Transportation Safety Board of Canada

Bureau de la sécurité des transports du Canada

GUIDE TO INVESTIGATING SLEEP-RELATED FATIGUE

2014

Transportation Safety Board of Canada
Bureau de la sécurité des transports du Canada

About This Guide

Purpose

This Guide to Investigating Human Fatigue was designed to complement the Transportation Safety Board (TSB) of Canada's training course on investigating human fatigue and to act as an internal reference document for well-trained TSB investigators. All investigators should complete the TSB Human Factors training as well as the TSB investigation methodology training prior to investigating human fatigue. Alternatively, TSB investigators may wish to seek support from a professional appropriately trained in accident investigation and human fatigue.

The construct of fatigue discussed in in this guide is considered synonymous with sleepiness. This guide is only concerned with sleep-related fatigue.

This guide provides an introduction to the scientific perspective of sleep and sleep-related fatigue, and is supported by footnoted references to peer reviewed research literature. The guide introduces and reviews risk factors that can lead to sleep-related fatigue and discusses the impact of fatigue on human performance.

Fatigue is pervasive in today's society, especially in the transportation industry. The U.S. National Sleep Foundation (NSF), a world leading sleep advocacy organization, says that, although adults need between seven and nine hours of sleep per night[1], many transportation workers report not

[1] Retrieved March 6, 2013, from http://www.sleepfoundation.org/article/how-sleep-works/how-much-sleep-do-we-really-need .

getting enough sleep because of their work schedules[2] (e.g., they may work too many hours or their irregular work hours coincide with normal sleep times) . In 2012, the NSF's annual poll found that, compared to non-transportation workers, train operators and pilots are the most likely to report sleep related job performance problems. An NSF article about the poll stated:

> "The results of the poll are striking. About one-fourth of train operators (26%) and pilots (23%) admit that sleepiness has affected their job performance at least once a week, compared to about one in six non-transportation workers (17%).
>
> Perhaps more disturbingly, a significant number say that sleepiness has caused safety problems on the job. One in five pilots (20%) admit that they have made a serious error and one in six train operators (18%) and truck drivers (14%) say that they have had a "near miss" due to sleepiness."[3]

Due to the pervasiveness of fatigue in transportation and the negative impact it has on human performance, accident investigators should consider whether fatigue played a role in virtually all investigations. A three step method for investigating fatigue is outlined in this guide. The first two steps involve first identifying whether fatigue was present (and if a finding as to risk can be documented) and secondly, whether fatigue played a role in an accident or incident (and if a finding as to cause can be documented). The third step involves examining the factors contributing to the

---

[2] Retrieved March 6, 2013 from http://www.sleepfoundation.org//article/press-release/sleepy-pilots-train-operators-and-drivers .
[3] Retrieved March 6, 2013 from http://www.sleepfoundation.org//article/press-release/sleepy-pilots-train-operators-and-drivers .

level of fatigue observed and whether the organization has the means in place to effectively manage the risks associated with sleep-related fatigue.

The TSB Human Factors Team can provide up to date fatigue research findings as well as ensure that your analysis of the role of fatigue is sound.

Scientific References

The literature cited in this guide is provided as examples of current findings. It does not represent an exhaustive review of the state of the science on human fatigue. TSB investigators should review the original sources cited within this guide and must evaluate the applicability of the findings to their investigations. This guide has not been reviewed by current scientific authorities on human fatigue and should, therefore, not be cited as a reference. Instead, the original sources should be cited in TSB reports.

Human Factors Team Assistance

The TSB Human Factors team can provide assistance to TSB modal investigators when investigating for human fatigue. Furthermore, the team may be able to provide more applicable examples of scientific literature and analytical reviews of the outcomes of previous human fatigue investigations. Contact the Manager, Human Factors and Macro Analysis for support.

What is fatigue?

The word “fatigue” is used to describe variety of phenomena. In the physical engineering sciences, the word “fatigue” can be used to describe the weakening of metal due to repeated use or bending. Fatigue can also be used to describe a human psychological state (i.e., mental fatigue) resulting from spending extended or intense periods of time on a task; for example, studying for an exam. Fatigue can also be used to describe a physical state resulting from body movements like exercise (e.g., physical fatigue). It can also be used to describe an overall psychological and physical condition of lethargy that can result from a number of illnesses such as depression or the common cold (e.g., lethargic fatigue).

Mental fatigue, physical fatigue, lethargic fatigue and sleep-related fatigue are very different human states.

These types of fatigue[4] are often confused with sleep-related fatigue. Although people experiencing mental, physical or lethargic fatigue may feel tired, they do not necessarily fall asleep more quickly than a normally rested person, that is, they are not necessarily 'sleepy'. This subtle, yet critical, distinction is used by health professionals and researchers to distinguish the type of fatigue with which they are concerned. For example, health professionals will often determine which type of fatigue a person is experiencing to clarify their diagnosis and decide on appropriate treatment. This can be the case with people suffering from depression who will often report feeling overwhelmingly fatigued. However, when they are assessed in a sleep clinic, they may not fall asleep more quickly than a normal healthy person. That is, they are not sleepy and are not experiencing sleep-related fatigue. Researchers also distinguish between the various types of fatigue to ensure that findings can be applied to subsequent research or to real life situations. For example, researchers studying the effects of extended periods of concentration on performance outcomes will indicate that they are working in the area of mental fatigue and that their findings may not be generalizable to, for

[4] These are only a few examples of the use of the word "fatigue". Other human fatigue types can usually be subcategorized under mental, physical or lethargic. For example olfactory receptor fatigue, the temporary inability to distinguish a specific smell after prolonged exposure to that smell, is a form of physical (i.e., biological) fatigue, and task fatigue, the point of diminishing returns where the effort exerted to stay on task is greater than the effort into moving forward on the task, is a form of mental fatigue.

example, sleep-related fatigue. In this context, the difference is important because, although concentrating for long periods of time may result in mental fatigue that may lead to performance impairments such as reduced attention switching abilities, it does not make one sleepy (i.e., it does not increase sleep-related fatigue) and one would not want to conclude that an activity such as studying may increase the risk of falling asleep.

This guide is only concerned with sleep-related fatigue.

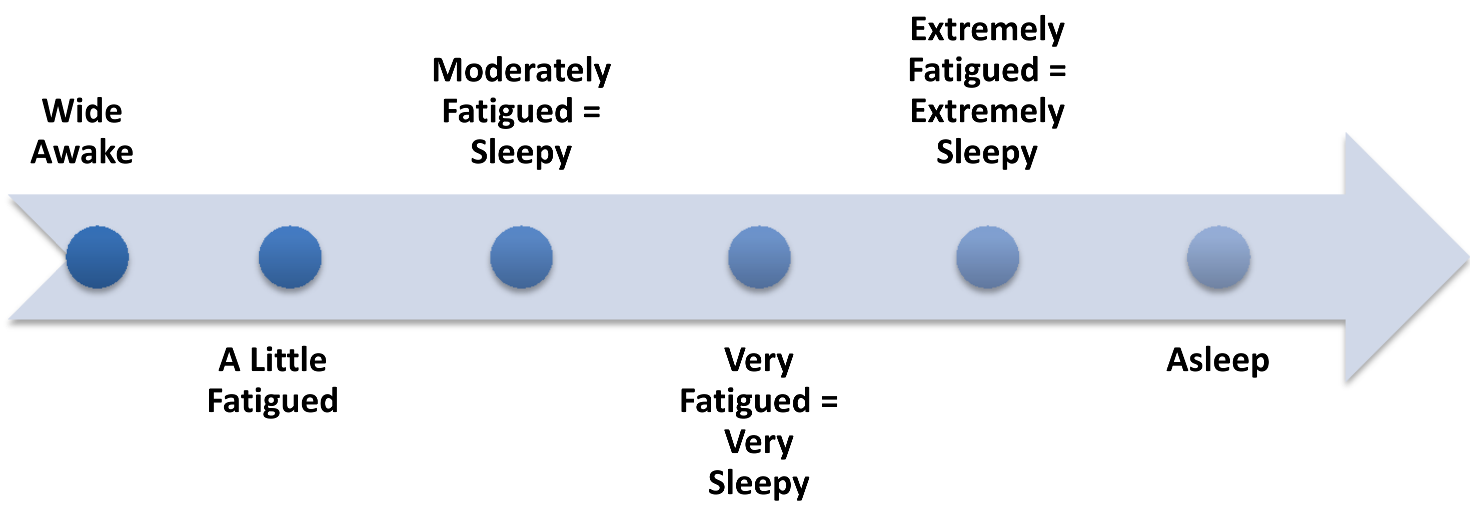
Although all types of human fatigue may contribute to performance impairments, this guide is only concerned with sleep-related fatigue. The word "fatigue" will be used throughout this guide to mean sleep-related fatigue (i.e., fatigue is synonymous with sleepiness). This type of fatigue can be conceptualized as a continuum between being asleep and being fully awake. At the extreme fatigue end (often referred to clinically as pathologically sleepy), a person would have difficulty maintaining wakefulness and, without being kept active and aroused, would readily fall into sleep within five minutes[5]. At the opposite end of the continuum, a person would be wide awake and would find it difficult to fall asleep within ten minutes[6].

---

[5] This level of fatigue is referred to as pathological sleepiness in the clinical sleep medicine literature. See for example: Carskadon, M., Dement, W., Mitler, M., Roth, T., Westbrook, P., & Keenan, S. (1986). Guidelines for the multiple sleep latency test (MSLT): A standard measure of sleepiness. Sleep, 9(4), 519-524.

[6] See for example: Carskadon, M., Dement, W., Mitler, M., Roth, T., Westbrook, P., & Keenan, S. (1986). Guidelines for the multiple sleep latency test (MSLT): A standard measure of sleepiness. Sleep, 9(4), 519-524.

Figure 1: Fatigue Continuum



Fatigue is intimately linked to sleep, as will be demonstrated in the section on fatigue risk factors. Sleep is a fundamental biological need that must be satisfied. Fatigue is a biological symptom of the unsatisfied biological sleep need. The biological nature of sleep and fatigue means that the state of fatigue cannot be prevented by characteristics of personality, intelligence, education, training, skill, compensation, motivation, physical size, strength or practice. All humans, even those who have worked irregular hours or shift-work for many years are susceptible to fatigue and its associated performance decrements.

Why Investigate Fatigue?

Some of the most highly respected sleep researchers[7] have suggested that fatigue may have played a contributory role in many of the world's worst disasters. A few examples of these historic disasters are:

---

[7] For example:
(A) Anch, A., Browman, C., Mitler, M., & Walsh, J. (1988). Sleep: A Scientific Perspective. New Jersey: Prentice-Hall

- United Airlines flight 2860 crash, 01:38 hrs, December 18, 1977; fatigue likely resulted from the air traffic controller sleeping very little and the pilots' frequently changing sleep-wake patterns
- Three Mile Island nuclear plant partial meltdown, 04:00 hrs, March 28, 1979; fatigue likely resulted from poorly managed sleep-wake patterns
- Bhopal gas leak, 12:30 hrs, December 2, 1984; faulty decision making of a sleep deprived supervisor and shift workers was implicated in this accident
- Space Shuttle Challenger explosion, 11:38 hrs, January 28, 1986; two of the top three managers who were involve with authorizing the launch had less than three hours of sleep for the three consecutive nights before the accident
- Chernobyl nuclear plant meltdown, 01:23 hrs, April 26, 1986; faulty decision making of sleep deprived shift workers was implicated in this accident
- Exxon Valdez oil spill, 12:04 hrs, March 24, 1989; the third mate who plotted the course and was piloting the vessel may have been awake for 18 hours preceding the accident
- Gaisal train crash, 01:30, August 2, 1999; fatigue due to the time of night was implicated in a switching error that led to this accident

In addition, there may have been many significant near miss incidents where fatigue played a contributory role, but due to the media's focus on newsworthy accidents, the general public were not made aware of the incidents.

(B) Folkard, S. (2000). Transport: Rhythm and blues. The 10th Westminster Lecture.   Parliamentary Advisory Council for Transport Safety: London. Retrieved January 18, 2013, from http://www.hf.faa.gov/docs/508/docs/folkard15.pdf.

(C) Maas, J. (1998). Power Sleep. New York: Villard Book, Random House, Inc.

(D) Shapiro, C., Heslegrave, R., Beyers, J., & Picard, L. (1997). Working the shift: A self-health guide for shiftworkers and their families. Toronto: Joli Joco Publications.

The TSB has also recognized that fatigue poses a risk to transportation safety and has conducted investigations into occurrences where fatigue was a concern. For example:

- Railway Investigation Report R09W0259, North Portal, Saskatchewan, 02:23 hrs, 19 December 2009; this investigation concluded that unpredictable work schedules can increase the risk of fatigue
- Aviation Investigation report A11F0012, North Atlantic Ocean, 01:54 hrs, 14 January 2011; among the many fatigue related findings in this investigation was that the pilot was fatigued due to interrupted sleep the night before the incident
- Marine Investigation Report, M04L0099, Saint-Nicolas, Quebec, 05:54 hrs, 11 August 2004; the pleasure craft crew fell asleep while on duty at the helm

The ultimate goal is to identify the causal and contributing factors that led to the fatigue.

There is enough scientific evidence to support the statement that fatigue results in human performance impairments that can lead to accidents. Fatigue is also manageable. If fatigue is manageable and accidents, whether near misses or major catastrophic accidents, related to fatigue continue to occur, it becomes important to determine why. One of the goals of all accident investigations is to determine the causal and contributing factors that may have led to the accident. If fatigue played a role in an occurrence, the goal would then be to investigate further to identify the causal and contributing factors that led to the fatigue. For example, investigating organizational and management factors may be required. Many organizations continue to function without Fatigue Risk

Management Systems (FRMS)[8]. FRMS is a current organizational and management factor in reducing the risk of fatigue[9]. The absence of FRMS can allow risky rosters that support operation needs without supporting biological sleep needs to continue. This can lead to irregular shifts that may make it very difficult for operators to obtain enough good quality sleep and this can result in fatigue and performance impairments. Recommendations could then be aimed at reducing the likelihood that the same or similar factors (e.g., no FRMS in place) will result in another fatigue related accident.

Stages one and two sleep are light sleep. Stages three and four are deep sleep. REM sleep is dream sleep.

The Basics of Sleep

Fatigue is intrinsically linked to sleep. To understand fatigue therefore, an investigator needs to have an understanding of sleep and its requirements. Adult, human sleep is divided into five different stages --stages one through four and a stage called rapid-eye-movement (REM) sleep. All five stages of sleep display different patterns of brainwaves, eye movements and muscle tone that can be recorded using a polysomnograph and displayed on a computer screen.

Stages one through four are referred to as non-REM sleep and are further subdivided into light and deep sleep. Stage one is the lightest stage of sleep. The first episode of stage one sleep normally lasts between 30 seconds and 10 minutes. In this stage people will often report feeling like they are still

---

[8] For more information on Fatigue Risk Management Systems (FRMS) consult Transport Canada's Fatigue Risk Management System for Canadian Aviation - FRMS Toolbox: http://www.tc.gc.ca/eng/civilaviation/standards/sms-frms-menu-634.htm

[9] For more general information on fatigue risk management in the workplace see: Lerman, S., Eskin, E., Flower, D., George, E., Gerson, B., Hartenbaum, N., Hursh, S., and Moore-Ede, M. (2012). Fatigue risk management in the workplace. Journal of Environmental Medicine, 54(2), 231-258.

awake; thus, the categorization as light sleep. Following stage one sleep, people enter stage two sleep. After experiencing about five to ten minutes of stage two sleep, people will usually report having felt like they were asleep. The first episode of stage two normally lasts for 20 to 35 minutes. Stages three and four are the deepest stages of sleep and are referred to collectively as synchronized sleep, slow-wave sleep (SWS), delta sleep, or deep sleep. The first episode of deep sleep in a normal night of sleep usually occurs about 30 to 45 minutes after sleep onset. People usually experience deep sleep as being asleep (thus the categorization as deep sleep), but have difficulty distinguishing between the experiences of stage two, three or four sleep. The first episode of deep sleep can last as long as one hour. Following deep sleep, there is a return to stage two, which is followed by the first rapid eye movement, or 'REM', period of the night. REM sleep is when dreams most often occur. If a person can remember a dream, they can normally recognize that they have experienced REM sleep. If dream recall is not possible, then it becomes difficult to distinguish between stage 2, 3, 4 and REM sleep. The first REM period is normally very short in duration, lasting only a few minutes[10].

90 minute sleep cycles repeat many times across one sleep period.

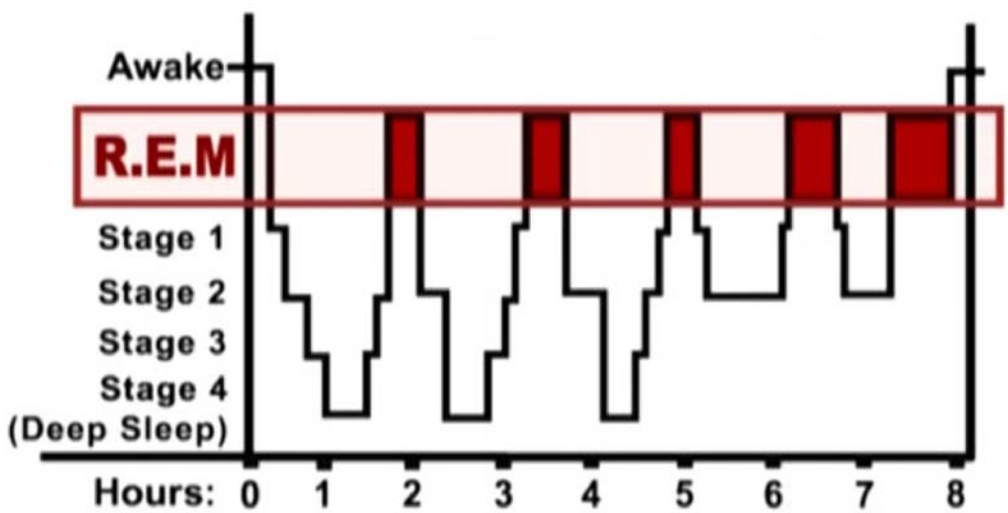
Stage one sleep makes up 5-10% of an entire night of sleep (referred to as a sleep period), stage two 40-50%, stages three and four 10-20%, and REM sleep comprises 15-20% of one sleep period[11].

[10] For an in depth understanding of the distribution of the stages of sleep refer to: Anch, A. M., Browman, C. P., Mitler, M. M., & Walsh, J. K. (1988). Sleep: A Scientific Perspective. New Jersey: Prentice-Hall.
[11] Roffwarg, H., Muzio, J., & Dement, W. (1966). Ontogenetic development of the human sleep-dream cycle. Science, 152, 604-619.

One sleep period is made up of four to six repeating cycles of approximately 90 minutes. One sleep cycle of normal human sleep proceeds, albeit in a 'textbook' fashion, from stage one, to stage two, to stage three, to stage four and then back to stage three, and then to stage two followed by REM sleep.

For a normal night-time sleeper, deep sleep (stages three and four) make up most of the earlier sleep cycles while REM makes up most of the later sleep cycles[12]. The following figure is a graph of the sleep stages experienced during one prototypical night of sleep. This type of graph is known as a hypnogram. Note how more stage three and four sleep (deep sleep) occurred between 00:00 and 05:00 and more REM sleep between 05:00 and 08:00.

Figure 2: One prototypical night of sleep displayed in a hypnogram[13].



[12] For a discussion of the differences in sleep stages across one night of sleep refer to:
(A) Anch, A. M., Browman, C. P., Mitler, M. M., & Walsh, J. K. (1988). Sleep: A Scientific Perspective. New Jersey: Prentice-Hall.
(B) Maas, J. (1998). Power Sleep. New York: Villard Book, Random House, Inc.

[13] Image courtesy of Share Your Graph (YGraph.com) and Luciddreamexplorers.

