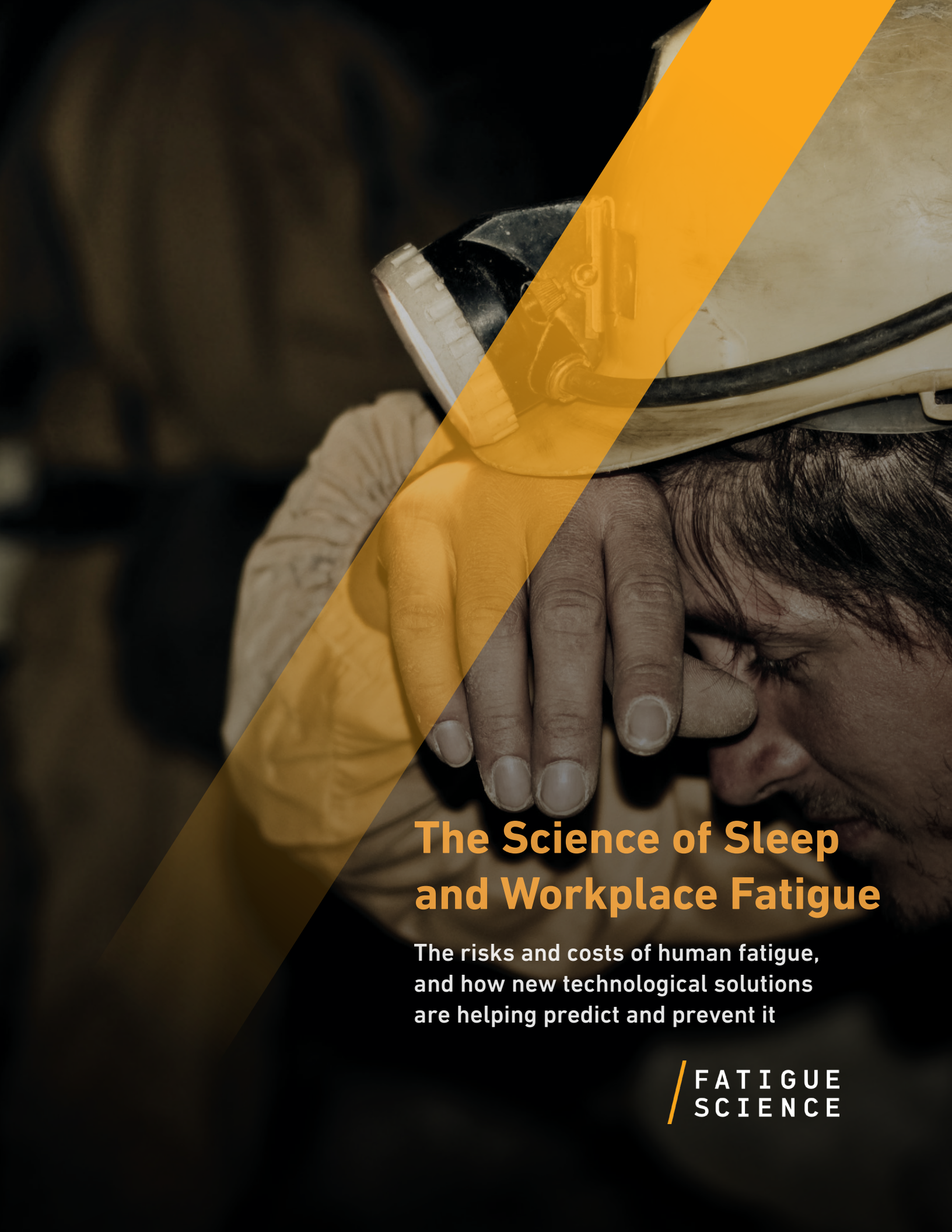


The Science of Sleep and Workplace Fatigue

The risks and costs of human fatigue, and how new technological solutions are helping predict and prevent it

FATIGUE SCIENCE

What you'll learn

The Science of Sleep

Page 8

We look at why and how we sleep, the factors that determine "good sleep", and how poor sleep leads to cognitive fatigue.

II

Fatigue at Work

Page 26

Next, we examine why workplace fatigue is such a serious concern—its impacts on safety, productivity and employee well-being.

III

Technology to Combat Workplace Fatigue

Page 40

And finally, we see how new technology is addressing fatigue, including the ability to predict it before it occurs.

