

6. Number of Subjects: 30

7. Study Procedures: This study will consist of four components. Participants will be required to
   (1) wear a Basis Band Activity Monitor beginning on Monday and concluding on
   Thursday. During this same time, they will be asked to (2) keep a sleep diary recording their
   total sleep time, number of awakenings, and sleep efficiency. On Tuesday, Wednesday, and Thursday morning, participants will be asked to (3) report to the lab
   within one to three hours of waking up in order to take a ten minute psychomotor
   vigilance task test before which they will complete (4) a subjective visual analog scale
   rating of their subjective feeling of fatigue.

8. Benefits: This study may yield valuable information concerning the potential to use of
   inexpensive activity monitors to self-monitor sleep and reduce accidents related to fatigue

9. Risks: The only study risk is the inadvertent release of sleep data and vigilance testing results.
   However, every effort will be made to maintain the confidentiality of your study
   records. Files will be kept in a secure cabinet to which only the investigator has access.

10. Right to Refuse: Subjects may choose not to participate or to withdraw from the study at any
    time without penalty or loss of any benefit to which they might otherwise be entitled.

11. Privacy: Results of the study may be published, but no names or identifying information will be
    included in the publication. Subject identity will remain confidential unless disclosure is
    required by law.

12. Signatures:

The study has been discussed with me and all my questions have been answered. I may direct additional questions
regarding study specifics to the investigators. If I have questions about subjects’ rights or other concerns, I can
contact Robert C. Matthews, Institutional Review Board, (225) 578-8692, irb@lsu.edu, www.lsu.edu/irb. I agree to
participate in the study described above and acknowledge the investigator’s obligation to provide me with a signed
copy of this consent form.

Subject Signature: __________________________ Date: _______________

STUDY EXEMPTED BY:
Dr. Robert C. Matthews, Chairman
Institutional Review Board
Louisiana State University
130 David Boyd Hall
225-578-8692, www.lsu.edu/irb
Exemption Expires: 3/17/2017
VITA

Vanessa Bégat Seitz was born in Beauvais, France in 1987. She received her bachelor’s degree with honors in Industrial and Systems Engineering at the University of Florida in May 2009. She started her work towards the master’s degree in Industrial Engineering in January 2012 after working in the valve industry for Cameron International. She also worked as a graduate research assistant during her time as a master’s student in the Department of Mechanical and Industrial Engineering.
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