Selectively depriving individuals of specific stages of sleep is argued to result in specific symptoms. Research indicates that deep sleep may serve a physiologically restorative function[14] and that REM sleep may serve as a mentally restorative phase[15]. For example, if a pilot has to wake up earlier than normal to start a duty day, REM sleep may be curtailed (recall that most REM sleep occurs at the end of the night sleep period) and this may result in cognitive performance decrements. Alternatively, if a ship's master is repeatedly awakened during the first half of the sleep period to aid bridge decision making, the master's deep sleep may be curtailed (recall that most deep sleep occurs at the beginning of the night sleep period). This may result in the master suffering more physiological symptoms, such as colds or flus, due to impaired immune system function (this is a very specific example and these outcomes could be due to many other causes). Investigators should take these symptoms into account in the analysis of performance impairments.

[14] Deep sleep may support physiological restoration, growth and immune system functioning. See for examples:

(A) (A) Krueger, J. M., & Majde, J. A. (1990). Sleep as a host defence: Its regulation by microbial products and cytokines. Clinical Immunology and Immunopathology, 57(2), 188-199.
(B) (B) Shapiro, C., Mitchell, D., Bartel, P., Jooste, P. (1981). Slow wave sleep: A recovery period after exercise. Science, 214, 1253-1254.
(C) (C) Vein, A. M. (1991). Physical exercise and nocturnal sleep in healthy humans. Human Physiology, 17, 391-397.

[15] REM sleep may support mood regulation, memory consolidation and learning. See for examples:

(D) Dujardins, K., Guerrien, A., & Leconte, P. (1990). Sleep, brain activation, and cognition. Physiology and Behavior, 47, 1271-1278.
(E) Fisher, C., & Dement, W. C. (1963). Studies on the psychopathology of sleep and dreams. American Journal of Psychiatry, 119, 1160-1168.
(F) Mandai, O., Guerrien, A., Sockeel, P., Dujardin, K., Leconte, P. (1989). REM sleep modification following a morse code learning session in humans. Physiology and Behavior, 46, 639-642.
(G) Smith, C., & Lapp, L. (1991). Increases in number of REMs and REM density in humans following an intensive learning period. Sleep, 14, 325-330.

Transportation Safety Board of Canada
Bureau de la sécurité des transports du Canada

The function of each stage of sleep continues to be researched. The debate over the most important stage of sleep is unresolved[16], although current thinking proposes that deep sleep is necessary to reduce the risk of fatigue and maintain physiological functioning while REM sleep is necessary for maintaining cognitive functioning as well as reducing the risk of fatigue.

Frequent awakenings such as those discussed in the above example of the ship's master, not only limit the total amount of sleep, but they may also disrupt the quality of sleep. After each awakening, the sleep cycle normally restarts. It does not resume where it was interrupted. Sleep that does not follow the natural uninterrupted progression through the five stages within repeated 90 minute cycles is described as having disrupted sleep architecture. This type of sleep is of poor quality and can result in fatigue during the waking hours.

Normal sleep occurs at night and is between 6 and 9 hours. The average daily quantity requirement is between 7 and 8 hours.

Disruptions to sleep quality can also occur without awakenings. Many sleep disorders (discussed in a later section) disrupt sleep quality by changing sleep architecture and mental stress can result in disrupted sleep quality by changing the electrical activity of the brain[17].

To reduce the risk of fatigue, good quality sleep must be obtained in sufficient quantity. The quantity of sleep required decreases as one becomes an adult. At birth, total daily sleep time can be as much as 18 hours, by two years of age total daily sleep time is about 12 hours, by four years of age it is

[16] Lubin, M., Moses, J., Naitoh, P. (1977). Hail sleep: Goodbye REM and slow wave sleep. Bulletin of the British Psychological Society, 30, 111-112.
[17] See for example: Hall, M., Buysse, D., Nowell, P., Nofzinger, E., Houck, P., Reynolds, C., & Kupfer, D. (2000). Symptoms of stress and depression as correlated od sleep in primary insomnia. Psychosomatic Medicine, 62, 227-230.

about ten hours, and by ten years of age a child sleeps about nine hours. During adolescence total sleep time drops abruptly to between seven and eight hours[18]. Therefore, depending upon where the adolescent is in their development, the quantity of sleep they may require can range between nine and seven hours.

Normal healthy adults need between six and nine hours of sleep each night to feel well-rested and to be able to maintain vigilance throughout the day, with the average being between seven and eight hours per night[19]. <u>Regularly</u> sleeping <u>less</u> than six, or <u>more</u> than nine, consecutive hours per sleep period is unusual[20] for normal healthy adults. Throughout evolution, normal human sleep has occurred at night with other activities of daily living occurring during the daylight hours.

Changing the normal 'textbook' human sleep pattern of seven to eight hours of regular nocturnal sleep increases the risk of fatigue. For example, most shift-workers who obtain very irregular sleep eventually become unable to sleep for more than five to seven consecutive hours per day[21]. This results in a pattern of chronic sleep deprivation[22] that leads to a higher risk of fatigue and subsequent performance decrements that can cause accidents.

---

[18] Anch, A., Browman, C., Mitler, M., & Walsh, J. (1988). Sleep: A Scientific Perspective. New Jersey: Prentice-Hall.
[19] Anch, A., Browman, C., Mitler, M., & Walsh, J. (1988). Sleep: A Scientific Perspective. New Jersey: Prentice-Hall.
[20] Anch, A., Browman, C., Mitler, M., & Walsh, J. (1988). Sleep: A Scientific Perspective. New Jersey: Prentice-Hall.
[21] Anch, A., Browman, C., Mitler, M., & Walsh, J. (1988). Sleep: A Scientific Perspective. New Jersey: Prentice-Hall.
[22] Tepas, D. I., & Mahan, R. P. (1989). The many meanings of sleep. Work and Stress, 3(1), 93-102.

Fatigue Risk Factors

Reducing total sleep time (acutely or chronically) is only one variable that can increase the risk of fatigue. The TSB investigates six risk factors that increase the risk of fatigue.

1. Acute Sleep Disruption
2. Chronic Sleep Disruption
3. Continuous Wakefulness
4. Circadian Rhythm Effects
5. Sleep Disorders
6. Medical and Psychological Conditions, Illnesses and Drugs

The TSB looks at 6 Fatigue Risk Factors when investigating fatigue.

Acute Sleep Disruption

As discussed above, there is a daily requirement for sleep. It must be good quality, that is, it must display normal sleep architecture without awakenings, and it must be of sufficient quantity, normally seven to eight hours. Acute sleep disruptions are reductions in the quality or quantity of sleep that have occurred within the prior three days.

Significant reductions in the quality or quantity of sleep can result in fatigue and performance decrements. Acute reductions in the quantity of sleep are normally considered remarkable when they are at least 30 minutes in duration. Reductions in the quality of sleep result from awakenings or other significant changes to the normal 'textbook' pattern of sleep due to such things as changes to the time the person goes to bed or wakes up, arousing sleep environments (e.g., noisy bunk rooms), food choices (e.g., caffeine, alcohol) or mental stress. Qualitative sleep reductions are normally considered remarkable when the amount of deep sleep is curtailed to less than the required 10 – 20% or REM sleep is curtailed to less than the required 15 – 20% but the total sleep time may remain unchanged[23].

Acute sleep quality reductions can be difficult to detect, but this does not mean that they do not exist. Although a person may report having slept for eight hours without awakening and may report that the sleep was good quality, this may not be the case. Caffeine, nicotine and alcohol for example, can acutely change a person's sleep architecture. If these substances are ingested, the person may still be able to sleep and may feel that the sleep was satisfactory, but it is entirely possible that they may not have obtained the proper amounts of each stage of sleep. Recall that people cannot normally distinguish stage two sleep from deep sleep, and often REM sleep, and that good quality sleep is comprised of 10-20% deep sleep and 15-20% REM sleep. Not obtaining an adequate amount of each stage of sleep can lead to fatigue or other specific impairments.

Acute sleep disruptions may occur only once in the preceding three days (e.g., a three hour awakening during one sleep period) or they may occur more frequently (e.g., three sleep periods each with a one hour awakening). They do not have to occur on each of the preceding three nights of sleep.

[23] Deep sleep and REM sleep are replaced by light sleep which does not provide adequate restoration to reduce the risk of fatigue.

For example, in the 2004 TSB investigation (A04H0001) into the loss of control of a Cessna Caravan[24] shortly after take-off from Pelee Island, Ontario, the pilot likely slept for only 5.25 hours before arriving at work at 04:45 hrs. This is considered an acute sleep disruption because it occurred within three days of the accident and the reduction in quantity of sleep (from normal) was greater than 30 minutes. The sleep period was likely 2.25 hours less than the pilot's normal 7.5 hour night of sleep and could have led to fatigue that may have degraded the pilot's decision making abilities.

Disruptions to sleep quantity and quality can lead to fatigue. These disruptions can be acute or chronic.

Chronic Sleep Disruption

In contrast to acute sleep disruption, sleep quantity or quality disruptions that are sustained for periods longer than three consecutive days are considered chronic sleep disruptions. These disruptions may also be less remarkable than acute sleep disruptions. For example, as little as 15 minutes less sleep for a number of consecutive nights (disruption to sleep quantity) can increase the risk of fatigue. Successive episodes of sleep loss can accumulate and result in what is commonly called a "sleep debt".

[24] Aviation Investigation Report, A04H0001, Loss of Control, Georgian Express Ltd., Cessna 208B Caravan, C-FAGA, Pelee Island, Ontario, 17 January 2004.

Comparing the amount of sleep obtained to the amount of sleep required for a given period of wakefulness can provide an estimate of a person's sleep debt. For example, in the 2010 TSB investigation (A10O0089) into the risk of collision of two aircraft[25], the air traffic controller had been sleeping for about six hours a night for the last five months. If the air traffic controller normally required eight hours of sleep per night, it would leave 16 hours of wakefulness per 24 hours. This translates into a ratio of eight hours of sleep for every 16 hours of wakefulness, a ratio of 1:2. Across seven days, the air traffic controller would have slept for 42 hours and would have been awake for 126 hours[26]. Applying the 1:2 ratio (1 / 2 = 0.50)[27], 126 hours of wakefulness requires 63 hours of sleep (126 x 0.50 = 63). Given that the air traffic controller only obtained 42 of the requisite 63 hours of sleep, a sleep debt of 21 hours would have accumulated. This is the equivalent of missing almost three nights of sleep.

Sleep Debt is a useful estimate of whether a person has obtained enough sleep for a specific amount of wakefulness.

The estimate of a sleep debt is based on the notion that a certain amount of sleep is required for a certain amount of wakefulness, as opposed to a certain amount of sleep being required every day. This approach does not perfectly reflect the human sleep pattern. For example it implies that a person could theoretically sleep for 24 consecutive hours and then be awake for 48 hours without

[25] Aviation Investigation Report, A10O0089, Risk of Collision, Nav Canada – Toronto Area Control Centre, Toronto/Billy Bishop Toronto City Airport, Toronto, Ontario, 11 May 2010.

[26] 7 days x 24 hours – 42 hours of sleep = 126 hours of wakefulness

[27] Applying the ratio, as opposed to simply comparing the sleep obtained (42 hours) to the sleep required across the number of days (e.g., 7 days x 8 hours = 56 hours), incorporates the increased hours of wakefulness that accumulate with the decrease in sleep obtained. That is, for every hour of sleep lost, one hour of wakefulness accumulates.

requiring additional sleep. It does, however, provide a useful estimate of whether a person has obtained enough sleep for a specific amount of wakefulness.

The formula for calculating a sleep debt is:

Sleep Debt = Total Sleep Time – Total Awake Time x Ratio of Sleep to Wakefulness[28]

From the above example, the formula would be:
21 Hour Sleep Debt = 42 Hours of Sleep – 126 Hours of Wakefulness x 0.50
-21 = 42 - 63

The formula is based on the notion that the restorative powers of sleep are used up by wakefulness. To properly use this formula, the calculations of total sleep and wakefulness times should begin with a period of sleep. For example, if the available data suggest that a person was awake for 16 hours, slept for 10 hours, was awake for 18 hours, slept for 8 hours and had an accident after being awake for 19 hours, the calculation of total sleep time would begin with the 10 hour sleep period and the calculation of the total wake time would being with the 18 hour wake period. For this example, a total sleep time of 18 hours and a total wake time of 37 hours would be used in the sleep debt formula. If the person required 9 hours of sleep per night, the sleep to wake ratio would be 9:15 (sleep : wakefulness in 24 hours) or 0.6. The sleep debt would then be calculated as follows.

[28] Note that a negative result indicates a sleep debt and a positive result indicates no sleep debt.

Sleep Debt = Total Sleep Time – Total Awake Time x Ratio of Sleep to Wakefulness

18 – 37 x 0.6 = - 4.2

= 4.2 hour sleep debt at the time of the accident

In addition to the smaller reductions in sleep quantity that accumulate to create a sleep debt, chronic sleep disruption can result from reductions in sleep quality that are sustained for periods of longer than three days. For example, mariners are often required to be at sea for months at a time, often sharing quarters with crewmates. On some vessels, the crew quarters are not well designed for sleep. Noise from crewmates, vessel engines and rough seas can disrupt sleep quality without a person being aware of the change. Although the disruptions may be small, they can change sleep architecture (e.g., reduce the amount of deep sleep or REM sleep without reducing total sleep time) and, if they occur chronically, they can result in fatigue or other specific impairments. As with acute disruptions to sleep quality, chronic disruptions to sleep quality can also be difficult to detect because people cannot easily tell if they have experienced deep sleep, REM sleep or stage two sleep and may, therefore, be unable to notice and then describe changes to sleep quality when they are interviewed. In spite of the difficulty in detection, chronic disruptions to sleep quality may still exist.

Continuous Wakefulness

A third fatigue risk factor is being awake for too long, commonly referred to as prolonged wakefulness or continuous wakefulness. One often cited research finding is that 17 hours of wakefulness produces impairments in psychomotor functioning equivalent to a blood alcohol concentration (BAC) of 0.05%[29]. For comparison, this BAC can be attained in a 180lb man who

[29] The often cited finding is from: Dawson, D., & Reid, K. (1997). Fatigue, alcohol and performance impairment. Nature, 388, 235.

consumes four beers in three hours[30]. Although 17 hours may be used as a general guideline for the maximum tolerable period of wakefulness within which adequate performance may be maintained, it must be used cautiously. This research indicated that a very specific component of psychomotor functioning, namely hand-eye coordination, was degraded after 17 hours. The research did not show that all aspects of performance are degraded after this amount of wakefulness. Therefore, this finding cannot be used to support the increased likelihood of performance impairments other than hand-eye coordination after 17 hours of wakefulness. Furthermore, the research did not measure fatigue levels, which could have been done with a valid test such as the Karolinska Sleepiness Scale (KSS)[31]. It was only assumed that participants were fatigued at the 17 hour point.

22 hours of continuous wakefulness is the upper limit at which almost all aspects of performance decline due to fatigue.

Although 17 hours of continued wakefulness may not be considered the point at which fatigue causes almost all aspects of human performance to decline, 22 hours of continuous wakefulness can be used as such a threshold. Uncontrollable brief episodes of sleep, commonly known as “micro-sleeps” (short periods of sleep lasting 3 to 4 seconds) and “state instability” (because wakefulness cannot be maintained) in the fatigue research literature, begin to occur in most individuals after this amount of

---

[30] This estimate was obtained from http://www.healthstatus.com/calculate/bac.

[31] The Karolinska Sleepiness Scale is a valid measurement of sleepiness and is positively correlated with electroencephalographic indicators of sleepiness. See for example: Kaida, K., Takahashi, M., Åkerstedt, T., Nakata, A., Otsuka, Y., Haratani, T., & Fukawaka, K. (2006). Validation of the Karolinska sleepiness scale against performance and EEG variables. Clinical Neurophysiology, 117(7), 1574-1581.

wakefulness[32] providing that countermeasures such as strategic use of caffeine and alertness sustaining medications have not been ingested. Sleep can only occur when people are fatigued, and people obviously cannot function at a normal level of performance when they are asleep. Therefore, if micro-sleeps begin to occur at 22 hours of wakefulness, this is the upper limit at which almost all aspects of human performance decline due to fatigue.

One additional consideration with regards to the period of continuous wakefulness and its potential effects on performance is the time at which it occurs. Day hours are not biologically equivalent to night hours in terms of sleep. Many years of evolution have anchored human biology with sleep occurring during the night hours and wakefulness within the day hours. This means that the biological drive for sleep during the night hours is much stronger than during the day hours[33]. It also means that fatigue may result from fewer hours of continuous wakefulness if these hours occur at night rather than during the day, even for regular night workers.

An illustration of the influence of continuous wakefulness on fatigue is provided by the 2004 TSB investigation (M04L0099) into the marine collision of a pleasure craft and a container ship[34]. The four pleasure craft travelers prepared their sailboat on the morning of departure. This took between four and six hours. The plan was to travel continuously and for each traveler to request a break from helm duties whenever required. A little over eighteen hours into the voyage, two people were sleeping in

---

[32] Beaumont, M., Batejat, D., Pierard, C., Coste, O., Doireau, P., Van Beers, P., Chauffard, F., Chassard, D., Enslen, M., Denis, J., & Lagarde, D. (2001). Slow release caffeine and prolonged (64-h) continuous wakefulness: Effects on vigilance and cognitive performance. Journal of Sleep Research. 10(4), 265-276.

[33] Many studies have shown that sleepiness is most profound in the early morning hours. See for example Åkerstedt, T. & Gillberg, M. (1982). Experimentally displaced sleep: Effects on sleepiness. Electroencephalography and Clinical Neurophysiology, 54, 220-226.

[34] Marine Investigation Report, M04L0099, Collision, Between the Pleasure Craft Mondisy and the Container Ship Canada Senator, Off Saint-Nicolas, Quebec, 11 August 2004.

their bunks, one person was at the helm and the fourth person was sitting near the helm acting as a companion to the helmsman. Sometime after 04:00 hrs, the companion fell asleep and, although it could not be confirmed with absolute certainty, the person at the helm also succumbed to uncontrollable sleep. The boat circled in the channel until it was struck by the container ship. Two of the four people on board perished. With four hours of preparation time and 18 hours of travel time, the person at the helm would have been awake for 22 hours; the period of continuous wakefulness that research suggests can result in uncontrollable sleep onset.

Circadian Rhythm Effects

Circadian Rhythm Timing

There are numerous daily (circadian) biological rhythms in humans; some estimates are in the hundreds[35]. For example, core body temperature drops[36] during a 'circadian rhythm trough', or overall low period of human performance, that is between approximately 22:30 and 04:30 hrs[37]. There is also a slight and very brief post-lunch dip in core body temperature that occurs around 14:00 hrs[38].

Many biological rhythms follow a circadian pattern similar to the core body temperature rhythm. For example, basic functions such as digestion and heart rate decrease during the circadian trough. Overall performance and cognitive functioning are also at their worst during the circadian rhythm

[35] Aschoff, J. (Ed.). (1981). Biological Rhythms. New York: Plenum Press.
[36] Note that core body temperature fluctuates within a narrow range of about one degree Celsius.
[37] Core body temperature trough generally occurs between 22:30 and 04:30: Duffy, J., Dijk, D., Klerman, E., Czeisler, C. (1998). Later endogenous circadian temperature nadir relative to an earlier wake time in older people. American Journal of Physiology, 275, R1478-R1487.
[38] See for example: Monk, T. (2005). The post-lunch dip in performance. Clinical Sports Medicine, 24, e15-e23.

trough[39], with performance also dropping during the post-lunch dip[40]. This pattern can occur in the absence of fatigue[41] -- that is, overall performance may be low during the circadian trough even if a person is not fatigued. Incidentally peak performance normally occurs late in the afternoon[42].

A circadian rhythm trough for most people occurs between about 22:30 and 04:30 hrs. During this time human performance is at its lowest.