A short introduction to a complex subject

The science of sleep is largely the science of the human brain—a world we have only scratched the surface of. Yet we know enough to know that "how we sleep" affects every aspect of our lives.

There's no doubt that workplace fatigue is an unavoidable consequence of our modern-day society, but science is also giving us the knowledge and tools to combat it.

Leading organizations are beginning to recognize the serious effects of fatigue on workplace safety and productivity, and are looking for ways to measure and manage it. Fortunately, new developments in connected technology are providing effective management tools to ensure safer, more productive, and healthier workplaces.

What do we mean by "fatigue?"

At Fatigue Science, when we say "fatigue," we're talking about the fatigue that's caused by poor or inadequate sleep.

Known as "cognitive fatigue," it's the fatigue that leads to reduced alertness, reaction time, and impaired decision-making on the job. The kind that can seriously compromise workplace safety.

Cognitive fatigue and physical fatigue aren't the same thing

While our discussion will focus on cognitive fatigue, sleep affects almost every type of tissue and system in the body.

At Fatigue Science we know, from our work with elite athletes, that a strict regimen of good sleep and nutrition greatly improves an athlete's performance, resistance to injury, and recovery. Scientific research is showing that good sleep promotes tissue growth and repair, hormonal and chemical rebalancing, and the destressing of organs and muscles.

Poor sleep increases the risk and severity of many conditions such as high blood pressure, weakened immune system, diabetes, depression, obesity, and most notably cardio-vascular disease. One US study of 3,000 subjects over the age of 45 found that those who slept fewer than six hours a night were about twice as likely to have a stroke or heart attack as those who slept six to eight hours.

I

The Science of Sleep

Why do we sleep?

Scientists once thought our bodies simply shut-down when we slept: a "recharging" for the day ahead. We now know that a whole lot more happens when we sleep.

One of the activities that keeps our brains busy during sleep is often referred to as "housekeeping"—an overly simplistic term to describe an extraordinarily complex process.

Brain housekeeping is when the brain checks and repairs itself, ensuring neural pathways are functioning well and toxins that have built up during the day are removed. It's also a time when the brain goes about cleaning up its stored memories, a process increasingly compared to organizing files on a computer.

Like a computer, Scientists believe that a clean, organized brain is better able to process higher-level cognitive tasks such as learning, decision-making and reasoning. It's these cognitive abilities that are impaired when we're not getting a good night's rest.

These activities are better suited to sleep, when the brain isn't preoccupied with the daily job of keeping us alert and functioning.

How much is normal?

The hours of sleep we need per night can vary between individuals; and it changes as we age. Sleep scientists, however, have established some generally accepted guidelines.

Infants sleep as much as 18 hours a day, which may be necessary for brain development. Similarly, young people need about 9.5 hours. Most adults need 7-9 hours.

There's still some debate among sociologists if we're sleeping less than our ancestors. It appears, however, that with longer work days, and 24/7 access to digital devices and leisure activities, that the scale is tipping. A 2013 report from the UK Sleep Council found that 33% of Britons get by on five to six hours' a night, compared with 27% in 2010. And in the US, the National Sleep Foundation has stated that Americans get 20% less sleep than they did a century ago.

Genetic freaks or super humans?

We've all heard of people who claim they can function well on less than 5 hours of sleep. For the most part these are misguided boasts, but for a small percentage of the population (estimated around 1%) it's true.

By studying these "short sleepers", scientists are discovering that a genetic mutation may account for what is still considered a sleep disorder. Or maybe the next step in our evolution?

Sleep has evolved

It's surprising how little we know of an activity that consumes about a third of our lives.

We know intuitively (and scientifically) that sleep is vital to our health, but sleep has varied greatly over the course of human evolution and history. There's no single "right way" to sleep, in fact, there are three.

Polyphasic sleep

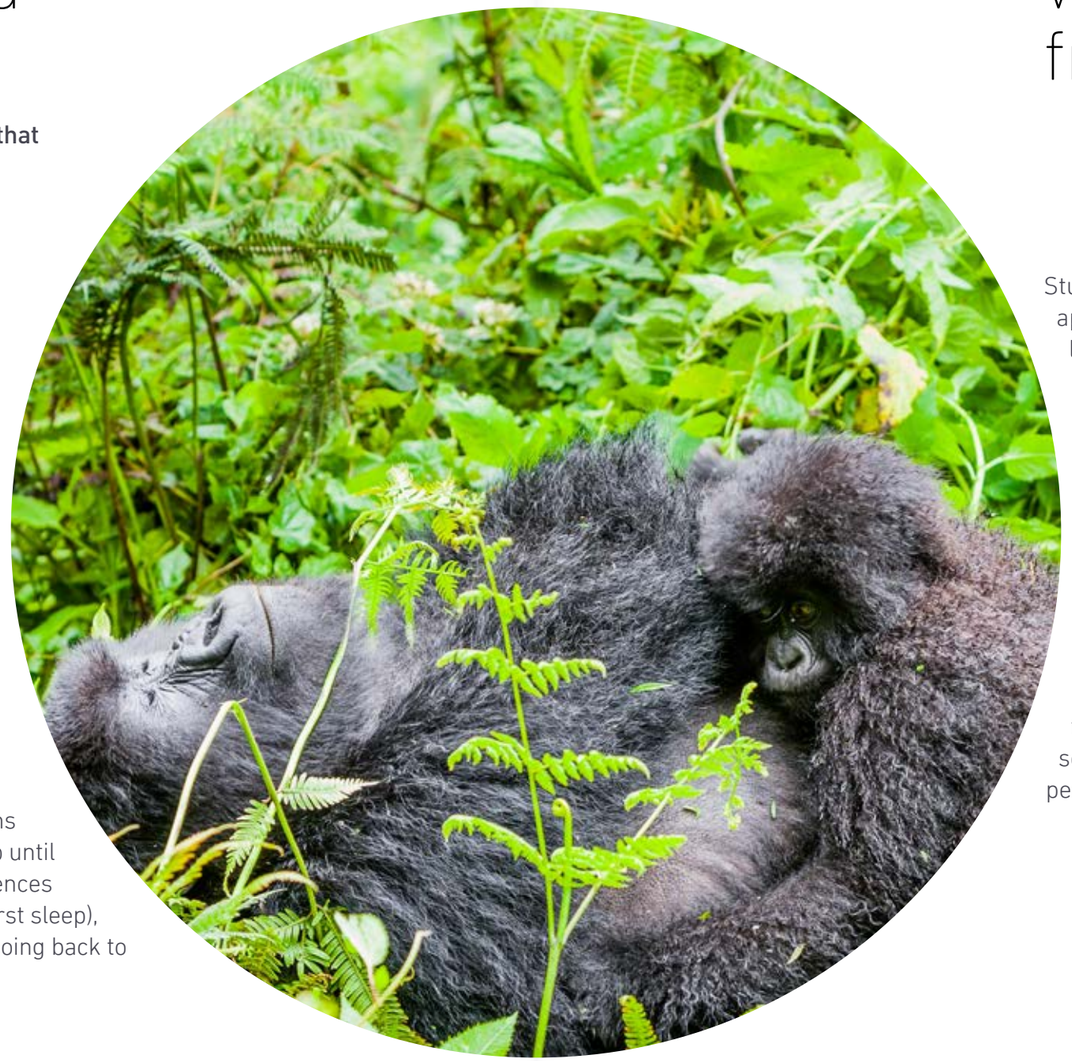
"Poly" for many, is several sleep periods over 24 hours, with great variation in timing and length. Most mammals sleep this way, and it's thought early man did as well—catching winks between hunting, gathering and sabretooth tiger fleeing.

Biphasic sleep

This is sleep in two periods over 24 hours. It seems this was common in early western civilizations up until industrialization, as there are many literary references to people sleeping for a few hours after sunset (first sleep), waking during the night for an hour or two, then going back to sleep until dawn (second sleep).

Monophasic sleep

As the name suggests, this is a single sleep period over 24 hours. Though people may have slept this way in the past, it was industrialization and the invention of artificial light that has made it the norm for most of us today.



And perhaps it's what separates us from the animals

Studies comparing the sleep habits of monkeys and great apes (gorillas, orangutans and chimpanzees) show that the latter sleep more like humans.

Apes build comfortable beds, sleep for longer periods, and achieve deeper sleep states than their less-evolved monkey relatives, that typically sleep lighter and sleep upright. It's believed this is to remain alert to predators—and other monkeys out to steal their bananas. Scientists theorize that the ability of larger primates to obtain better sleep, has led to higher cognitive abilities.

The same could be true of humans. As we developed tools, weapons and social structures to ensure mutual security, we also slept better, and thus got smarter. So perhaps "the wheel" was the result of a good night's sleep.