Sleep propensity also demonstrates a similar circadian rhythm. It increases dramatically at night and moderately in the middle of the afternoon[43]. It follows then that fatigue will also increase slightly in the middle of the afternoon and significantly during the circadian rhythm trough. Night (i.e., in the circadian rhythm trough) levels of fatigue can climb to high levels after working 10 hours of a night shift. For example, a study of long haul airline pilots demonstrated that self-reported fatigue levels climbed to what were described as "critical" or "dangerously high levels" in over 25% of the pilots by the end of their 10 hour night flights [44]. Another study[45] found that

---

39 See for example: Monk, T. (1988). Shiftwork: Determinants of coping ability and areas of application. Advance in the Biosciences, 73, 195-207.

40 See for example: Monk, T. (2005). The post-lunch dip in performance. Clinical Sports Medicine, 24, e15-e23.

41 See for example: Monk, T., Folkard, S., & Wedderburn, A. (1996). Maintaining safety and high performance on shift work. Applied Ergonomics, 27(1), 17–23.

42 Anch, A., Browman, C., Mitler, M., & Walsh, J. (1988). Sleep: A Scientific Perspective. New Jersey: Prentice-Hall.

43 Dinges, D. F. (1989). The influence of the human circadian timekeeping system on sleep. In M. H. Kryger, T. Roth, & W. C. Dement (Eds.), Principles and Practice of Sleep Medicine (pp. 153-162). Philadelphia: W. B. Saunders Company.

44 Samel, A., Vejvoda, M., Maass, H., & Wenzel, J. (1999). Stress and fatigue in 2-pilot crew long-haul operations. Proceedings of CEAS/AAAF Forum "Research for Safety in Civil Aviation", Paris, 9; as cited in Folkard, S. (2000). Transport: Rhythm and blues. The 10th Westminster Lecture. Parliamentary Advisory Council for Transport Safety: London. Retrieved January 18, 2013, from http://www.hf.faa.gov/docs/508/docs/folkard15.pdf.

45 Samel, A., Wegmann, H. M., Vejvoda, M., Drescher, J., Gundel, A., Manzey, D., & Wenzel, J. (1997). Two-crew operations: Stress and fatigue during long-haul night flights. Aviation, Space and Environmental Medicine, 68(8), 679-687; as cited in Folkard, S. (2000). Transport: Rhythm and blues. The 10th Westminster Lecture. Parliamentary Advisory

sleepiness in long haul pilots during successive night shifts increased from night one to night two and, that after six hours of flying, the incidences of micro-sleeps increased substantially.

Studies of accident rates support this circadian pattern of fatigue. Motor vehicle accidents are most likely to occur during the circadian trough and the post-lunch dip[46], and single vehicle truck accidents may be 3.8 times more likely to occur between 03:00 and 05:00 hrs compared to between 08:00 and 16:00 hrs[47]. The risk of motor vehicle accidents is therefore, highest during periods of time when the risk of fatigue is also high.

Circadian Rhythm Desynchronization

Optimal human performance occurs when all the circadian rhythms are synchronized to each other as well as to external time cues. For example, hunger patterns must be internally synchronized with digestive patterns and sleep-wake patterns. These patterns must also be externally synchronized with external time cues or "zeitgebers"[48] such as the light–dark cycle, meal times and socializing periods[49]. Changing sleep-wake patterns too quickly can cause circadian rhythms to desynchronize and this can lead to performance impairments. Circadian rhythm desynchronization has been implicated with degraded responsiveness to pharmacological treatments, increased rate of

---

Council for Transport Safety: London. Retrieved January 18, 2013, from http://www.hf.faa.gov/docs/508/docs/folkard15.pdf.

[46] See for examples:

(A) Mitler, M., Carskadon, M., Czeiler, C., Dement, W., Dinges, D., & Graeber, R. (1988). Catastrophes, sleep, and public policy: Consensus report. Sleep, 11(1), 100-109.

(B) Folkard, S. (1997). Black times: temporal determinants of transport safety. Accident Analysis and Prevention, 29, 417-430.

[47] Kecklund, G. & Åkerstedt, T. (1995). Time of day and Swedish road accidents. Shiftwork International Newsletter, 12(1), 31.

[48] Aschoff, J. (1951). The 24-hour period of the mouse under constant environmental conditions (Die 24-stundenperiodik der maus unter konstanten umgebungs bedingungen). Naturwissenschaften, 38, 506-507.

[49] Aschoff, J., & Wever, R. (1981). The circadian system of man. In J. Aschoff (Ed.), Handbook of Behavioural Neurobiology (pp. 311-332). New York: Plenum Press.

myocardial infarctions, worsening of insulin-dependent diabetes, epilepsy, and neuropsychiatric disorders[50]. It also results in fatigue, daytime sleepiness, anxiety, depression, moodiness, general malaise, impairment of well-being, physical fatigue, insomnia and other sleep disturbances, gastrointestinal disorders, impairment of overall performance including psychomotor impairment and reduced cognitive skills[51]. Contrary to popular belief, people who have worked shift-work for many years do not become immune to circadian rhythm desynchronization and its effects[52]. A good example of the deleterious effects of shift-work is the fact that there is a negative correlation between length of service in shift-work and subjective sleep quality[53].

Irregular shift patterns increase the risk of fatigue due to circadian rhythm desynchronization.

People working shifts with irregular patterns usually have to adjust their sleep-wake patterns quickly to keep up with the changing shifts. One study of train operators working irregular shifts showed that the resulting circadian rhythm

---

[50] Phillips, B., Magan, L., Gerhardstein, C., & Cecil, B. (1991). Shift work, sleep quality, and worker health: A study of police officers. Southern Medical Journal, 84(10), 1176-1184.

[51] See for examples:

(A) Anch, A. M., Browman, C. P., Mitler, M. M., & Walsh, J. K. (1988). Sleep: A Scientific Perspective. New Jersey: Prentice-Hall

(B) Graeber, R. C. (1989). Jet lag and sleep disruption. In M. H. Kryger, T. Roth, & W. C. Dement (Eds.), Principles and Practice of Sleep Medicine (pp. 324- 331). Philadelphia: W. B. Saunders Company.

(C) Kales, A, & Kales, J. (1984). Evaluation and Treatment of Insomnia. New York: Oxford University Press.

[52] Pati, A. K., Chandrawanshi, A., & Reinberg, A. (2001). Shift work: Consequences and management. Current Science, 81(1), 32-52.

[53] Anch, A., Browman, C., Mitler, M., & Walsh, J. (1988). Sleep: A Scientific Perspective. New Jersey: Prentice-Hall.

desynchronization led to severe sleepiness[54] as measured by the KSS. In this study, the operators felt they were severely sleepy at least once during 49% of the night shifts and during 20% of the early morning shifts. Interestingly, the risk of severe sleepiness in train operators working irregular shifts appears to be related to the shift duration. Increasing the shift duration from six hours to nine hours can increase the risk of severe sleepiness by 51%[55].

A 2009 TSB investigation (R09W0259) into a non-main-track train collision[56] supports the notion that fatigue can result from circadian rhythm desynchronization. During the investigation, it was noted that the locomotive engineer had worked 28 shifts in the 30 days prior to the accident and that the conductor had worked 16 shifts in the preceding 30 days. Furthermore, there had been no predictable pattern to the start and finish times for any of these shifts. They started and finished at all times of the day and night and required numerous changes to sleep-wake patterns. One of the findings as to risk cited in the report was that “Operating crews that work variable and unpredictable work schedules may be at increased risk of performance impairments due to fatigue.” Additionally, the collision took place at 02:23, right in the middle of the circadian trough, suggesting that circadian rhythm timing may also have played a role.

The risk of fatigue and performance impairment resulting from circadian rhythm desynchronization and from changing sleep-wake patterns too quickly can be reduced by allowing people enough time to adjust to a new sleep-wake pattern. Research generally shows that the detrimental effects of a

---

[54] Härmä, M., Sallinen, M., Ranta, R., Mutanen, P., & Müller, K. (2002) The effect of an irregular shift system on sleepiness at work in train drivers and railway traffic controllers. Journal of Sleep Research, Vol. 11, pp. 141 – 151.
[55] Härmä, M., Sallinen, M., Ranta, R., Mutanen, P., & Müller, K. (2002) The effect of an irregular shift system on sleepiness at work in train drivers and railway traffic controllers. Journal of Sleep Research, Vol. 11, pp. 141 – 151.
[56] Railway Investigation Report R09W0259, Non-Main-Track Train Collision, Between Canadian Pacific Railway Freight Train 870-013, Canadian Pacific Railway Freight Train 2-298-16, and Canadian Pacific Railway Freight Train 2-199-15, Mile 159.31, Weyburn Subdivision, North Portal, Saskatchewan, 19 December 2009.

sleep-wake pattern changes will fully dissipate within 8 to 10 days providing that the person makes an effort to change the timing of exposure to zeitgebers in order to re-synchronize circadian rhythms[57]. For example, if a pilot is required to phase advance the sleep period (i.e., start sleeping at an earlier time than normal) to be able to work at night, the pilot must also change meal and socializing times and replace daytime sunlight with exposure to bright light at night. These changes should be maintained and stable for at least eight days to minimize the risk of fatigue.

In some cases, an 8 to 10 day adaptation period may not be required. Although some research shows that all circadian rhythms can adapt at a rate of about 1 hour per day[58], the human body adapts to counter-clockwise changes in sleep-wake patterns (i.e., where bedtime is earlier than normal) at a slower rate than it does to clockwise changes (i.e., where bedtime is later). It is, therefore, a good scheduling practice to allow longer adaptation times for counter-clockwise sleep-wake pattern changes. To reduce the risks of circadian rhythm desynchronization and fatigue, a good rule of thumb is to allow people one day of adaptation for every hour of counter-clockwise change in sleep-

---

[57] 57 See for examples:

(A) Campbell, S. (1997). The basics of biological rhythms. In M. R. Pressman & W. C. Orr (Eds.), Understanding Sleep: The Evaluation and Treatment of Sleep Disorders (pp. 35-56). Washington, D.C.: American Psychological Association.
(B) Cho, K. (2001). Chronic "jet lag" produces temporal lobe atrophy and spatial cognitive deficits. Nature Neuroscience, 4(6), 567-568.
(C) Folkard, S. (1980). Shiftwork and its effects on performance. In L. E. Scheving, & F. Halberg (Eds.), Proceedings of the NATO Advanced Study Institute on Principles and Applications of Chronobiology to Shifts in Schedules with Emphasis on Man (pp. 293-306). Netherlands: Sijthoff and Noordhoff.

[58] See for examples:

(A) Mills, J. (1976). Partial adaptation to simulated time zone shifts. Journal of Physiology, 265, 23.
(B) Wever, R. (1980). Phase shifts of human circadian rhythms due to shifts of artificial Zeitgebers. Chronobiologia, 7, 303-327.

wake pattern and to allow one day of adjustment for every 1.5 hours of clockwise change in sleep-wake patterns[59].

For example, relocating a train operator to a yard that is three time zones to the west would mean that the operator would go to bed three hours later than his body's normal circadian sleep onset time. The operator's circadian rhythms would require two days to full resynchronize.. However, if the same train operator were relocated three time zones to the east, it would take three days of adaptation for the operator's circadian rhythms to fully resynchronize.

Sleep Disorders

Researchers estimate that more than 24% of the people in the United States suffer from a sleep disorder[60] and that 50% of shift-workers suffer from a sleep disorder[61]. The 2001 edition of The International Classification of Sleep Disorders (ICSD)[62] describes 88 medically recognized sleep disorders. Many of these disorders result in higher than normal levels of fatigue if they are untreated or not managed properly. Three of the more common sleep disorders are psychophysiological insomnia, obstructive sleep apnea and periodic limb movement disorder.

Sleep disorders are very common in the general population and more prevalent in shift-workers.

[59] Klein, K. & Wegmann, H. (1980). Significance of circadian rhythms in aerospace operations, NATO AGARD-AG- 247. Neuilly sur Seine, France: NATO AGARD.
[60] Institute of Medicine, 2005. Sleep disorders and sleep prevention: an unmet public health problem. Washington, D.C.: National Academies Press.
[61] Åkerstedt, T. (1984). Work schedules and Sleep. Experientia, 40(5), 417-422.
[62] AASM (2001). The International Classification of Sleep Disorders, Revised: Diagnostic and Coding Manual. Chicago, Illinois, American Academy of Sleep Medicine.

Psychophysiological Insomnia

According to the ICSD, people with psychophysiological insomnia find it hard to fall asleep and/or stay asleep. They experience more light sleep (stage one) and sometimes less deep sleep (stages three and four) than people without a sleep disorder. These poor sleepers, as they are often described, report decreased well-being, deterioration of their mood and motivation, decreased attention, vigilance, energy and concentration. Most importantly, they also report increased fatigue[63] but they may not be more sleepy than normal individuals.

The rate of psychophysiological insomnia in the general population is unknown, likely due to under-reporting. Insomnia can be managed with medications and cognitive behavioural therapy and these treatments may reduce the risk of fatigue in the insomniac.

Obstructive Sleep Apnea

People with obstructive sleep apnea stop breathing for multiple successive periods of 10 seconds or longer while they sleep. Although their bodies attempt to breathe, the normally relaxed oropharyngeal muscles of the nose and throat allow soft tissue in the upper airway to block airflow. The hallmark of obstructive sleep apnea is a cessation of airflow in spite of a continuation of respiratory effort. The apneic episodes can result in a reduction of blood oxygen saturation and normally give rise to frequent arousals and awakenings. People with obstructive sleep apnea may be unaware of the frequent arousals and awakenings[64]. In fact, it is common for people with sleep apnea to report that they sleep very well. This is normally related to the fragmented sleep they get from the arousals and awakenings that produce their excessive sleepiness. The sleepiness in turn allows them

[63] AASM (2001). The International Classification of Sleep Disorders, Revised: Diagnostic and Coding Manual. Chicago, Illinois, American Academy of Sleep Medicine.
[64] AASM (2001). The International Classification of Sleep Disorders, Revised: Diagnostic and Coding Manual. Chicago, Illinois, American Academy of Sleep Medicine.

to fall asleep quickly and resume sleep within seconds of experiencing an awakening. People with obstructive sleep apnea are, therefore, at a high risk of experiencing excessive daytime fatigue[65].

Obstructive sleep apnea can result in anxiety, depression, irritability, loss of libido and erectile ability, and profound despair[66], and is common in middle-aged overweight men and women. The prevalence has been estimated to be 4% in men and 2% in women[67]. Some estimates indicate a higher prevalence for middle-aged men, perhaps as high as 10% for men between the ages of 40 and 60[68]. It is more common in people who snore[69], is reliably linked to large neck sizes[70] and obesity[71]. Some studies

---

[65] See for examples:
(A) Chung, F., Yegneswaran, B., Liao, P., Chung, S., Vairavanathan, S., Islam, S., Khajehdehi, A., & Shapiro, C. (2009). STOP questionnaire: A tool to screen patients for obstructive sleep apnea. Comment in: Anesthesiology, 110(1), 193; author reply 193-194. Anesthesiology, 108(5), 812-821.
(B) Mills, P., Kim, J., Bardwell, W., Hong, S., & Dimsdale, J. (2008). Predictors of fatigue in obstructive sleep apnea. Sleep & Breathing, 12(4), pp. 397-399.

[66] AASM (2001). The International Classification of Sleep Disorders, Revised: Diagnostic and Coding Manual. Chicago, Illinois, American Academy of Sleep Medicine.

[67] Young, T., Palta, M., Dempsey, J., Skatrud, J., Weber, S., & Badr, S. (1993). The occurrence of sleep-disordered breathing among middle aged adults. New England Journal of Medicine, 328(17), 1230-1273.

[68] Bearpark, H., Fell, D., Grunstein, R., Leeder, S., Berthon-Jones, M., & Sullivan, C. (1990). Road Safety and Pathological Sleepiness: The Role of Sleep Apnea. Sponsored by the Roads and Traffic Authority, NSW and the Federal Office of Road Safety, Canberra, Australia. Road Safety Bureau Consultant's Report CR 3/90.

[69] AASM (2001). The International Classification of Sleep Disorders, Revised: Diagnostic and Coding Manual. Chicago, Illinois, American Academy of Sleep Medicine.

[70] See for examples:
(A) Chung, F. & Elsaid, H. (2009). Screening for obstructive sleep apnea before surgery: Why is it important? Current Opinion in Anaesthesiology, 22(3), 405-411.
(B) Chung, F., Yegneswaran, B., Liao, P., Chung, S., Vairavanathan, S., Islam, S., Khajehdehi, A., & Shapiro, C. (2009). STOP questionnaire: A tool to screen patients for obstructive sleep apnea. Comment in: Anesthesiology, 110(1), 193; author reply 193-194. Anesthesiology, 108(5), 812-821.
(C) Chung, F., Yegneswaran, B., Herrera, F., Shenderey, A., & Shapiro, C. (2008). Patients with difficult intubation may need referral to sleep clinics. Anesthesia & Analgesia, 107(3), 915-920.

[71] See for examples:
(A) Chung, F. & Elsaid, H. (2009). Screening for obstructive sleep apnea before surgery: Why is it important? Current Opinion in Anaesthesiology, 22(3), 405-411.

have shown that people with body mass indices (BMI) greater than 33kg/m^2 are at higher risk of obstructive apnea[72] than those with normal BMI's.

Obstructive sleep apnea can be managed by various treatments including Continuous Positive Airway Pressure (CPAP), mandibular advancement devices (MAD) and surgery. These treatments may reduce the risk of fatigue in the apneic.

The role of obstructive sleep apnea was explored in a 2010 TSB investigation (R10Q0011) into a main-track derailment[73]. Although the crew's planning and reaction to complex issues were found to be degraded due to fatigue, the TSB report did not directly implicate obstructive sleep apnea as a causal or contributing factor. The report did, however, highlight the importance of medical monitoring of people with sleep disorders and that ineffective tracking and transferring of medical information can increase the risk of unsafe operations in the transportation industry.

Periodic Limb Movement Disorder[74]

(B) Chung, F., Yegneswaran, B., Liao, P., Chung, S., Vairavanathan, S., Islam, S., Khajehdehi, A., & Shapiro, C. (2009). STOP questionnaire: A tool to screen patients for obstructive sleep apnea. Comment in: Anesthesiology, 110(1), 193; author reply 193-194. Anesthesiology, 108(5), 812-821.
(C) Dagan, Y., Doljansky, J., Green, A., & Weiner, A. (2006). Body Mass Index (BMI) as a first-line screening criterion for detection of excessive daytime sleepiness among professional drivers. Traffic Injury Prevention, 7(1) 44-48.
(D) Hiestand, D., Britz, P., Goldman, M., & Phillips, B. (2006). Prevalence of symptoms and risk of sleep apnea in the US population: Results from the national sleep foundation sleep in America 2005 poll. Chest, 130(3), 780-786.

[72] See for examples
(A) Dagan, Y., Doljansky, J., Green, A., & Weiner, A. (2006) Body Mass Index (BMI) as a first-line screening criterion for detection of excessive daytime sleepiness among professional drivers. Traffic Injury Prevention, 7, 44-48.
(B) Gurubhagavatula, I., Maislin, G., Nkwuo, J., & Pack, A. (2004). Occupational screening for obstructive sleep apnea in commercial drivers. American Journal of Respiratory and Critical Care Medicine, 170, 371-376.

[73] Railway Investigation Report R10Q0011, Main-Track Derailment, Via Rail Canada Inc., Passenger Train No. 15, Mile 100.78, Canadian National Montmagny Subdividion, Saint-Charles-de-Bellechasse, Quebec, 25 February 2010.

[74] The information on periodic limb movement disorder is exclusively from the ICSD: AASM (2001). The International Classification of Sleep Disorders, Revised: Diagnostic and Coding Manual. Chicago, Illinois, American Academy of Sleep Medicine.