The rhythms of life

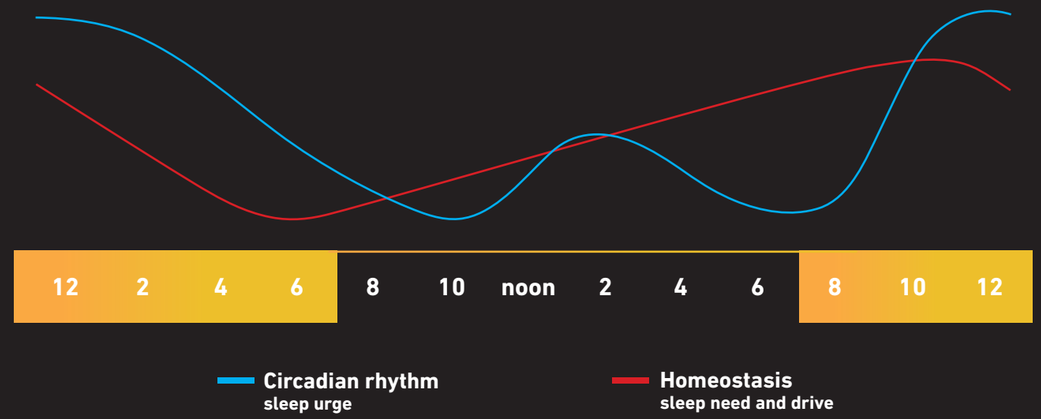
To understand sleep and fatigue, it helps to look at two of sleep's controlling mechanisms.

Circadian rhythm

Simply put, circadian rhythms are any biological processes governed by daily, 24-hour cycles. As we move through the day, we all experience fluctuations in appetite, blood pressure, body temperature, and yes, fatigue levels. We've likely all struggled to stay awake during an after-lunch meeting. With consistent and adequate sleep, this rhythm, with its troughs and peaks, is quite regular and predictable.

Circadian rhythms take most of their cues from daylight, which we of course have little control over. They're also slow to adjust to changes in daylight, which is why when we turn our clocks forward or backwards, it can take us many days to feel "right again."

So how does that affect a worker? Let's assume someone gets a good night's sleep of 8 hours. Throughout the day, their alertness levels and reaction times will vary up to about 10% as their body passes through these natural troughs and peaks. But as we'll see further on, less sleep greatly increases these variations in alertness, and that's when we can begin to talk about fatigue.

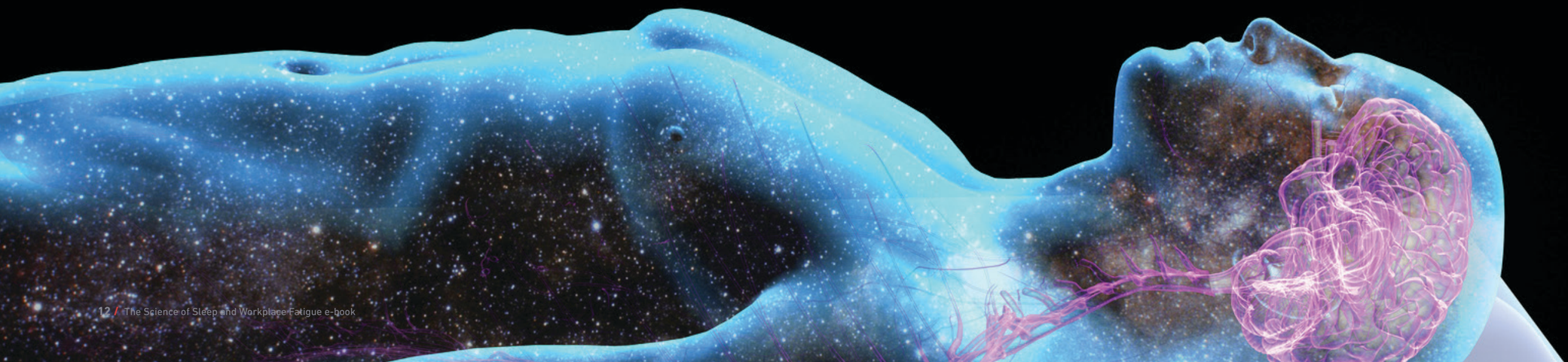


Sleep-wake homeostasis and the sleep drive

Homeostasis refers to natural control mechanisms that keep the body's various systems in check and in balance. In addition to sleep, these include blood and tissue metabolism, body temperature, and blood pressure.