The muscles in the legs and sometimes the arms of people with periodic limb movement disorder (PLM) uncontrollably flex while they are asleep. Similar to obstructive sleep apnea episodes, the limb movements can result in arousals and awakenings of which the person may be unaware. Their sleep is fragmented and they may report that they are a good sleeper, also similar to obstructive sleep apnea. People with PLM disorder are at higher risk of fatigue and excessive sleepiness due to the fragmented sleep. They may also be prone to anxiety and depression related to the sleep disturbance.

People with sleep disorders will often be at risk for fatigue and sometimes excessive sleepiness.

The prevalence of periodic limb movements in the general middle-aged population is unknown. It is, however, common in people older than 60 and occurs in 34% of this age group. It is also common in 1 to 15% of people who have been diagnosed as having insomnia. PLM disorder can be treated with medication and behavioural approaches aimed at maximizing the quality of sleep.

Medical and Psychological Conditions, Illnesses and Drugs

Fatigue is a symptom of many untreated illnesses and a result of many untreated or poorly managed medical and psychological conditions. For example, people diagnosed with depression or diabetes will often suffer from excessive daytime sleepiness[75] when their conditions are not treated or properly managed; research has also demonstrated that obesity is a predictor of excessive daytime sleepiness (i.e., high levels of fatigue) even if obstructive sleep apnea is not present[76]. The biological mechanisms through which medical conditions and illnesses produce fatigue are varied. Some illnesses, medical conditions (e.g., pain), and psychological conditions (e.g., depression, anxiety and other conditions involving stress) result in poor sleep quality by fragmenting sleep architecture and reducing the amount of deep sleep or REM sleep. Similarly, some illnesses and medical conditions result in poor sleep quantity by reducing total sleep time, and some have limited effects on sleep but still produce fatigue.

Illnesses can lead to fatigue by disrupting sleep or on their own without remarkable effects on sleep.

The 2005 TSB investigation (R05E0008) into a railway level crossing accident[77] explored the role of hyperglycemia due to uncontrolled diabetes. In this accident, a logging truck driver sustained

[75] Bixler, E., Vgontzas, A., Lin, H., Calhoun, S., Vela-Bueno, A., & Kales, A. (2005). Excessive daytime sleepiness in a general population sample: The role of sleep apnea, age, obesity, diabetes, and depression. The Journal of Clinical Endocrinology and Metabolism, 90(8), 4510-4515.

[76] See for examples:

(A) Dagan, Y., Doljansky, J., Green, A., & Weiner, A. (2006) Body Mass Index (BMI) as a first-line screening criterion for detection of excessive daytime sleepiness among professional drivers. Traffic Injury Prevention, 7, 44-48.

(B) Gurubhagavatula, I., Maislin, G., Nkwuo, J., & Pack, A. (2004). Occupational screening for obstructive sleep apnea in commercial drivers. American Journal of Respiratory and Critical Care Medicine, 170, 371-376.

[77] Railway Investigation Report R05E0008, Crossing Accident, Via Rail Canada Inc., Passenger Train Number 1, Mile 92.26, Edson Subdivision, Mackay, Alberta, 31 January 2005.

serious injuries from striking the side of a passenger train after traveling through a protected crossing. The truck driver was sick and had not slept well the night before the accident. The disturbed sleep likely increased his risk of fatigue. He was also not managing his diabetes through diet, blood sugar monitoring or medication, and was dehydrated from being sick the night before. The poor sleep, the hyperglycemia from the uncontrolled diabetes and the dehydration created a complicated combination of daytime symptoms and, although the TSB report did not state that fatigue from hyperglycemia alone impaired the driver's performance, it did state "It is likely that the combination of hyperglycemia, fatigue, and dehydration acted either separately or in aggregate to impair his performance. The truck driver's physiological condition (hyperglycemic, fatigued, dehydrated) was such that it likely impaired his ability to recognize and react to the warning signals and approaching train in time to avert the collision". As this example highlights, it is helpful to consider the relationship between fatigue and illnesses when investigating an occurrence, including whether fatigue is a result of poor sleep caused by the illnesses or as a direct result of the illness.

The fatigue effect of many drugs is very similar to the fatigue effect of illnesses in that some drugs can reduce sleep quality or quantity to produce fatigue and some can produce fatigue independently of poor sleep. For example, many over the counter cold medications contain a stimulant called pseudoephedrine. The stimulating properties of this medication reduce nasal congestion, but if it is taken too close to bed time, the stimulating properties can also disrupt sleep quantity and quality[78] which can result in fatigue the following day. Nicotine's effects are very similar, with increased time to fall asleep[79] and decreased total sleep time[80], and both sleep quality and quantity being affected.

[78] Idzikowski, C. & Shapiro, C. (1993). ABC of sleep disorders: Non-psychotropic drugs and sleep. British Medical Journal, 306, 1118-1121.
[79] See for example: Marquardt, C., Perugini, M., Orr, L., Chow, D., Banga, N., & Krelina, M. (1999). Sleep onset latency effects of nicotine polacrilex gum. Sleep, 22, Supplement, S86.

Caffeine is also a stimulant and has even more effects on sleep. This drug, long considered simply a food product, increases the time it takes to fall asleep, decreases total sleep time, increases the number of awakenings, and decreases REM and deep sleep[81], thereby decreasing sleep quantity and quality and increasing the risk of fatigue during the waking hours. Caffeine, however, can also increase the risk of fatigue without having any effects on sleep. High caffeine consumption can lead to biological tolerance which changes the way the brain's chemicals work. When tolerance occurs, the person is biologically addicted to caffeine and, without a steady supply of caffeine, the person becomes fatigued[82].

As mentioned previously, some drugs can produce fatigue without disturbing sleep. Most medications designed as sleep aids will make people fatigued or even sleepy shortly after they are taken, even without a person having an intervening poor quality sleep period. Logically this makes sense; the sleep medication is having its desired effect -- that is, to make a person sleepy. Some seemingly innocuous medications can also increase fatigue shortly after they are taken. For example, common over the counter allergy medications containing the antihistamine diphenhydramine increase sleepiness[83]. Sleep and allergy medications will also have disruptive effects on sleep architecture and these effects can increase the subsequent risk of fatigue.

---

[80] See for example: Chokroverty, S. (1999). Sleep Disorders Medicine: Basic Sleep, Technical Considerations, and Clinical Aspects. Boston: Butterworth-Heineman.

[81] Chokroverty, S. (1999). Sleep Disorders Medicine: Basic Sleep, Technical Considerations, and Clinical Aspects. Boston: Butterworth-Heineman.

[82] For an interesting discussion about caffeine see: Marquardt, C. (2007) Caffeine: Beware the Insidious Nature of Caffeine. Retrieved February 6, 2013 from http://sleepanddreams.com/?p=129.

[83] Roth, T., Roehrs, T., Koshorek, G., Sicklesteel, J., & Zorick, F. (1987). Sedative effects of antihistamines. Journal of Allergy and Clinical Immunology. 80(1), 94-98.

Alcohol is another drug whose effects on sleep have been well researched. Although people will use alcohol's sedating effects to help them fall asleep, it can disturb the sleep they eventually obtain. Alcohol tends to disturb the second half of the night's sleep more than the first half. It can decrease total sleep time, increase awakenings and decrease REM sleep[84], all of which can increase the risk of fatigue.

All drugs, including over the counter and prescription medications and herbal remedies should be investigated. Nicotine, alcohol and food containing caffeine should also be considered.

As with medical and psychological conditions and illnesses, all drugs should be considered when investigating fatigue. This includes over the counter and prescription medications, herbal remedies, nicotine, recreational drugs, alcohol and food substances such as caffeine.

A 2008 TSB investigation (M08C0024) into a vessel grounding[85] provides a good example of how drugs may play a role in accidents. The ship's master was attempting to quit smoking with the aid of a prescription smoking cessation drug called Champix (also known as Chantix and generically as varenicline) for which the United States Federal Drug Administration had issued a health advisory[86]. The advisory outlined adverse effects such as disturbed sleep and an impaired ability to drive or operate heavy machinery. As discussed, disturbed sleep can

[84] Chokroverty, S. (1999). Sleep Disorders Medicine: Basic Sleep, Technical Considerations, and Clinical Aspects. Boston: Butterworth-Heineman.
[85] Marine Investigation Report M08C0024, Grounding, Bulk Carrier Algomarine, Bruce Mines North Channel, Lake Huron, Ontario, 28 May 2008.
[86] U.S. FDA Advisory (5/16/2008) - Public Health Advisory Important Information on Chantix (varenicline).

lead to fatigue. The master reported poor sleep on each of the five nights before the occurrence. The TSB determined that fatigue may have resulted from a combination of the adverse effects of Champix and poor sleep which in turn may have led to the master choosing to use visual cues rather than reliable bridge equipment that could have prevented the grounding.

Fatigue and Performance Impairment

Increasing levels of fatigue --that is, as a person moves along the fatigue continuum[87] from wide awake to asleep-- increases the likelihood of some form of human performance impairment. With excessive levels of fatigue, almost all aspects of human performance can be degraded. For example, if a person is almost asleep, it would be very difficult for them to physically react with any degree of rapidity, difficult for them to speak and difficult for them to comprehend visual stimuli because their eyes would likely be closed. At less extreme levels of fatigue, performance may also be impaired. The degree to which fatigue affects performance through sleep or micro-naps occurring can also be modified by working conditions - note that while conditions cannot reduce fatigue levels, they can reduce the likeliness of sleep occurring. For instance, sleep is less likely in a brightly lit room with a stimulating task compared to a warm, dark room with a monotonous task. Fatigue-related performance impairments have been very well researched and a small sample of the findings is presented below.

General Cognitive Functions

As discussed, fatigue increases as time awake increases. Similarly, cognitive performance deteriorates with time awake. Research has shown that performance on problem solving, vigilance and communication tasks shows a 30 per cent decrement after 18 hours of wakefulness and a 60 per cent decrement after 48 hours[88] when compared to levels after less continuous wakefulness. The duration of wakefulness in this finding is similar to the psychomotor research finding, discussed previously, that hand-eye coordination can become impaired after 17 hours of wakefulness.

---

[87] Discussed in the section entitled *What is fatigue?*

[88] Angus, R., Pigeau, R., & Heslegrave, R. (1992). Sustained operation studies: From the field to the laboratory. In C. Stampi (Ed.) Why We Nap: Evolution, Chronobiology, and Functions of Polyphasic and Ultrashort Sleep. Boston: Birkhäuser.

Fatigue can also result in a reduced rate of information processing[89] and this can affect the speed with which a person can identify important information, process and react to it. For example, fatigue can lead to reductions in the ability to process visual information from the peripheral retina[90] and to subsequently react to it.

Problem Solving

Fatigue can also reduce a person's ability to problem solve and, instead of being flexible in their approach to a situation that is perceived to be different from the routine, they perseverate and repeat previously ineffective responses. Perseveration increases the likelihood that the normal routine will be maintained, which can lead to a failure to revise the original plan[91] and make it difficult for a fatigued person to devise and try a novel solution.

[89] See for examples:

(A) Belenky, G., Wesensten, N., Thorne, D., Thomas M., Sing, H., Redmond, D., Russo, M., & Balkin, T. (2003). Patterns of performance degradation and restoration during sleep restriction and subsequent recovery: A sleep dose-response study. Journal of Sleep Research, 12(1), 1-12.

(B) Dinges, D. (1992). Probing the limits of functional capability: The effects of sleep loss on short –duration tasks. In Broughton, R. (Ed.) Sleep, Arousal, and Performance. Boston: Birkhäuser.

(C) Galy, E., Mélan, C., & Cariou, M. (2008). Investigation of task performance variations according to task requirements and alertness across the 24-h day in shift workers. Ergonomics, 51(9), 1338-1351.

(D) Van Dongen, H., Maislin, G., Mullington J., & Dinges, D., (2003). The cumulative cost of additional wakefulness: Dose-response effects on neurobehavioral functions and sleep physiology from chronic sleep restriction and total sleep deprivation. Sleep, 26(2), 117-126.

(E) Wylie, C. & Mackie, R. (1988). Stress and sonar operator performance: Enhancing target detection performance by means of signal injection and feedback. Goleta, CA: Essex Corporation, Human Factors Research Division.

[90] Haworth, N., Heffernan, C., & Horne, E. (1989). Fatigue in truck accidents. Report No. 3. Victoria: Monash University Accident Research Centre.

[91] See for examples:

(A) Horne, J. (1988). Sleep deprivation and divergent thinking ability. Sleep, 11, 528-536.

(B) Wimmer, F., Hoffman, R., Bonato, R., & Moffit, A. (1992). The effects of sleep deprivation on divergent thinking and attention processes. Journal of Sleep Research, 1, 233-230.

Decision Making

In general, performance on more complicated tasks, such as decision making[92], is degraded to a higher degree than performance on easier tasks[93] such as simple counting when people are fatigued. More recent research has shown that tasks specifically involving higher cognitive load, such as logical reasoning, problem solving and decision making, may not be affected as much as monotonous tasks by partial sleep deprivation[94]. This may be due in part to compensatory efforts to perform normally on complex, interesting, variable or short tasks such as logical reasoning, problem solving and decision making. In other words, people may become more engaged in the higher cognitive load tasks and exert more effort to perform normally; thereby increasing physiological arousal levels and temporarily counteracting fatigue related performance impairments.

Whether decision making is complex or monotonous, if an emotional component is involved, as is often the case in emergency situations, decision making is significantly impaired after 23 hours of

[92] See for examples:

(A) Babkoff, H., Mikulincer, M., Caspy, T., Kempinski, D., & Sing, H. (1988). The topology of performance curves during 72 hours of sleep loss: A memory and search task. Quarterly Journal of Experimental Psychology, 324, 737-756.

(B) Fiorica, V., Higgins, E., Iampietro, P., Lategola, M., & Davis, A. (1968). Physiological responses of man during sleep deprivation. Journal of Applied Physiology, 24(2), 169-175.

(C) Horne, J. (2012). Working throughout the night: Beyond 'sleepiness' – impairments to critical decision making. Neuroscience and Biobehavioral Reviews, 36(10), 2226-2231.

(D) Linde, L. & Bergstrom, M. (1992). The effect of one night without sleep on problem-solving and immediate recall. Psychological Research, 54(2), 127-136.

[93] Lamond, N. & Dawson, D. (1999). Quantifying the performance impairment associated with fatigue. Journal of Sleep Research, 8, 255-262.

[94] Balkin, T., Bliese, P., Belenky, G., Sing, H., Thorne, D., Thomas, M., Redmond, D., Russo, M., Wesensten J. (2004). Comparative utility of instruments for monitoring sleepiness-related performance decrements in the operational environment. Journal of Sleep Research, 13(3), 219-227.

wakefulness, compared to decision making after less wakefulness, even if large amounts of caffeine (600mg) are consumed[95].

Memory

Memory, predominantly short term and working memory, can be impaired by fatigue[96]. Short term memory can be conceptualized as the cognitive function that allows the temporary storage of information. Short term memory impairment may only occur when people have to try to recall information without receiving any cues and when the cues are for recall of visual information rather than for auditory information[97].

Working memory is a concept similar to short term memory in that information is only retained for a short period of time. Specifically, working memory is the system that temporarily stores information while it is being manipulated for tasks such as reasoning[98]. It requires the simultaneous storage and processing of information. Working memory can be impaired by fatigue[99].

---

[95] Killgore, W., Grugle, N., & Balkin, T. (2012). Gambling when sleep deprived: Don't bet on stimulants. Chronobiology International, 29(1), 43-54.

[96] See for examples:
(A) Babkoff, H., Mikulincer, M., Caspy, T., Kempinski, D., & Sing, H. (1988). The topology of performance curves during 72 hours of sleep loss: A memory and search task. Quarterly Journal of Experimental Psychology, 324, 737-756.
(B) Fiorica, V., Higgins, E., Iampietro, P., Lategola, M., & Davis, A. (1968). Physiological responses of man during sleep deprivation. Journal of Applied Physiology, 24(2), 169-175.
(C) Linde, L. & Bergstrom, M. (1992). The effect of one night without sleep on problem-solving and immediate recall. Psychological Research, 54(2), 127-136.

[97] See for examples:
(A) Galy, E., Camps, J., Mélan, C. (2004). Influence of the perceptual mode on serial probe recognition across the 24-hr day in experienced shift-workers. Cognitive Systems, 6, 249-254.
(B) Mélan, C., Galy, E., & Cariou, M. (2007). Mnemonic processing in air traffic controllers (ATCs): Effects of task parameters and work organization. International Journal of Aviation Psychology, 17(4), 391-409.

[98] Baddeley, A. (1992). Working memory. Science, 255(5044), 556-559.

[99] See for examples:

Attention and Vigilance

Fatigue makes it difficult to pay attention[100]. Lapses in attention and increased distractibility result from fatigue[101]. For example, train drivers more frequently miss alerting signals and fail to sound the horn at level crossings when they are fatigued[102].

Vigilance is operationally defined in the fatigue research as the ability to sustain attention on a task for a given period of time[103]. Vigilance, especially psychomotor vigilance, where people have to respond to a stimulus with some form of body movement[104], is reliably reduced by fatigue[105]. Fatigued people are less able to detect and react to stimuli.

(A) Dinges, D. (1992). Probing the limits of functional capability: The effects of sleep loss on short –duration tasks. In Broughton, R. (Ed.) Sleep, Arousal, and Performance. Boston: Birkhäuser.
(B) Galy, E., Mélan, C., & Cariou, M. (2008). Investigation of task performance variations according to task requirements and alertness across the 24-h day in shift workers. Ergonomics, 51(9), 1338-1351.
(C) Lo, J., Groeger, J., Santhi, N., Arbon, E., Lazar, A., Hasan, S., Von Schantz, M., Archer, S., & Dijk, D. (2012), Effects of partial and acute total sleep deprivation on performance across cognitive domains, individuals and circadian phase. Plos One, 7(9), 1-16.

[100] See for examples:
(A) Kjellberg, A. (1974). Effects of sleep deprivation on voluntarily controlled reversal rate of ambiguous figures. Scandinavian Journal of Psychology, 15, 149-153.
(B) Sanders, A. & Reitsma, W. (1982). Lack of sleep and covert orienting of attention. Acta Psychologica, 52, 137-145.

[101] Wylie, C. & Mackie, R. (1988). Stress and sonar operator performance: Enhancing target detection performance by means of signal injection and feedback. Goleta, CA: Essex Corporation, Human Factors Research Division.

[102] Thomas, G., Raslear, T., Kuehn, G. (1997). The effects of work schedule on train handling performance and sleep of locomotive engineers: A simulator study (No. DOT/FRA/ORD-97-09). , Washington, D.C.: US Department of Transportation, Federal Railroad Administration and IIT Research Institute.

[103] See for examples:
(A) Davies, D. & Parasuraman, R. (1982). The Psychology of Vigilance. London: Academic.
(B) Oken, B., Salinsky, M., & Elsas, S. (2006). Vigilance, alertness, or sustained attention: Physiological basis and measurement. Clinical Neurophysiology, 117, 1885-1901.

[104] For example, pressing a button as soon as a light appears.

[105] See for examples:
(A) Dinges, D., Pack, F., Williams, K., Gillen K., Powell, J., Ott, G., Aptowicz, C., Pack A. (1997). Cumulative sleepiness, mood disturbance, and psychomotor vigilance performance decrements during a week of sleep restricted to 4-5 h per night. Sleep, 20(4), 267-277.

Reaction Time

Fatigued individuals will normally respond to stimuli more slowly than alert people[106] and can display reaction times that are significantly long[107] known as "blocks". Blocking commonly occurs in response to emergency or difficult decision making situations[108] and can be worse in the fatigued individual.

Mood

There is some evidence to suggest that negative mood states may be related to partial sleep deprivation. For example, one study found that physicians who slept less than they normally did, scored worse on a standardized test of mood called the Profile of

Fatigue can lead to impairments in general cognitive functioning, problem solving, decision making, memory, attention & vigilance, reaction time and mood.

(B) Ingre, M., Åkerstedt, T., Peters, B., Anund, A. & Kecklund, G. (2006). Subjective sleepiness, simulated driving performance and blink duration: Examining individual differences. Journal of Sleep Research, 15, 47-53.

[106] See for examples:
- (A) Babkoff, H., Mikulincer, M., Caspy, T., Kempinski, D., & Sing, H. (1988). The topology of performance curves during 72 hours of sleep loss: A memory and search task. Quarterly Journal of Experimental Psychology, 324, 737-756.
- (B) Fiorica, V., Higgins, E., Iampietro, P., Lategola, M., & Davis, A. (1968). Physiological responses of man during sleep deprivation. Journal of Applied Physiology, 24(2), 169-175.
- (C) Linde, L. & Bergstrom, M. (1992). The effect of one night without sleep on problem-solving and immediate recall. Psychological Research, 54(2), 127-136.

[107] See for examples:
- (A) Bills, A. (1935). Fatigue, oscillation, and blocks. Journal of Experimental Psychology, 18(5), 562-573.
- (B) Shinar, D., Zaidel, D., & Paarlberg, W. (1978). Driver performance and individual differences in attention and information processing. Volume 1: Driver inattention, Report No. DOT-HS-8-01819-78-DAP, NTIS No. PB 292165 & 6.

[108] See for examples:
- (A) Shinar, D., Zaidel, D., & Paarlberg, W. (1978). Driver performance and individual differences in attention and information processing. Volume 1: Driver inattention, Report No. DOT-HS-8-01819-78-DAP, NTIS No. PB 292165 & 6.
- (B) Teichner, W. (1968). Response blocking. A necessary performance criterion. Pre-crash Factors in Traffic Safety. American Association for Automotive Medicine, Proceedings of the12th Annual Symposium, 165-169.

Mood States (POMS)[109]. The mood states of these physicians after partial sleep deprivation during their on-call shifts was worse than before their on-call shifts. Given that partial sleep deprivation leads to fatigue[110], this result implies that a worsening of mood may be an indicator of increased fatigue.

Similarly, sleep loss has a generally negative impact on mood[111] and, given that sleep loss leads to fatigue, a fatigued person can be lethargic, display a lack of interest, and may be irritable[112].

Physiological Effects

There are reliable physiological indicators of fatigue, including: increasing eye blink duration measured by electrooculography[113], changes in speech patterns detected by computer analyses[114], and decrements in postural balance detected by computer analyses[115]. Physiological changes such as these cannot easily be detected by casual observers. For example, a co-pilot may not be able to detect an increase in eye-blink duration in the captain; likewise for speech patterns between a conductor and engineer. The only reliable observation of sleepiness is objective evidence such as seeing

---

109 Wali, S., Qutah, K., Abushanab, L., Basamh, R., Abushanab, J., & Krayem, A. (2013). Effect of on-call-related sleep deprivation on physician's mood and alertness. Annals of Thoracic Medicine, 8(1), 22-27.

110 Lo, J., Groeger, J., Santhi, N., Arbon, E., Lazar, A., Hasan, S., Von Schantz, M., Archer, S., & Dijk, D. (2012), Effects of partial and acute total sleep deprivation on performance across cognitive domains, individuals and circadian phase. Plos One, 7(9), 1-16.

111 Lubin, A., Moses, J., Johnson, L., & Naitoh, P. (1974). The recuperative effects of REM sleep and stage 4 sleep on human performance after complete sleep loss: Experiment 1. Psychophysiology, 11, 133-146.

112 See for example: Anch, A., Browman, C., Mitler, M., & Walsh, J. (1988). Sleep: A scientific perspective. New Jersey: Prentice-Hall.

113 See for example: Sandberg, D., Anund, A., Fors, C., Kecklund, G., Karlsson, J., Wahde, M., & Åkerstedt, T. (2011). The characteristics of sleepiness during real driving at night: A study of driving performance, physiology and subjective experience. Sleep: Journal of Sleep and Sleep Disorders Research, 34(10), 1317-1325.

114 See for example: Krajewski, J., Schnieder, S., Sommer, D., Batliner, A., & Schuller, B. (2012). Applying multiple classifiers and non-linear dynamic features for detecting sleepiness in speech. From Neuron to Behaviour: Evidence from Behavioral Measurements, Neurocomputing, 84, 65-75.

115 See for example: Forsman, P., Hæggström, E., Wallin, A., Topplia, E., & Pyykkö, I. (2010). Principal component analysis detects sleepiness-related changes in balance control. Gait & Posture, 32(3), 419-421.

someone close their eyes, lose muscle tone, slump over and fall asleep. Even micro-sleep episodes require sophisticated physiological monitoring equipment to be reliably detected[116].

Subjective Assessment of Fatigue and Performance

At high levels of fatigue, approaching sleep, it is arguably difficult to not realize that one is fatigued. However, at lower levels of fatigue, detecting one's own level of fatigue can be more difficult. Stimulating qualities within the operational environment (e.g., flashing lights, loud noise) may lead to subjective fatigue ratings that do not correlate well with objective physiological measures of fatigue[117]; so in these cases fatigue levels can be subjectively underestimated.

Fatigued people are not very good judges of their own fatigue level or their ability to perform well.

In addition to exhibiting decrements in being able to accurately assess their own fatigue levels, fatigued people are less able to accurately rate and monitor their overall performance[118]. Typically, fatigued people overestimate their abilities[119]. As with subjective assessments of fatigue, predicting one's performance based on one's self-assessment

[116] For an example of micro-sleep detection equipment see: Deshmukh, S., Radake, D., & Hande, K. (2011). Driver fatigue detection using senor network. International Journal of Engineering Science & Technology, 3(Sup), 89-92.
[117] Dinges, D. & Graeber, R. (1989). Crew fatigue monitoring. Flight Safety Foundation: Flight Safety Digest, October, 65-75.
[118] Dorrian, J., Lamond, N., Holmes, A., Burgess, H., Roach, G., Fletcher, A. & Dawson, D. (2003). The ability to self-monitor performance during a week of simulated night shifts, Sleep, 26(7), 871-877.
[119] See for example: Asaoka, S., Masaki, H., Ogawa, K., Murphy, T., Fukuda, K., & Yamazaki, K. (2010). Performance monitoring during sleep inertia after a 1-h daytime nap. Journal of Sleep Research, 19, 436-443.

of fatigue is influenced by the stimulating qualities of the operational environment[120]. For example, if a person is in a stimulating environment, such as a ship's bridge during an emergency with many alarms sounding, he may not be able to accurately assess his subjective fatigue level and/or predict subsequent performance on his shift.

Sleep Inertia

Although not a performance impairment per se, sleep inertia[121] is a transient physiological state that occurs immediately after awakening. The state is characterized by confusion, disorientation, low arousal and deficits in various types of cognitive and motor performance skills[122]. This compromised state of performance can occur after any sleep period but is usually considered in the context of napping (also known as controlled rest). The deleterious effects of sleep inertia can last 30 minutes[123] or longer[124], but normal levels of performance usually return in most people within 1 to 15 minutes[125] after awakening.

---

[120] Yang, C., Lin, F., & Spielman, A. (2004). A standard procedure enhances the correlation between subjective and objective measures of sleepiness. Sleep, 27, pp. 329-332.

[121] The term "sleep inertia" was coined by Lubin et al., see Lubin, A., Hord, D., Tracy, M., & Johnson, L. (1976). Effects of exercise, bedrest and napping on performance decrements during 40 hours. Psychophysiology, 13, 334-339.

[122] Ferrara, M. & De Gennaro, L. (2000). The sleep inertia phenomenon during the sleep-wake transition: Theoretical operational issues. Aviation, Space and Environmental Medicine, 71, 843-848

[123] (A) Dinges, D., Orne, M., Whitehouse, W., & Orne, E. (1987). Temporal placement of a nap for alertness: Contributions of circadian phase and prior wakefulness. Sleep, 10, 313-329.
(B) Ferrara, M. & De Gennaro, L. (2000). The sleep inertia phenomenon during the sleep-wake transition: Theoretical operational issues. Aviation, Space and Environmental Medicine, 71, 843-848.

[124] See for examples:
- (A) Haslam, D. (1985). Sleep deprivation and naps. Behavior Research Methods, Instruments, and Computers, 17, 46-54.
- (B) Jewitt, M., Wyatt, J., Ritz-De Cecco, A., Khalsa S., Djik D., & Czeisler, C. (1999). Time course of sleep inertia dissipation in human performance and alertness. Journal of Sleep Research, 8, 1-8.
- (C) Naitoh, P. (1981). Circadian cycles and restorative power of naps. In L. Johnson, D. Tepas, W. Colquhoun, & M. Colligan, (Eds.), Biological Rhythms, Sleep and Shift Work (pp. 553-580). New York: Spectrum Publications.
- (D) Rogers, A., Spencer, M., Stone, B., & Nicholson, A. (1989). The influence of a 1-hour nap on performance overnight. Ergonomics, 32(10), 1193-1205.

[125] See for examples:

The performance impairments associated with sleep inertia are very similar to those of an extremely fatigued person. For example, memory[126], reaction time[127], speed of information processing[128] and logical reasoning[129] are impaired during periods of sleep inertia compared to other periods. In addition, confusion and disorientation[130] as well as impaired visual information processing[131] are more common during sleep inertia than otherwise.

The duration and severity of sleep inertia is generally worse if a person naps for longer than 20 minutes[132], if the nap takes place during the circadian rhythm trough[133], if the nap occurs when the

---

(A) Dissipation within 1 to 5 minutes: Webb, W. & Agnew, H. (1974). The effects of a chronic limitation on sleep length. Psychophysiology, 11, 265-274

(B) Dissipation within 1 to 15 minutes: Wilkinson, R. & Stretton, M. (1971). Performance after awakening at different times of night. Psychonomic Science, 23, 283-285.

126 Folkard, S., Knauth, P., Monk, T., & Rutenfranz, J. (1976). The effect of memory load on the circadian variation in performance efficiency under a rapidly rotating shift system. Ergonomics, 19, 479-488.

127 See for example: Tassi, P & Muzet, A. (2000). Sleep inertia. Sleep Medicine Reviews, 4(4), 341-353.

128 Evans, F. & Orne, M. (1976). Recovery from fatigue. Annual Summary Report No. 60. Fort Derrick, MD: US Army Medical Research and Development Command

129 See for examples:

(A) Naitoh, P. (1981). Circadian cycles and restorative power of naps. In L. Johnson, D. Tepas, W. Colquhoun, & M. Colligan, (Eds.), Biological Rhythms, Sleep and Shift Work. New York: Spectrum Publications.

(B) Stones, M. (1977). Memory performance after arousal from different sleep stages. British Journal of Psychology, 68, 177-181.

130 Ferrara, M. & De Gennaro, L. (2000). The sleep inertia phenomenon during the sleep-wake transition: Theoretical operational issues. Aviation, Space and Environmental Medicine, 71, 843-848.

131 See for example: Matchock R. & Mordkoff (2007). Visual attention, reaction time, and self-reported alertness upon awakening from sleep bouts of varying lengths. Experimental Brain Research, 178, 228-239.

132 See for examples:

(A) Dinges, D., Orne, E., Evans, F., & Orne, M. (1981). Performance after naps in sleep-conducive and alerting environments. In L. Johnson, D. Tepas, W. Colquhoun, & M. Colligan, (Eds.), Biological Rhythms, Sleep and Shift Work. New York: Spectrum Publications.

(B) Evans, F. & Orne, M. (1976). Recovery from fatigue. Annual Summary Report No. 60. Fort Derrick, MD: US Army Medical Research and Development Command.

(C) Matchock R. & Mordkoff (2007). Visual attention, reaction time, and self-reported alertness upon awakening from sleep bouts of varying lengths. Experimental Brain Research, 178, 228-239.

133 See for examples:

person is sleep deprived or has been awake for an extended period[134], or if the person experiences deep sleep during or at the end of the nap (i.e., wakens from deep sleep)[135].

Debate over the optimum nap duration beyond 20 minutes continues. This may due in part to the numerous variables, such as the duration of intervening wakefulness[136] and timing within the normal sleep period[137], that influence the occurrence of deep sleep. Recall that sleep cycles repeat approximately every 90 minutes and that the first episode of deep sleep normally occurs 30 to 45 minutes after sleep onset. If waking up from deep sleep increases the duration and severity of sleep inertia, then allowing the person to transition through deep sleep and waken from light sleep may allow the person to experience the restorative effects of deep sleep without increasing effects of sleep inertia. In other words, if the person is allowed to transition from deep sleep back to light sleep and then wakens at around the 80 minute point, a second episode of deep sleep may be avoided and sleep inertia duration and severity may be reduced while still providing the person with the restorative effects of deep sleep. This notion is supported by research that demonstrates that the performance

---

(A) Dinges, D., Orne, M., & Orne, E. (1985). Assessing performance upon abrupt awakening from naps during quasi-continuous operations. Behavior Research Methods, Instruments, and Computers, 17, 37-45.
(B) Dinges, D., Orne, M., Whitehouse, W., & Orne, E. (1987). Temporal placement of a nap for alertness: contributions of circadian phase and prior wakefulness. Sleep, 10, 313-329.
(C) Lavie, P. & Weler, B. (1989). Timing of naps: effects on post-nap sleepiness levels. Electroencephalography and Clinical Neurophysiology, 72, 218-224.

[134] See for examples:
(A) Dinges, D., Orne, M., & Orne, E. (1985). Assessing performance upon abrupt awakening from naps during quasicontinuous operations. Behavior Research Methods, Instruments, and Computers, 17, 37-45
(B) Ferrara, M., De Gennaro, L., & Bertini, M. (2000). Voluntary oculomotor performance upon awakening after total sleep deprivation. Sleep, 23, 801-811.

[135] See for example: Feltin, M. & Broughton, R. (1968). Differential effects of arousal from slow wave sleep and REM sleep. Psychophysiology, 5, 231.

[136] Longer periods of wakefulness increase sleep deprivation which increase sleep inertia deprivation. See for example: Ferrara, M., De Gennaro, L., & Bertini, M. (2000). Voluntary oculomotor performance upon awakening after total sleep deprivation. Sleep, 23, 801-811.

[137] Recall that deep sleep occurs mainly during the first half of a nocturnal sleep period and therefore waking up during the first half of the night will increase the likelihood of waking up from deep sleep.

impairments of sleep inertia were worse in a 50 minute nap condition compared to 20 and 80 minute nap conditions[138]. In addition, because sleep reduces fatigue and reductions in fatigue improve performance, it follows that napping for many hours may also reduce sleep inertia's performance effects. However, research has demonstrated that this may not be the case. Napping for four or seven hours compared to one hour increases the likelihood of visual distractions after awakening[139]. The optimum nap duration with respect to reducing the performance effects of sleep inertia therefore remains unclear.

The TSB investigated an aviation occurrence (A11F0012) involving sleep inertia[140] in 2011. In this incident, the first officer napped during flight for about 75 minutes. This duration of sleep likely allowed the first officer to experience deep sleep. The first officer was also partially sleep deprived from interrupted sleep the night before the flight and the nap occurred during the circadian rhythm trough. These conditions likely worsened the sleep inertia when the captain woke the first officer up and immediately started talking to him. Confused and disoriented, the first officer perceived the aircraft to be on a collision course and pushed forward on the

Sleep inertia is a state of confusion, disorientation and impaired performance that can occur immediately after awakening.

[138] Stampi, C., Mullington, J., Rivers, M.,Campos, J., & Broughton, R. (1990). Ultrashort sleep schedules: Sleep architecture and the recuperative value of multiple 80- 50- and 20 –min naps. In J. Horne (Ed.) Sleep, Bochum, U.K.: Pontenagel Press
[139] Matchock R. & Mordkoff (2007). Visual attention, reaction time, and self-reported alertness upon awakening from sleep bouts of varying lengths. Experimental Brain Research, 178, 228-239.
[140] Aviation Investigation report A11F0012, Pitch Excursion, Air Canada, Boeing 767-333, C-GHLQ, North Atlantic Ocean, 55°00′N 029°00′W, 14 January 2011.

control column. This caused vertical acceleration forces to change from -0.5g to +2.0g within five seconds. Fourteen passengers and two flight attendants were injured during this pitch excursion.

Managing the Risks Associated with Fatigue

The risks associated with sleep related fatigue must be effectively managed in 24/7 transportation operations. Like other hazards, the aim should be to reduce the risks to a level which is as low as reasonably practicable (ALARP). Doing so requires a proactive, multifaceted approach which includes regulations, measures to prevent fatigue which go beyond regulation and measures to mitigate the impact of fatigue.

Regulation

Regulations which set out duty time limitations and minimum rest intervals are the most basic control in place in many (but not all) sectors of the transportation industry. Such regulations are useful in that they establish work time limits and provide for the opportunity to obtain sleep and are the only contribution prescriptive regulation can make in the management of fatigue.

Duty time regulations only address how much time the individual has spent at, or away from, work in a given period and do not ensure the individual is well rested. In essence, they address the question of whether the individual is "legal" to work but ignore many contributors to fatigue and fail to ask the question of whether the individual is "too tired" to perform their duties safely.

Many collective agreements also serve to set out work and rest time provisions and some segments of the industry are moving toward performance based regulations requiring operators to have a fatigue management plan or program in place (discussed below).

With respect to regulations and fatigue, a TSB investigation should examine:

- The duty and rest provisions in regulation and collective agreements;
- The extent to which these provisions provide an adequate opportunity to obtain quality sleep;
- The extent to which these provisions are in line with the science of human sleep and fatigue; and,
- The extent of compliance with these provisions.

Prevention

The prevention of fatigue in the workplace is a shared responsibility between the organization and the employee.

The organization's contribution to preventing fatigue involves educating their people at all levels on the causes and mitigations of fatigue, defining appropriate policies and procedures with respect to fatigue management, ensuring a working environment which minimizes fatigue as much as practicable and striving for continual improvement in reducing fatigue.

The employee's contribution includes applying their knowledge of the prevention and effects of fatigue to take all reasonable steps to report for work well rested, making effective use of fatigue countermeasures, recognizing the signs of fatigue in themselves and co-workers and taking action to ensure fatigue arising from activities insider or outside of work does not lead to performance issues on the job.

With respect to fatigue prevention, the TSB investigation should examine:

- Employee and manager understanding of their responsibilities with respect to fatigue prevention;
- The level of knowledge throughout the organization of the science of sleep and fatigue and how it may be managed;
- The organization's policies and procedures with respect to fatigue;
- The extent to which these policies and procedures are adhered to; and,
- The organization's efforts to collect data on fatigue and continually improve.

Mitigation

Even in the face of the most diligent efforts to prevent fatigue through scheduling, education etc. instances will always arise when an individual who is scheduled to work is suffering from the effects of fatigue. In addition to the fatiguing effects of prolonged hours of wakefulness and working during periods of circadian low, issues such as illness (of the employee or a family member), having young children, difficulty sleeping, and unexpected operational requirements will mean that the effects of fatigue will need to be mitigated.

In the case of minor to moderate fatigue, this may be accomplished through the use of fatigue countermeasures including caffeine, exercise and strategic napping. In the case of significant fatigue, this may require the employee to recognize their level of fatigue and take steps up to and including recusing themselves from duty.

Like prevention, the mitigation of fatigue is a shared responsibility between the operator and the employee. Again in this instance, the employer contributes through the provision of education and the development of policies and procedures which support the mitigation of fatigue while the employee has a responsibility to take reasonable steps to recognize when they are fatigued and manage the situation.

For the purposes of our investigation we need to understand:

- The education and tools available to employees to help assess current levels of fatigue;
- The policies and procedures in place to mitigate the impact on safety when an employee is fatigued;
- The availability and frequency of use of fatigue countermeasures in the workplace; and,
- The employee's level of comfort reporting that they be fatigued and taking steps to mitigate this.