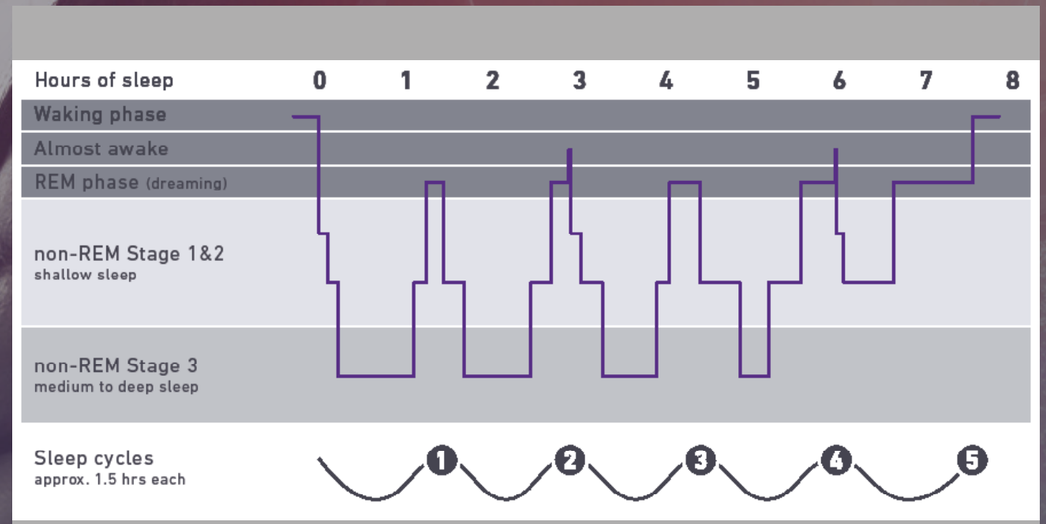
The homeostatic sleep drive is like an hour glass, counting down the time since our last sleep, and reminding the body that when the sand runs out, we'll need to sleep again.

This drive gets stronger with every passing hour of wakefulness, and when we don't get enough sleep (deprivation) it forces the body to sleep longer and deeper to replenish and restore balance.



We all go through phases

In 1875, scientists detected electrical activity in the brain, and 50 years later, invented the electroencephalograph to study it. We now know there are two distinct sleep phases, named for the "rapid eye movements" characteristic of deep sleep.



A sleep hypnogram for a healthy adult sleeping 7-8 hours

Non-REM sleep

Non-REM sleep is characterized by slow, highly synchronized, but relatively high voltage oscillations in the brain. During non-REM sleep, our muscles are relaxed, with only occasional movements. non-REM sleep is further divided into three stages of successively deeper sleep.

Stage 1 non-REM: Lasting only a few minutes, this is the transition from wakefulness to sleep. Our brain waves, heartbeat, breathing, and eye movements slow, and our muscles relax with occasional twitches.

Stage 2 non-REM: We enter deeper sleep, and except for the occasional brain wave spike, our brain and core bodily functions slow even further. Our body temperature drops and eye movements stop.

Stage 3 non-REM: We enter the lowest level of brain wave activity, heartbeat and breathing slow to their lowest level, and muscles are fully relaxed. We're unaware of our external surroundings and waking someone from this stage is difficult. Dreaming sometimes occurs in stage 3.

REM sleep

REM sleep follows stage 3 non-REM and first occurs about 90 minutes after falling asleep. It's characterized by the brain returning to almost-waking levels of brain wave activity, and is accompanied by increases in heart rate, breathing and blood pressure.

Curiously, even though our brains go into overdrive—and this is where most dreaming occurs—our arm and leg muscles go into complete paralysis. Some scientists theorize that this stops us from acting out our dreams.

Infants and youth spend most of their sleep in REM sleep, but this lessens to 20% as we age. This supports the belief that the developing brain and the mature brain have very different needs for sleep.

Dream a little dream

Dreams are one of sleep's biggest mysteries and one of the more perplexing experiences of our everyday lives.

Science doesn't know why we dream, though there are numerous theories. Many are along the lines that dreams are yet another part of the brain's housekeeping chores, and that dreams are simply the brain's waste bin, where random thoughts and emotions are tossed before deletion. Others suggest that dreams are a way for the brain to process thoughts and emotions in a free and safe environment, even suggesting it's a place to "get the crazy out" before the conscious brain wakes up.