Performance Based Approaches to Fatigue Management

Fatigue Management Plans

Under requirements set out in the Work Rest Rules for Operating Employees, railway companies are required to submit fatigue management plans to Transport Canada.

Included in the aspects of what a fatigue management plan must consider are:

a) Education and training

b) Scheduling practices

c) Dealing with emergencies

d) Alertness strategies

e) Rest environments

f) Implementation policies

g) Evaluation of fatigue management plans and crew management effectiveness[141]

Fatigue Risk Management Systems (FRMS)

The recognition of the limitations of duty and rest regulations has led to a move toward Fatigue Risk Management Systems in some sectors of the transportation industry. Transport Canada (aviation) describes an FRMS as: "an integrated set of management policies, procedures, and practices for monitoring and improving the safety and health aspects related to fatigue within your organization." [142] The move toward such a system is supported by ICAO[143] and pilot associations provided the data collected through such a system is used appropriately and adequately protected.[144]

---

[141] Transport Canada (2011). Fatigue Management Plans: Requirements and Assessment Guidelines. Revised 1 March, 2011. Downloaded on 13 May 2014 from http://www.tc.gc.ca/eng/railsafety/guideline-618.htm

[142] Transport Canada (2007). Fatigue Risk Management System for the Canadian Aviation Industry: Policy and Procedures Development Guidelines. TP 14576E, April 2007. Downloaded on 3 July 2013 from: http://www.tc.gc.ca/media/documents/ca-standards/14576e.pdf

[143] International Civil Aviation Organization (ICAO) (2012). Fatigue Risk Management Systems – Manual for Regulators. ICAO DOC 9966. Downloaded on 3 July 2013 from

Transport Canada has yet to require FRMS from operators, but anticipate FRMS being integrated with a Company's Safety Management System (SMS) and including:

- a statement of senior management commitment;
- defined purpose and goals of the FRMS and specified responsibilities of all employees for managing fatigue risk;
- training requirements;
- reporting procedures for fatigue related hazards;
- a fatigue reporting policy (any punitive actions that may be taken as a result of non-compliance, for example); and,
- a procedure for evaluation and continuous improvement of the FRMS.

These elements are intended to ensure the FRMS addresses the five levels of control for fatigue related hazards outlined in the figure below.

http://www.icao.int/safety/fatiguemanagement/frms%20tools/doc%209966%20-%20frms%20manual%20for%20regulators.pdf

[144] Airline Pilots Association (ALPA) (2008). Air Line Pilots Association White Paper : Fatigue Risk Management Systems. Downloaded on 3 July 2013 from: http://www.alpa.org/portals/alpa/pressroom/inthecockpit/FatigueRiskMSWP_6-2008.pdf

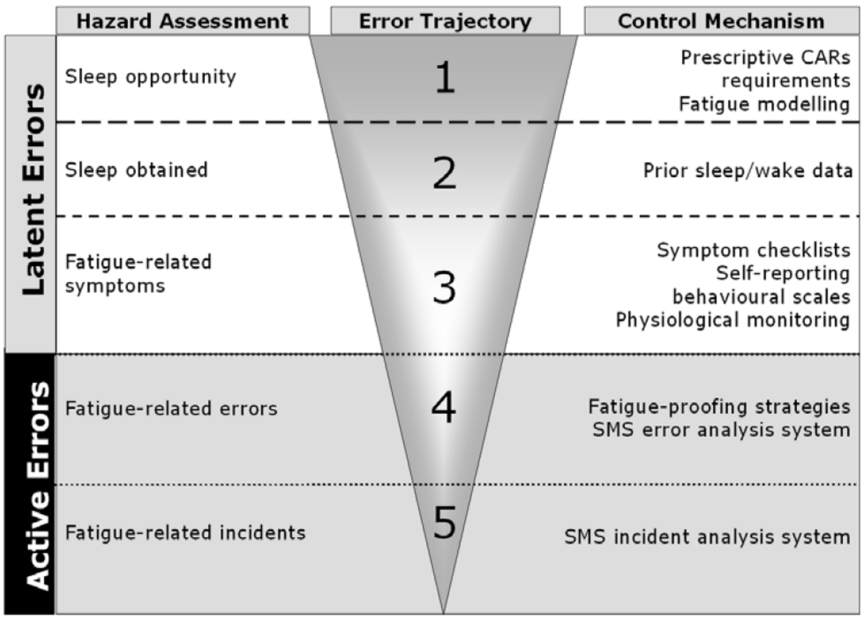


Figure 3: Five Level Fatigue Hazard Control Model (TC, 2007)

The Three Step Method for Investigating Fatigue

There are three steps in the analysis of sleep related fatigue in a transportation occurrence:.

1. Determine the level of fatigue present;
2. Determine if the state of fatigue played a role in the occurrence;
3. Determine if the practices in place were sufficient to effectively manage the risks of fatigue.

Drawing conclusions with respect to fatigue can be challenging given the many variables which can influence human performance. There will always be a small probability that some factor other than fatigue may better explain the occurrence. Carefully performing the analysis related to the existence and influence of fatigue will lead to defensible conclusions about the role fatigue may have played in an accident or incident.

Step One: Determine the Level of Fatigue Present (Test for Existence)

Determining whether a person involved in an occurrence was sufficiently fatigued at the time of a safety significant event[145] to impair performance is the crucial first step to investigating fatigue. It is the test of existence for fatigue. If fatigue is sufficiently likely, it can be documented in TSB terms as a finding as to risk even if it is later determined that it did not play a role in the occurrence.

Data Collection

Collecting the data required to investigate fatigue should be completed as soon after the occurrence as possible. The longer one waits to collect information about a person's sleep, the more difficult it will be for that person to recall the necessary data. In addition, diligently collecting all the required data will reduce the need to estimate missing parameters and the need to be overly conservative in the conclusions. **A Fatigue Data Collection and Analysis Form can be found in Appendix A**. Using

[145] A safety significant event is an event that played or could have played a role in an occurrence.

this form as part of the routine data collection will make it easier to look into fatigue later on in the investigation even if it was not immediately suspected to have played a role. All questions should be probed in depth, particularly if the operator is a shift worker as this affects several risk factors.

Optimal Sleep-Wake Pattern

To perform the test of existence for fatigue, it is extremely important to collect data to determine the optimal sleep-wake pattern of the person who was involved in the safety significant event. In the absence of a well-documented optimal sleep-wake pattern, analysis of the data will be unlikely to result in strong conclusions. The optimal sleep-wake pattern will act as the baseline to which the person's recent sleep-wake pattern will be compared. To determine this pattern, it is important to understand the quantity and quality of sleep the person normally needs to be able to maintain alertness and optimal performance across a subsequent wakefulness period. In other words, one must figure out what amount and quality of sleep the person needs so they do not become fatigued until the following sleep period. Remember that the average daily quantity of sleep is seven to eight hours, but that the normal range can be between six and nine hours. If the person is available for an interview, one can figure out their optimal sleep quality and quantity by asking about their sleep-wake patterns on their days off or during vacations. Be sure to ask how much sleep they get on those days and if they actually need more to feel really good throughout the day. Determining the lights out time, time it takes to fall asleep (referred to as sleep onset latency), the number, duration and time of awakenings, the wake up time, the lights on time , as well as napping details and the total sleep

Determine the optimal sleep-wake pattern required to maintain alertness and optimal performance without becoming fatigued until bedtime.

time , will help establish the baseline optimal sleep-wake pattern. If they normally have a broken sleep, for instance waking for half an hour per night, then the total sleep time may be reduced so long as the breaks are not so frequent or long that they could disrupt the quality of sleep obtained. In this case chronic fatigue may be an issue.

If the person is not available for an interview, obtaining the information from someone intimately familiar with the person's optimal sleep-wake pattern and sleep quantity and quality, while keeping potential inaccuracies in mind, may be necessary. If an individual's optimal sleep-wake pattern cannot be determined, one may assume the 'textbook' sleep-wake pattern described in the section entitled *The Basics of Sleep* (e.g., 7.5 hours of good quality sleep starting and finishing at logical times). It is important to be conservative when assuming the 'textbook' sleep-wake pattern, as this will reduce the likelihood of overestimating fatigue in the analysis phase.

Establish the sleep-wake history working backwards to the last two nights of good quality and quantity of sleep.

Sleep-Wake History

After a person's optimal sleep-wake pattern is determined, their recent sleep-wake history should be established. This is accomplished by first determining when the person must have been awake and then determining when sleep occurred. For example, obtaining work schedules, hotel door key records, telephone activity records, detailed credit card activity statements, and recollections of watched television programs, can be helpful indicators of wakefulness. Graphically depicting the wakefulness, as illustrated below in Table 1, according to the wakefulness data and then asking the person to look at the data and indicate when they slept can establish an accurate sleep-wake history.

Although it is difficult for people to determine the quality of their own sleep, if the person felt that a particular sleep period was of poor quality, this should be noted. Recording the sleep-wake history in terms of home base time --that is, the time zone the person's biology is synchronized to–- can reduce confusion in instances where the person has traveled across time zones. In addition, rather than arbitrarily limiting this sleep-wake history to 72 hours, one should attempt to build a clear and detailed sleep-wake history that extends back to the last two nights [146] of good quantity and quality sleep. Most sleep deprivation research indicates that two nights of good quantity and quality of nighttime recovery sleep returns performance levels back to baseline[147]. Working backwards to the last two nights of good quantity and quality sleep will provide a starting point should one wish to calculate a sleep debt. If exact sleep details are not available, ask the person when they would most likely have slept given the pattern of wakefulness.

If the person is not available, determining when sleep occurred can be a challenge. Considering information from roommates, colleagues, spouses and others may be necessary. If determining the sleep periods from these sources is not possible, then one may assume that the person attempted to maintain a sleep pattern that was consistent with their optimal sleep-wake pattern determined above; if details about the optimal sleep-wake pattern are not available, the 'textbook' sleep-wake pattern described in the section entitled *The Basics of Sleep* may be used to estimate sleep periods.

---

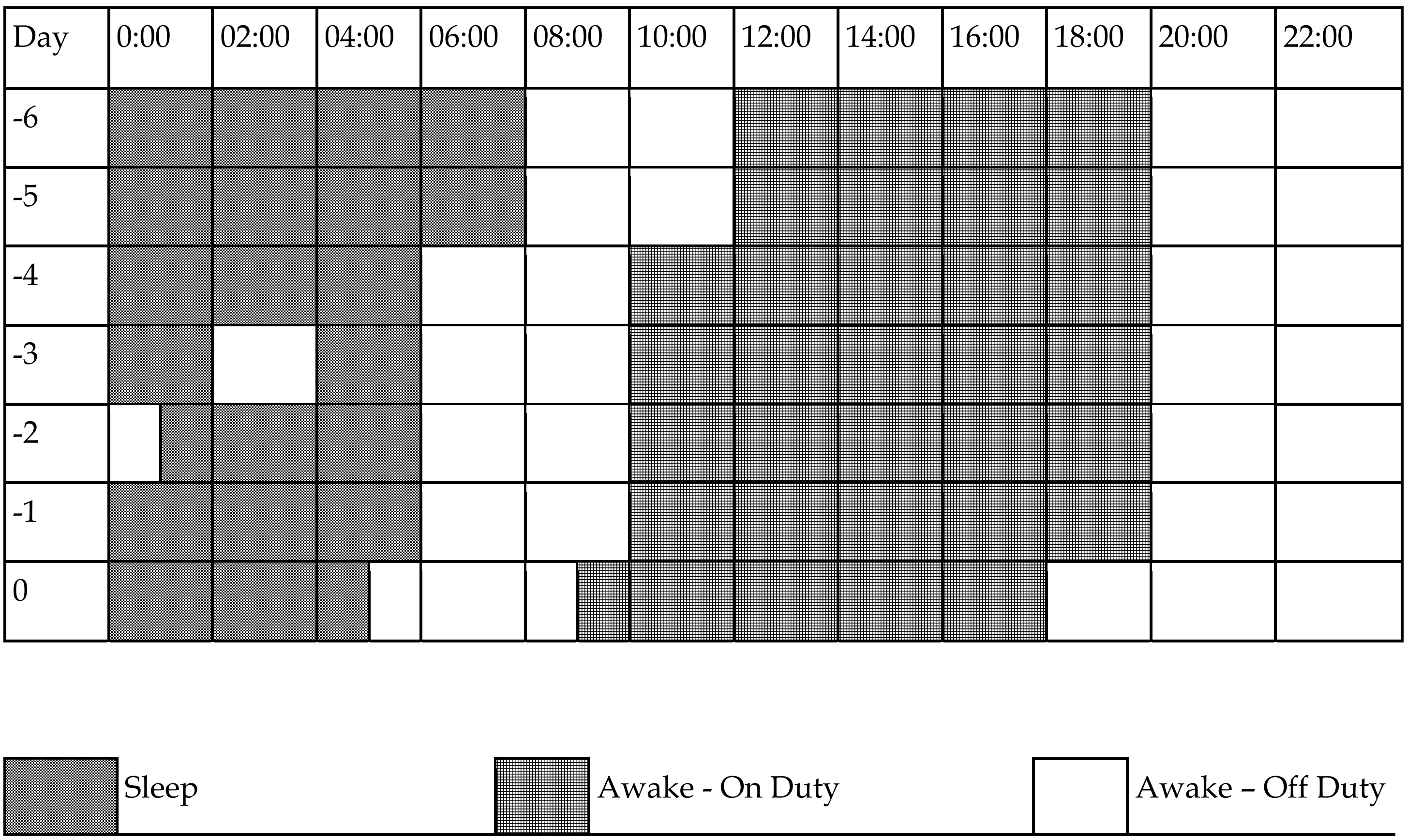
[146] Nocturnal, as opposed to diurnal, recovery sleep is required.

[147] See for examples:

(A) Drummond, S., Paulus, M., & Tapert, S. (2006). Effects of two nights sleep deprivation and two nights of recovery sleep on response inhibition. Journal of Sleep Research, 15(3), 261-265.

(B) Wehrens, S., Hampton, S., Kerkhofs, M., & Skene, D. (2012). Mood, alertness, and performance in response to sleep deprivation and recovery sleep in experienced shiftworkers versus non-shiftworkers. Chronobiology International, 29(5), 537-548.

Table 1: Example of a sleep-wake history.



Record at least as far back as the last 2 consecutive nights of good quantity and quality sleep.

Use blocks of 15 minutes. Two hour blocks are used here to simplify the appearance of the figure.

Medical and Psychological History

A thorough collection of data regarding a person's medical and psychological history is necessary to determine whether any sleep disorders, medical and psychological conditions, illnesses or drugs may have increased the risk of fatigue. Simply asking the person if they have been diagnosed with a medical, psychological or sleep condition can be a good starting point. If the person cannot be asked directly or if someone close to the person cannot provide information about diagnoses, then examining medical and psychological records may be required. Psychologists will often make notations about sleep problems that are not reported to medical doctors. For example, many psychologists are trained in cognitive behavioural therapies to treat psychophysiological insomnia. The sleep disorder may therefore only be reported and treated by the psychologist and the medical doctor may be unaware of the patient's sleep disorder. In addition, many psychologists treat depression and anxiety disorders both of which have a relationship with stress and decreased sleep quality.

If no diagnoses are reported, it does not mean that the person does not have a medical, psychological or sleep problem. They may have an undiagnosed sleep disorder, for example. One should therefore, at least, ask about symptoms of sleep disorders. General questions such as "Do you have problems falling asleep, staying asleep, or with waking up too early?", "Do you snore?", "Do you feel fatigued on your days off?", or "Does your bed partner say that your legs move when you sleep?" can be helpful in determining whether a sleep disorder should be suspected. In addition, measurements of neck circumference and body mass indices (BMI) should be obtained because they can predict the risk of obstructive sleep apnea.

If a sleep disorder is suspected, then consider asking the person to undergo an over-night sleep study and a daytime assessment of fatigue[148] performed in a reputable sleep disorders center staffed by a physician certified by the American Board of Sleep Medicine (ABSM)[149]. The physician can provide a

[148] Sleep studies are only accurate at the time they are performed and may not reflect the state of health of the person at the time of the occurrence. Accurate assessments of fatigue are completed through the Multiple Sleep Latency Test (MSLT) and the Maintenance of Wakefulness Test (MWT) although these assessments are only accurate at the time of testing and may not reflect fatigue levels at the time of the occurrence.
[149] The TSB may need to cover the expense of this testing.

report with conclusive evidence to support or negate the presence of a sleep disorder as well as document current levels of daytime fatigue.

As part of the data collection for the medical and psychological histories, personal stress levels should also be explored. Mental stress can decrease sleep quality which increases the risk of fatigue. Asking questions such as "Can you tell me about the stress in your life?" can be useful.

Obtain a thorough medical and psychological history to determine if a sleep disorder, illness or drug may have played a role.

A complete list of all drugs ingested over the last month should also be compiled. This list should include dosages or quantities as well as the time of ingestion. Be sure to collect information about all drugs, including over the counter medications, prescriptions, herbal and naturopathic remedies, recreational drugs, as well as alcohol, nicotine and all sources of caffeine (e.g., chocolate, coffee, tea, energy drinks). Although the primary concern will be with substances recently ingested, do not limit the inquiry to looking at the last day or two. Some drugs can stay in a person's system for many days or even weeks; and whether they have an effect on fatigue or performance is dependent upon such factors as duration of ingestion or exposure time and amount ingested.

Some companies require blood and/or urine tests for any employee involved in an accident; and many hospital emergency departments routinely obtain and test blood and urine. Although these tests may provide some indication of ingested substances, they may not be accurate predictors of fatigue or performance impairments. Always consider obtaining a sample of blood taken by the company or hospital and a sample of urine for testing at an independent laboratory. Be sure to select a laboratory that can detect low levels of substances that can affect fatigue and performance.

Note that although the chemistry and electrical activity of the human brain changes with increases in fatigue and sleepiness[150], there is no blood or urine test that can provide an estimate of fatigue levels. HF support must be sought when requesting medical samples.

Analysis

Having established a baseline for the optimal sleep-wake pattern[151] (based on data from interviewing the person or others intimately aware of the person's daily patterns, or by assuming a conservative 'textbook' sleep-wake pattern), their sleep-wake history, as well as the medical and psychological history, a determination of the presence and magnitude of any fatigue risk factors can be made. A caution should be observed at this point. There is no rigid formula that can be applied to the fatigue risk factors to demonstrate that fatigue was sufficient to impair performance. . The magnitude of each risk factor in addition to the number of risk factors must be considered. For example, a person may have slept three hours less than normal the night before the accident, confirming the presence of acute sleep disruption, but they may not have been fatigued if the safety significant event was performed early in the day. In contrast, one hour less sleep for three consecutive sleep periods may result in fatigue.

[150] For a complete understanding of the brain's electrical and chemical changes coincident with sleep, refer to: Anch, A., Browman, C., Mitler, M., & Walsh, J. (1988). Sleep: A Scientific Perspective. New Jersey: Prentice-Hall.
[151] I.e., details about the quality and quantity of sleep a person needs to maintain alertness and performance throughout wakefulness.

Without a formula to rely upon, the test of existence for fatigue requires a strong familiarity with the research literature. Investigators are strongly encouraged to use the fatigue data collection and analysis worksheet in their investigations. Support may also be obtained by contacting the Manager, Human Factors and Macro Analysis.

There is no formula that can be applied to the fatigue risk factors to determine if fatigue existed.

Acute Sleep Disruption

To determine if the person was suffering from acute sleep disruption at the time of the safety significant event, compare the three most recent sleep periods from immediately prior to the occurrence to the person's optimal sleep-wake pattern or the 'textbook' sleep-wake pattern.

1. If the person obtained 30 minutes (or more) less sleep during any of the three recent sleep periods when compared to the optimal sleep-wake pattern or the 'textbook' sleep-wake pattern of seven to eight hours per sleep period, then the acute sleep disruption fatigue risk factor <u>may</u> exist.

2. Recall that 'textbook' good quality sleep is not disturbed by awakenings. Therefore, if the optimal sleep-wake pattern is not available as a comparator, and one or more 30 minute awakenings occurred on any of the three most recent sleep periods, then the acute sleep disruption fatigue risk factor <u>may</u> exist. Alternatively, if the optimal sleep-wake pattern is available as a comparator, and the awakenings were more frequent, at a different time or longer duration than usual on any of the three most recent sleep periods, then the acute sleep disruption risk factor <u>may</u> exist.

These three conditions have been qualified by the words "may exist" because the magnitude and timing for the individual conditions must be considered along with the number of conditions met. For example, if a person obtained two hours less sleep than required by their optimal sleep-wake pattern three nights prior to the occurrence, and then obtained two hours extra recovery sleep on the night immediately preceding the occurrence, then the acute sleep disruption fatigue risk factor likely does not exist. If, however, the two hours of recovery sleep was not obtained and on the two nights immediately preceding the occurrence the person experienced more awakenings than normally experienced during their optimal sleep-wake pattern, and they fell asleep 30 minutes later and woke up 30 minutes earlier on the night immediately preceding the occurrence, then the acute sleep disruption fatigue risk factor likely does exist.

Chronic Sleep Disruption

Chronic sleep disruption is assessed by comparing the entire sleep-wake history to the person's optimal sleep-wake pattern or the 'textbook' pattern.

1. If the optimal sleep-wake pattern is not available as a comparator, and awakenings were frequent throughout the sleep-wake history, then the chronic sleep disruption fatigue risk factor <u>may</u> exist. Alternatively, if the optimal sleep-wake pattern is available and awakenings were more frequent, occurred at different times or were longer when compared to the optimal sleep-wake pattern, then the chronic sleep disruption fatigue risk factor <u>may</u> exist.

2. If a sleep debt of eight hours or more existed at the time of the safety significant event, then the chronic sleep disruption fatigue risk factor <u>exists</u>. If a sleep debt of less than eight hours existed, the chronic sleep disruption fatigue risk factor <u>may</u> still exist.

Similar to the acute sleep disruption conditions, the first two conditions for chronic sleep disruption are qualified by the words "may exist". Again the magnitude and timing of the individual conditions must be considered along with the number of conditions met.

In the last condition, eight hours is used as the threshold for a sleep debt that will affect performance because it is the equivalent of missing one entire sleep period for most people, which almost guarantees a level of fatigue that will impair some aspects of performance. In general, the greater the chronic sleep debt, the higher the degree of confidence that fatigue was present at a level which would negatively impact performance.

Continuous Wakefulness

To calculate the period of continuous wakefulness, use the sleep-wake history and work backwards from the time of the safety significant event to the end of the last full sleep period. The number of hours between these two points is the period of continuous wakefulness. If a nap of less than one hour occurred in between these two points, count it towards the period of continuous wakefulness. Naps of less than one hour are not likely to provide a reduction in the risk of fatigue for the entire subsequent period of wakefulness because it normally takes a person 30 to 45 minutes to enter deep sleep. If a nap of more than one hour occurred, do not count it towards the period of continuous wakefulness. After the period of the continuous wakefulness has been calculated, the following thresholds should be considered.

1. If the person was awake for 17 hours, then the continuous wakefulness fatigue risk factor may exist. A more conservative threshold may be used if the hours of continuous wakefulness occur at night.

2. If the person was awake for 22 hours or more, then the continuous wakefulness fatigue risk factor exists.

As with the sleep disruption fatigue risk factors, the first two conditions for the continuous wakefulness fatigue risk factor have been qualified by the words "may exist". As mentioned in the section entitled *Medical and Psychological Conditions, Illnesses and Drugs,* caffeine has stimulating effects. Research has demonstrated that appropriately timed countermeasures, such as caffeine consumption at strategic times, can reduce the risk of fatigue[152]. Therefore, it may be possible for a person who has ingested caffeine to be awake for prolonged periods without demonstrating the same performance effects associated with fatigue.

Circadian Rhythm Effects

In the practical setting, general rules based on research findings for the circadian rhythm of fatigue and circadian rhythm adjustment time are used to determine the likelihood of fatigue due to circadian rhythm effects.

[152] Scientific evidence supports the use of caffeinated energy drinks as effective countermeasures to fatigue during a single night shift. See for example: Jay, S., Petrilli, R., Ferguson, S., Dawson, D., & Lamond, N. (2006). The suitability of a caffeinated energy drink for night-shift workers. Physiology & Behavior, 87(5), 925-931.

Circadian Rhythm Timing

1. If the person was involved with the safety significant event during the circadian rhythm trough (22:30 to 04:30 hrs +/- 1.5 hours for individual variability), then the circadian rhythm effects fatigue risk factor due to circadian rhythm timing <u>may</u> exist.

2. If the person was involved with the safety significant event during the post-lunch dip (14:00 hrs +/- 0.75 hours for individual variability) then the circadian rhythm effects fatigue risk factor due to circadian rhythm timing <u>may</u> exist.

Circadian Rhythm Desynchronization

To assess this component of the circadian rhythm effects fatigue risk factor, the sleep-wake history is examined for frequent sleep pattern changes and the actual circadian rhythm adjustment time is compared to the optimal adjustment time.

To determine the frequency of sleep pattern changes, examine the sleep-wake history for the eight days preceding the safety significant event. If the sleep-wake history was compiled by applying the 'textbook' pattern of sleep, then it may be prudent to examine this data for work periods that would require changes to sleep patterns rather than rely on 'textbook' estimates of the sleep patterns. Otherwise, examining the regularity of the sleep as reported by the person who was involved with the safety significant event is preferred. Calculate the number of small changes of about one hour to the sleep onset times and the number of large changes of about three hours or more to the sleep onset times.

To compare the actual and optimal circadian rhythm adjustment times, first, examine the sleep-wake history for a point where the person's sleep occurred at the same time for at least two consecutive sleep periods. It may be beneficial to start at the beginning of the sleep-wake history, at the point where the last two nights of good quality and quantity of sleep were obtained. Next, determine the difference in clockwise or counter-clockwise hours between the sleep onset time at that point and the sleep onset time for the sleep period immediately preceding the safety significant event. Finally, calculate the number of days between the two points. This calculation provides the actual circadian rhythm adjustment time.

To calculate the optimal adjustment time, divide a clockwise difference in hours by 1.5 and divide a counter-clockwise difference in hours by 1.0 to obtain the optimal number of days that would be required for full circadian rhythm adjustment.

1. If there are frequent small changes (1-3 hour), or one or more large changes (>3 hours) to the sleep onset time, then the circadian rhythm effects fatigue risk factor due to circadian rhythm desynchronization <u>may</u> exist.

2. If the actual circadian adjustment time is less than the optimal circadian rhythm adjustment time, then the circadian rhythm effects fatigue risk factor due to circadian rhythm desynchronization <u>exists</u>.

The first condition above has been qualified by the words "may exist" because if the major portion of the sleep period, as little as four hours, occurs at the same time every day, it may anchor circadian rhythms[153] and reduce the likelihood of circadian rhythm desynchronization.

---

[153] Mills, J. N., Minors, D. S., & Waterhouse, J. M. (1978). Exogenous and endogenous influences on rhythms after sudden time shifts. Ergonomics, 21, 755-761.

Sleep Disorders

Examining the information obtained in the medical and psychological history will help to determine if the sleep disorders fatigue risk factor exists. If the person has been diagnosed with a sleep disorder or if they report symptoms consistent with a sleep disorder, the disorder should be researched to determine if fatigue normally results from the disorder. A component of this research should focus on whether treating or managing the disorder can reduce fatigue and then determining if the person's sleep disorder was treated or managed properly (e.g., was CPAP prescribed to an apneic and was the person complying with the treatment; often CPAP machines record to what extent they were used).

As mentioned in the *Data Collection* section above, if a sleep disorder is suspected, an assessment by a reputable sleep disorders center can provide objective data and should be requested whenever possible.

1. If a sleep disorder has been diagnosed, and is not being effectively managed, , then the sleep disorders fatigue risk factors <u>exists</u>.

2. If symptoms consistent with a sleep disorder are reported, then the sleep disorders fatigue risk factors <u>may</u> exist.

Consideration must be given to how well the condition was being treated or managed thereby reducing the risk of fatigue.

Medical Conditions, Illnesses and Drugs

As with the sleep disorders fatigue risk factor, examining the information obtained in the medical and psychological history will help determine if the medical and psychological conditions, illnesses and drugs fatigue risk factor exists. All medical conditions and illnesses from which the person may have been suffering when the safety significant event occurred should be researched to conclude if fatigue could be a symptom or result of the condition or illness. Keep in mind that some medical conditions, although not considered illnesses, may also result in fatigue. For example any condition that causes pain such as common back pain, has the ability to disturb sleep and result in fatigue. Consideration should also be given to how well the condition was being treated or managed thereby reducing the risk of fatigue.

In addition, all drugs, including over the counter, prescription, herbal, naturopathic and recreational drugs as well as alcohol, caffeine and nicotine, that the person ingested should be researched. Whether the substance produces fatigue directly or indirectly through disturbed sleep, may be dependent upon the dosage, quantity or time of ingestion.

1. If the person was suffering from a medical or psychological condition or illness with fatigue as a symptom or a result of poor quality sleep, the medical and psychological conditions, illnesses and drugs fatigue risk factor <u>may</u> exist.

2. If the person ingested a drug that produces fatigue directly or as a result of poor quality sleep, the medical conditions, illnesses and drugs fatigue risk factor <u>may</u> exist.

The human factors team can facilitate conclusions about whether fatigue was a risk factor in the occurrence.

Conclusions from the Test of Existence

The test of existence for fatigue ends with a conclusion about whether fatigue was sufficient to impact performance at the time of the safety significant event. It does not draw a causal link as that is covered in the next test. Statements about a person's level of fatigue are normally qualified with a level of certainty such as "was likely not fatigued", "may have been fatigued", "likely was fatigued", "highly likely was fatigued". The level of certainty that can be applied to the conclusion is dependent upon what was learned about the presence and magnitude of the fatigue risk factors. Exceptions to this approach may occur in such cases where the data is inadequate to make conclusions or when the data is conclusive, for example, when a person states they fell asleep or when the person was observed to fall asleep. In these cases, concluding statements such as "the data were inconclusive and fatigue could not be ruled out/in", or "given that the operator fell asleep, fatigue was most definitely present" may be required. The TSB does not make assertions about the absence of a factor 'for instance the presence of fatigue could not be discounted', however we may comment of the quality of data available ' insufficient data was available to draw conclusions about the magnitude of fatigue' so long as this is not used to lead the reader into assuming that fatigue may have been/was present.

Review how many fatigue risk factors were present and the magnitude of each one to determine the likelihood the person was fatigued. Remember that there is no formula that can be applied to determine this likelihood. The presence of one fatigue risk factor of high magnitude may be sufficient to conclude that the person was fatigued. For example, if acute sleep disruption was present in the form of a two hour sleep period on the night prior to a safety significant event that occurred 15 hours after awakening, it would be safe to conclude that it was highly likely that the person was fatigued.

Alternatively, a combination of low magnitude fatigue risk factors may be sufficient to conclude the person was fatigued. For example, if the person was diagnosed with obstructive sleep apnea and no treatment was provided, a sleep debt of four hours was calculated, and the person worked a series of shifts that required numerous sleep pattern changes within a short period of time, it would be safe to conclude that the person was likely fatigued.

Making conclusions about the test of existence for fatigue can be challenging. If the test of existence is 'passed' (i.e., fatigue existed) then it may also be appropriate to conclude, using TSB terminology, that fatigue was a risk factor in the occurrence. The research discussed in this guide as well as additional scientific literature and the Human Factors team may need to be consulted to form such a conclusion.

The existence of fatigue does not guarantee a negative outcome. Understanding whether the actions were consistent with a fatigue related performance decrement is the key to the test of influence.

Step Two: Determine if Fatigue Played a Role (The Test of Influence)

Determining whether a fatigued person's actions that caused or contributed to the safety significant event were due to fatigue is the second step. It is the test of influence for fatigue. It is important to realize that a fatigued person does not guarantee an accident. It is highly likely that some aspect of the fatigued person's performance will be impaired, but that aspect of performance may not have influenced the safety significant event. For example, a fatigued person's mood may have been impaired at the time of a safety significant event. But, if the safety significant event was related to ergonomic issues, fatigue cannot be identified as a causal or contributing factor. The test of influence therefore is not 'passed'.

The essence of the test of influence is to understand whether the actions of the person were consistent with what is known about human performance in a state of fatigue. To perform this test, data must be gathered and analyzed.

Data Collection

At this point in the overall investigation, the safety significant events, as well as the actions and performance impairments that led to the safety significant events of the people involved, should already be known. The first step in identifying the role of fatigue in the occurrence is to ensure the safety significant event is well understood. Applying the integrated investigation process as part of the ISIM analysis will help to better understand the human performance by identifying the cognitive processing mode in use at the time (i.e. skill, rule or knowledge based performance) and the error type (slip, lapse, mistake or adaptation (violation) and the factors contributing to the error. This must be completed <u>prior</u> to the test of influence for fatigue.

Knowing the performance impairments prior to the test of influence described below is crucial in avoiding confirmation bias regarding the role of fatigue. Confirmation bias is the tendency to search for information that confirms one's preconceptions[154]. Fatigue affects many aspects of performance and this can make it easy to erroneously attribute an action to a fatigue related performance impairment. For example, if the test of existence confirmed that an engineer was fatigued at the time of the safety significant event, confirmation bias can lead one to look for and find evidence of an influential fatigue related performance impairment. In this case the investigator may look for and find a cognitive impairment that explains the action that led to the safety significant event. This may

[154] For a discussion of confirmation bias see: Myers, D. (1990). Social Psychology (3rd Ed.). New York: McGraw-Hill Publishing.

lead to erroneous conclusions such as impaired decision making or degraded problem solving due to fatigue led to the accident. In other words, the approach that must be avoided is determining that a person was fatigued and then searching for a fatigue related performance impairment that could explain the outcome.

The data collection component of the test of influence consists of reviewing the independent analyses of the safety significant events already completed and listing the associated performance issues. A table is provided in the data collection and analysis form at appendix A for this purpose.

Analysis

Understanding whether the causal or contributing performance impairments could have been due to fatigue is normally a matter of comparison. If the performance impairment falls into one of the following categories, then it may have resulted from fatigue, providing that the test of existence was 'passed'.

- Rate of information processing
- Problem solving
- Decision making
- Memory
- Attention or vigilance
- Reaction time
-

Specific fatigue related performance impairments may be found in current fatigue research literature.

These categories of fatigue related performance impairment were discussed in the section entitled *Fatigue and Performance Impairment* and represent frequently researched outcomes of fatigue. The list is general in nature and is not exhaustive. The Fatigue Data Collection and Analysis Form will assist in documenting the effects of fatigue by outlining all of the available information which supports or refutes the influence of fatigue. The Human Factors team may be able to provide more specific research findings linking fatigue to other, and possibly more specific, performance impairments. Furthermore, the Human Factors team can ensure that alternate hypotheses (non-fatigue explanations) are appropriately tested[155] and ruled out to strengthen the fatigue related conclusions.

The Human Factors team can strengthen your fatigue conclusions by ruling out other explanations for the performance impairments.

Conclusions from the Test of Influence

The test of influence ends with a conclusion about whether the observed performance impairment is consistent with the known effects of fatigue on performance. If the safety significant event and action resulting from the performance impairment had a direct influence on the occurrence, then it may also be appropriate to conclude, using TSB terminology, that fatigue was <u>a causal or contributing factor</u> rather than a risk factor.

Conclusions about the influence of fatigue on performance impairments must also be qualified with levels of certainty. In most cases, the fatigue research literature reliably links fatigue to the performance impairments discussed in this guide. Concluding statements with qualifiers such as "highly likely due to fatigue", and "likely due to fatigue" can be used. For example, statements such

[155] Testing alternate hypotheses is an integral part of research based on probability theory introduced previously.

as "slowed reaction time likely due to fatigue" or "poor decision making highly likely due to fatigue" can be used when, according to the fatigue research literature, the link between fatigue and the performance impairment is very reliable. In cases where the link is less reliable or there may be competing explanations for the performance impairment, such as alcohol intoxication, concluding statements with less certainty such as "possibly due to fatigue" may be appropriate.

Bio-mathematical Analysis of Fatigue

Accident investigators may request a complete subject matter expert analysis of the existence of fatigue and its effects on performance from the Human Factors team. If data have been diligently collected, the Human Factors team can also perform a validation and quantification of the existence of fatigue and its effect on performance using the Fatigue Avoidance Scheduling Tool (FAST)[156]. FAST is sophisticated bio-mathematical software that can provide estimates of human performance at specific points within sleep-wake patterns.

In addition to estimates of performance, FAST can predict the following metrics:

- Mean cognitive ability: A score which approximates the average cognitive throughput on standard cognitive tests (average speed of mental operations as a percent of rested performance)
- Lapse index: A value that represents the likelihood of a lapse in attention relative to a well-rested person performing during the day
- Reaction time: The average reaction time, expressed as a percent of the average reaction time of a well-rested person performing during the day

[156] Fatigue Avoidance Scheduling Tool (FAST). Detailed scientific information about FAST and the underlying SAFTE model and its validation are contained in: Hursh, S., Redmond, D., Johnson, M., Thorne, D., Belenky, G., Balkin, T., Storm, W., Miller, J., & Eddy, D. (2004). Fatigue models for applied research in warfighting. Aviation, Space, and Environmental Medicine, 75(3 Suppl), A44-A53. FAST is wholly owned and exclusively distributed by Fatigue Science, 700 Bishop Street, Suite 2000, Honolulu, Hawaii, 96813, USA, http://www.fatiguescience.com.

- Sleep reservoir: The remaining restorative value from preceding sleep, may be conceptualized as the amount of energy or time left to be awake given the previous sleep and wake periods

Combining a subject matter analysis with a secondary bio-mathematical validation from the Human Factors team can result in strong conclusions regarding the role of fatigue in an occurrence.

Step 3: Examine Fatigue Risk Management in the Organization

The aim of a fatigue management plan or program is to reduce the risks associated with fatigue in 24/7 operations to a level that is as low as reasonably practicable (ALARP). To assess, whether the organization has taken reasonable steps in this area, investigators should gather and analyze data in the following areas. The Fatigue Data Collection and Analysis Form can be employed to assist with this.

Scheduling

- Obtain schedule going back 1 full cycle – analyze for risk factors which make it more difficult to obtain sufficient, quality sleep (e.g. lack of predictability, frequent changes, backward rotation, inadequate recovery time).
- Look for other scheduling risks for fatigue (excessive overtime, trading of shifts)
- Consider conducting FAST analysis.

Prevention

- Examine content of fatigue management training provided to employees.
- Identify what fatigue countermeasures available and permitted (e.g. exercise facilities, nap facilities, food and beverages).

- Examine practices with respect to work rotation and opportunity for breaks.

Mitigation

- Examine tools provided to assist employees in recognizing fatigue.
- Determine means for employees to report fatigue and take appropriate steps to mitigate.

Quality Assurance

- Determine whether schedules are reviewed for the potential for fatigue.
- Document the means for employees to report situations which could lead to fatigue?
- Identify whether/how fatigue is considered in organization’s internal investigation of incidents.

Final Investigation Findings

TSB reports should include all the fatigue related data and should document fatigue levels with appropriate levels of probability and conservatism. Providing sleep-wake histories, details on optimum sleep-wake patterns, background information on sleep disorders or medical and psychological conditions, as well as reviews of scientific literature will build support for the final investigation findings. Being conservative with estimates of sleep-wake patterns and conclusions about fatigue will ensure that fatigue levels are not overestimated and easily disputed.

TSB reports conclude with three different categories of findings.

1. Findings as to causes and contributing factors
2. Findings as to risk
3. Other findings

Findings in the first category have 'passed' both the test of existence and the test of influence. Findings in the second category, and often the third category, have only 'passed' the test of existence. In all cases, the findings should identify fatigue risk factors as well as fatigue related performance impairment concerns. Additionally, whenever possible, the conditions or actions that led to the fatigue risk factors, for example organizational and management factors such as poor FRMS, irregular work schedules and a lack of fatigue awareness and management training, should also be identified in the finding.

Model statements for each finding category are listed below. These statements represent the final outcomes of investigations into human fatigue.

Example of a Finding as to Cause and Contributing Factor

*The locomotive engineer applied the dynamic brake too late due to an impaired reaction time (**fatigue related performance impairment**) highly likely caused by fatigue. The locomotive engineer was highly likely fatigued from the acute sleep disruption (**fatigue risk factor**) of being woken up during a sleep period due to on-call scheduling practices (**condition that led to the fatigue risk factor**).*

Example of a Finding as to Risk

*The air traffic controller was likely fatigued at the time of the accident due to poor sleep pattern management resulting from a lack of understanding of circadian rhythms (**fatigue risk factor**) due to the absence of fatigue awareness training (**condition that led to the fatigue risk factor**) in the fatigue risk management system.*

Note that a fatigue related 'finding as to risk' may still be possible even if fatigue was not present -- that is, the test of existence for fatigue was not 'passed'. For example, organizations with continuous operations may be exposing their operators to the risk of becoming fatigued if the organization does not have a fully developed FRMS. It this case the 'finding as to risk' could be:

Although the operator may not have been fatigued at the time of the accident, the organization was not managing fatigue through a Fatigue Management Risk System which could increase the risk that operators may become fatigued.

Example of an Other Finding

*Mariners in safety critical positions, such as watchkeepers, may become fatigued from continuous periods of wakefulness (**fatigue risk factors**) during the nighttime hours if the organization's Fatigue Risk Management System does not ensure that all operators receive training on appropriate and strategic fatigue countermeasures (**condition that led to the fatigue risk factor**) such as the strategic use of caffeine and controlled rest.*

Transportation Safety Board of Canada

Bureau de la sécurité des transports du Canada

Appendix A: Fatigue Data Collection and Analysis Form

Transportation Safety Board of Canada
Fatigue Data Collection and Analysis Form
Collect as soon as possible after the occurrence

Background Information:

Occurrence Number:	
Common Title:	
Name and Title of Person:	
Date Form Completed:	
Role in Occurrence	
TSB Investigator:	
Data Sources:	❑ **Work schedule** ❑ **Transportation schedule (e.g. means of commuting to work)** ❑ **Interview with involved person** ❑ **Interview with person close to involved person** **Specify: ____** ❑ **Other activity data (e.g. cell phone, room key records)** **Specify:** **____** **____**

Part A: Data Collection

Step 1: Determine Optimal Sleep-Wake Pattern

The optimal sleep-wake pattern is the one which allows the individual to maintain effective performance without experiencing fatigue throughout the waking period. The purpose of collecting this information is to establish the person's normal sleep requirements and sleep habits; this is essential for any fatigue analysis.

When asking the following questions, it may be helpful to tell the interviewee to describe the sleep they need to feel good during the day or the sleep they get when they are not working or the sleep they get when they are on holidays.

Questions	Interviewee's Answers
What time do you go to bed?	
How long does it take you to fall asleep?	
How many times do you wake up during one sleep period?	
At what times are the awakenings?	
How long is each awakening?	
What time do you wake up?	
What time do you get out of bed?	
Do you feel sleepy or fatigued on your days off?	
Do you ever fall asleep during the day or the evening?	
When do you nap?	
How long is each nap?	
Investigator Use:	
Investigator's assessment of Total Optimal Sleep Time (number of hours sleep normally required per 24 hours)	
Sources of data (e.g., person involved in occurrence, roommate, spouse)	
Notes:	

Questions	Interviewee's Answers

Step 2: Establish Actual Sleep-Wake History

A comprehensive sleep-wake history is critical to the analysis of sleep related fatigue. Using all available sources of data complete the grid below in as much detail as possible. Data is required back until the individual had two good sleeps, or if they do not recall two good sleeps, two weeks. The most effective way to do this will be to:

1. Indicate the occurrence time (X) in the bottom right of the grid.
2. Using the individual's work schedule, indicate periods of awake and on-duty (AD).
3. Through interviews with the involved individual or others who can provide information, fill in periods of awake and off duty (A), asleep (S) and napping (SN).

Although each cell in the grid represents one hour, attempt to obtain details for every 15 minute block of time. Write the times of changes between AD, A, S, and SN. Work backwards to the last two nights of optimal sleep or further as required. If exact sleep details are not available, ask the person when they would most likely have slept given the pattern of wakefulness.

Example Sleep-Wake History

Name: Rail Engineer One																									
Home Base Time ->		0000 0100	0100 0200	0200 0300	0300 0400	0400 0500	0500 0600	0600 0700	0700 0800	0800 0900	0900 1000	1000 1100	1100 1200	1200 1300	1300 1400	1400 1500	1500 1600	1600 1700	1700 1800	1800 1900	1900 2000	2000 2100	2100 2200	2200 2300	2300 0000
Day	Date																								
Monday	19May																								
Tuesday	20May	S	S	S	S	S	S	S	S- 0730 -A	A	A	A	A	A	A	SN	SN	A	AD	AD	AD	AD	AD	AD	A
Wednesday	20May	S	S	S	S	S	S	S	S- 0745 -A	A	A	A	A	A	A	A	A	A	A	A	A	A- 2015 -AD	AD	AD	AD
Thursday	21May	AD	AD	A	A	S	S	S	S	S	A	A	A	A	A	A	A	A	A	A	A	A- 2030 -AD	AD	AD	AD
Friday	22May	AD	AD	AD	AD	AD	A	A- 0615 -S	S	S	S	S	S- 1115 -A- 1130 -S	S	S	A	A	A	A	A	A	A- 2015 -AD	AD	AD	AD
Saturday	23May	AD	AD	AD	AD	AD	A	A- 0630 -S	S	S	S	S	S	S	S	A	A	A	A	A	A	A	AD	AD	AD
Sunday	24May	AD	AD	AD	AD	AD	A	A	S	S	S	S	S	A	A	A	A	A	A	A	A	A	AD	AD	AD
Monday	25May	AD	AD	AD	AD- 0315 -X																				

Sources of Data Used to Gather this Information (e.g., person involved in occurrence, roommate, spouse): Interview with Rail Engineer One, Duty Records

Notes: Engineer felt sleep was poor quality on 24May

Sleep-Wake History

Key: ***AD*** = awake and on duty, ***A*** = awake and off duty, ***S*** = main sleep period, and ***SN*** = nap.
Notes: Include details of any instances of poor quality sleep in the Notes section
Go back to last two periods of good quality sleep or 2 weeks (whichever is greater)

Home Base Time ->		0000 0100	0100 0200	0200 0300	0300 0400	0400 0500	0500 0600	0600 0700	0700 0800	0800 0900	0900 1000	1000 1100	1100 1200	1200 1300	1300 1400	1400 1500	1500 1600	1600 1700	1700 1800	1800 1900	1900 2000	2000 2100	2100 2200	2200 2300	2300 0000
Day	Date																								
Monday																									
Tuesday																									
Wednesday																									
Thursday																									
Friday																									
Saturday																									
Sunday																									
Monday																									
Tuesday																									
Wednesday																									
Thursday																									
Friday																									
Saturday																									
Sunday																									
Sources of Data Used to Gather this Information (e.g., person involved in occurrence, roommate, spouse):																									
Notes: (Include any periods of poor quality sleep.																									

Step 3: Medical and Psychological History

Questions about medical and psychological issues are a normal part of every investigation and must be asked. The questions suggested below should be asked in the same manner as any other question in the interview.

Questions to Ask	Interviewee's Answers
Are you a shift-worker? For how long?	
Describe your sleep environments (home, crew rest facilities etc). Include details of noise, light, other disruptions (e.g. bed partners habits).	
Do you snore?	
When do you feel sleepy?	
Do you have problems falling asleep, staying asleep or waking up too early?	
Has a bed partner told you that your arms or legs twitch or move a lot when you sleep?	
Do you feel discomfort in your arms or legs when you are falling asleep?	
Have you been diagnosed with a sleep disorder? If Yes, what is it?	
Are you receiving any treatment for this condition? What steps have you taken to manage this condition?	
How old are you?	
How much do you weigh?	
How tall are you?	

Questions to Ask	Interviewee's Answers
Investigator's Calculation of Body Mass Index BMI = Weight in Kilograms/(Height in Meters X Height in Meters)	
What is your neck size? Measure if unknown.	
Can you tell me about all medical conditions you may have (e.g., diagnoses, problems, illnesses, injuries)? If Yes, list them.	
What treatment are you receiving for these conditions?	
Tell me about the stress in your life	
Do you have any psychological conditions	

Questions to Ask	Interviewee's Answers
(e.g., diagnoses, anxiety, depression)? If Yes, list them	
Are you receiving any treatment for this conditions? What steps have you taken to manage this condition?	
Investigator's Assessment of Need for Over-night Sleep Study	
Do you take any prescription medications not identified above? If Yes, list them along with dosages and time of ingestion (general and prior to occurrence).	
Do you take any over the counter medications? If Yes, list them along with dosages and time of ingestion (general and prior to occurrence).	
Do you take any herbal or naturopathic medications or supplements? If Yes, list them along with dosages and time of ingestion.	
Do you take recreational drugs? If Yes, list them along with amounts and time of ingestion (general and prior to occurrence).	

Questions to Ask	Interviewee's Answers
Do you drink alcohol? If Yes, how often, how much, when was last drink and how much was consumed?	
Do you smoke? If Yes, how often, how much, when did you last smoke prior to occurrence and how much was smoked?	
Do you drink coffee, tea, cola, energy drinks or consume anything else with caffeine in it (e.g., chocolate bars, chocolate cake, coffee beans)? If yes, how often, how much, when was last caffeinated substance consumed prior to occurrence and how much was consumed?	
Were blood and/or urine samples taken? If Yes, by whom?	
Investigator's Assessment of Need for Independent Blood and/or Urine Analysis	
Please describe any fatigue management training you have received (when provided, by whom what content etc). Alternatively, please describe any self-study, reading etc you have undertaken to better manage your sleep or avoid fatigue.	
Sources of Data Used to Gather this Information (e.g., person involved in occurrence, roommate, spouse)	

Questions to Ask	Interviewee's Answers
Notes:	

Step 4: Fatigue Management in the Organization

Required Information	Notes
Obtain details of typical crew schedule.	
Are crew-rest facilities conducive to quality sleep?	
Obtain details of any fatigue management policies in place. Are these followed?	
Obtain details of any fatigue management training provided to employees (content, frequency etc).	
Identify what fatigue countermeasures available and permitted (e.g. exercise facilities, nap facilities, food and beverages.	
Examine practices of work rotation and opportunities for breaks.	

Required Information	Notes
Identify any tools provided to help employees recognize fatigue.	
Determine policies and practices in place to help employees mitigate situation where they are fatigued.	
Identify whether and how fatigue is examined in organization's internal investigation of incidents.	

Part B: Analysis

Part 1: Estimating the Level of Fatigue (Test for Existence)

1. Use the following table to summarize the evidence for or against an assessment that the individual was fatigued. Use the quick reference guide (below) to assist in assessing the information.
2. Considering the number, magnitude and combination of risk factors present, develop a conclusion as to whether fatigue was present to a degree which could impact performance. If a fatigued state did not exist, you may terminate your analysis here. If a fatigued state did exist, continue to part 2.

Step 1: Test for Existence – Determine the Level of Fatigue *The purpose of this step is to review the evidence related to the 6 risk factors and determine if there is sufficient information to conclude that fatigue was present at a level sufficient to impact performance*			
Fatigue Risk Factor	Description of Items of Evidence (supporting or refuting)	Strength of Evidence (strong, medium, weak)	Assessment (Risk factor: likely exists, may exist, likely does not exist)
1. Acute sleep disruption.			
2. Chronic sleep disruption [157].			
3. Continuous wakefulness.			
4. Circadian rhythm effects.			
5. Sleep disorders.			
6. Medical, psychological conditions, illnesses or drugs.			
Conclusion: *Is there a sufficient number and/or degree of risk factors present to conclude that the individual was <u>sufficiently fatigued to effect performance</u>? (Yes/No)*			
Other Evidence: Describe any other indicators of fatigue observed – declaring fatigue, yawning, napping, micro-sleeps, unusual behaviour consistent with fatigue (irritability, risk taking, taking short-cuts), occurrence happened during circadian low, late in the shift			
Rationale: *Describe your reasoning in a sentence (e.g. Based on [ ], the fatigue risk factors of [ ] were present and the individual was [likely, may have been] fatigued at the time of the occurrence.*			

[157] To calculate chronic sleep debt:
a) Determine person's preferred ratio of sleep to wakefulness (preferred hours of sleep/preferred hours awake). An 8 hour sleeper will have a ration of 0.5.
b) Calculate Sleep Debt = Total Sleep Time – Total Awake Time x Ratio of Sleep to Wakefulness

Quick Reference Guide: Fatigue Risk Factors

	Lower →	Fatigue Risk	→ Higher
	Lower	**Propensity to Sleep**	Higher
Risk Factor	**Not present**	**May be present**	**Likely present**
	No performance effect	**Possible performance effect**	**Likely performance effect**
1. Acute sleep disruption	<30 minutes departure in optimal sleep quantity in last 3 sleep periods. No awakenings >30 minutes during last 3 sleep periods	Some restriction to optimal sleep quantity in last 3 sleep periods. One or more awakenings resulting in >30 minutes lost sleep during last 3 sleep periods.	Significant restriction of sleep or multiple awakenings during last 3 sleep periods and/or no opportunity to recover.
2. Chronic sleep disruption[158] (Total Sleep Time – Total Awake Time x Preferred Ratio of Sleep to Wakefulness)	Chronic sleep debt of <2 hours. Few, or no, awakenings in sleep-wake history.	Chronic sleep debt of <8 hours. Awakenings occurred frequently in sleep-wake history.	Chronic sleep debt of >8 hours.
3. Continuous wakefulness	Continuous wakefulness <17 hours .	Continuous wakefulness > 17 hours[159].	Continuous wakefulness > 22 hours.
4. Circadian rhythm effects	Event took place outside of nighttime or afternoon circadian rhythm troughs. Sleep onset time consistent with optimal routine.		Event took place during night time circadian rhythm trough (22:30 to 04:30 +/- 1.5 hours) Event took place during day time circadian rhythm trough (14:00 +/- .75 hours) Frequent small changes or one large change to sleep onset time with

158 To calculate chronic sleep debt:
a) Determine person's preferred ratio of sleep to wakefulness (preferred hours of sleep/preferred hours awake). An 8 hour sleeper will have a ratio of 0.5.
b) Calculate Sleep Debt = Total Sleep Time – Total Awake Time x Ratio of Sleep to Wakefulness

159 May be shorter if hours of wakefulness are at night.

	Lower →	Fatigue Risk	→ Higher
	Lower	**Propensity to Sleep**	Higher
Risk Factor	**Not present**	**May be present**	**Likely present**
	No performance effect	**Possible performance effect**	**Likely performance effect**
			insufficient adjustment time.
5. Sleep disorders	No symptoms consistent with sleep disorder reported.	Symptoms consistent with a sleep disorder are reported and disorder not being effectively managed.	Individual diagnosed with sleep disorder and disorder not being effectively managed.
6. Medical and psychological conditions, illnesses and drugs	No medical conditions identified which could lead to fatigue or disrupt sleep. No indication of drug use which could cause fatigue or disrupt sleep.	Individual suffering from a condition or illness has the potential to disrupt sleep. Individual ingested a drug which leads to fatigue directly or disrupts sleep.	Individual reports significant sleep disruption associated with condition or illness or treatment.

Part 2: Linking Fatigue to Human Performance (Test for Influence)

1. Identify the safety significant events where fatigue may have played a role.
2. Identify the area of human performance shown in the event and list all evidence which supports or refutes the role of fatigue in that event. (The quick reference guide which follows can be used to support). If there are alternative explanations for the behaviour, include these in evidence against.
3. On the balance of information, draft a conclusion statement as to whether human performance was consistent with a person in a fatigued state using the format provided after the table.

Step 2: Test for Influence – Determine whether fatigue contributed to performance *The purpose of this step is to review the safety significant events and determine if there is sufficient evidence to conclude fatigue contributed to the human performance.*			
Safety Significant Event	Area of Human Performance	Evidence (for and against)	Strength of Evidence
Conclusion: *Is there a sufficient evidence to conclude that the fatigue played a role in the occurrence? (Yes/No)*			
Rationale: *Describe your reasoning in a sentence (e.g. The presence of [human performance effects] are consistent with a person in a fatigued state and it is [possible, likely] that fatigue was a contributing factor.*			

Quick Reference Guide: Impacts of Fatigue on Human Performance

Area of Human Performance	Indicators (What would we see?)
General cognitive functioning	• Increasing difficulty problem solving • Decreasing vigilance • Increasing difficulty with communication tasks • Increasing difficulty with hand eye coordination • Increasing reaction time • Increasing information processing time.
Problem Solving	• Decreased flexibility – not adapting to change in situation. • Increased perseveration in the face of evidence the plan is not working.

Memory	• Error form is related to memory (slip)
	• Increased difficulty maintaining information in short term or working memory:
	    o Asking for information multiple times
	    o Having to refer to reference material frequently
	    o Leaving tasks unfinished
	    o Frequent reminders from co-workers.

Attention and Vigilance	• Error form is related to attention (lapse) • Slower response to stimuli • Not responding to stimuli • Less focus on task as demonstrated by decreased secondary task behaviour (less proactive task management).
Reaction Time	• Responds to stimuli more slowly than usual • Excessively long time to react to emergency situation • Prolonged time to make a decision
Mood	• Increased lethargy • Decreased interest in task • Increased irritability
Physiological Effects	• Indications of succumbing to sleep (nodding off, falling asleep)

Part 3: Assessment of Fatigue Management Practices

The purpose of this section is to examine the fatigue management practices in place within the organization. This will help to assess whether fatigue is being adequately managed and to assess the risks of future fatigue related occurrences.

Fatigue Management Aspect	Notes
Describe the aspects of the operation which increase the risk of fatigue (e.g. shift work, crossing multiple time zones, scheduling practices etc)	
Is fatigue risk management seen as a shared responsibility between the employee and the employer?	
Do scheduling practices meet the regulatory minimum requirements?	
Do scheduling practices meet best practice to minimize the impacts of shift work on human performance: • Forward rotating shifts • Sufficient time between shifts for recovery • Predictability	
Are employees educated and made aware of the effects of fatigue on performance and how to mitigate them? How is this provided?	
Are supervisors, managers, crew schedulers educated and made aware of the effects of fatigue on performance and how to best	

Fatigue Management Aspect	Notes
mitigate them?	
Are fatigue counter measures available (e.g. caffeine, exercise) and used by employees?	
Are strategic naps allowed and used?	
Are crew rest facilities conducive to good quality sleep?	
Are adequate arrangements in place to manage a situation where an employee is fatigued (e.g. due to poor quality of sleep, being awake with sick child etc)? Can you provide an example(s) of where you or your colleagues have used these arrangements?	
Are employees trained in self-assessment for fatigue?	
Does the organization consider fatigue in internal incident investigations?	
Does the organization have clearly documented policies and procedures to effectively manage fatigue?	
Is there a system in place to identify and fix schedules which are particularly conducive to fatigue?	
Conclusion: Are the risks associated with fatigue managed to a level which is as low as reasonably practicable (ALARP) within the organization?	

GUIDE TO INVESTIGATING

SLEEP-RELATED FATIGUE

2014