Study of brain wave activity while dreaming (mostly in REM sleep) shows considerable activity in areas of the brain associated with emotions and mood, which leads many scientists to believe they play a role in the brain's processing of emotional memories.

Whatever their purpose, dreams seem to be a necessary part of sleep, as most healthy individuals spend about two hours a night in la la land.

So what causes fatigue?

Cognitive fatigue occurs for two reasons, and when both are combined, the negative effects are compounded.

Sleep deprivation

Sleep deprivation is not obtaining enough sleep within a 24-hour period—such as sleeping six hours a night rather than the recommended seven.

Sleep desynchronization

Sleep desynchronization is forcing our body to remain awake (or asleep) out of synch with its circadian and homeostatic mechanisms—shiftwork, pulling an all-nighter, or jet lag, are experiences we can all relate to.

Unfortunately, we can't train our bodies to tolerate sleep deprivation or desynchronization like we can train our muscles or cardiovascular system. Cognitive fatigue affects everyone, and when the quality of our sleep is poor, our alertness, health, and performance suffers.

Factors that influence sleep desynchronization

Earth's 24-hour day triggers changes in our body that push us to sleep at night—which is why irregular work hours can be so detrimental to good sleep.

A Time of day

The amount of daylight we're exposed to can have a profound effect on our sleep. As a result, geographic location and seasonal variations also need to be considered.

B Circadian rhythm and homeostasis

Layered on top of the time of day, are the human circadian rhythm and homeostasis mechanisms already discussed. The body's levels of cognitive fatigue will vary depending where we are with respect to these cycles.

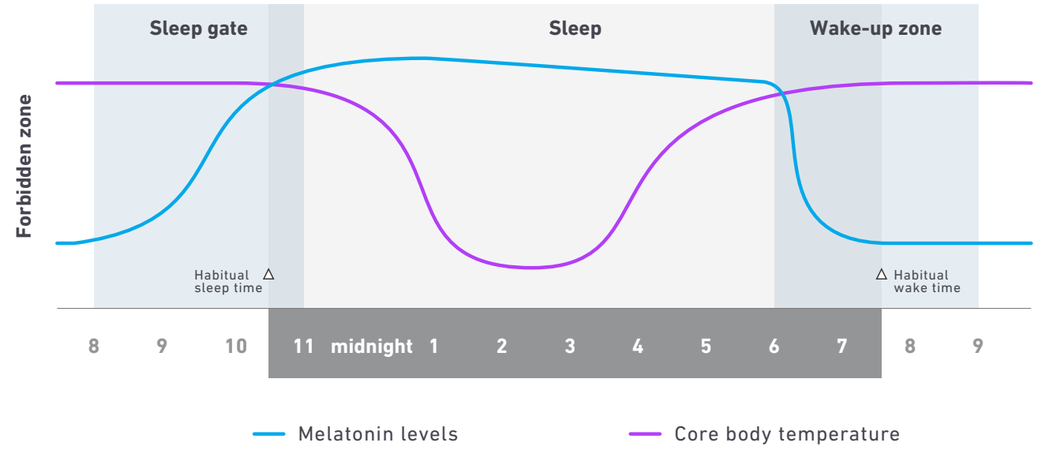
C Sleep and wake consistency

It's not just how much sleep we get, but the consistency of when we get it. When we cooperate with nature, and fall in line with our circadian and homeostatic cycles, the restorative value of sleep is maximized, and waking alertness optimized.

When a worker's ability to stick to a sleep/wake routine is disrupted, both waking performance and nighttime sleep quality are negatively impacted.

Melatonin matters

Our daily light/dark cycle causes changes in body temperature and hormone production. One of these is the hormone melatonin, which regulates our sleep/wake cycles and plays a key role in healthy sleep. Melatonin levels increase with the absence of light.



As darkness falls melatonin levels rise. About six hours before minimum body temperature, we enter a 3-hour period called the "sleep gate." We sleep longer when we start sleep within this period.

It's difficult to fall asleep before the gate opens—a period called the "forbidden zone". And it can be hard after the gate closes, though less so as our homeostatic sleep drive builds.

Daylight causes melatonin levels to drop as we enter the "wake-up zone"—when we're pushed to wake-up regardless of how long we've slept.

Since we're governed by these fixed sleep/wake cycles, we risk sleep deprivation when we alter them significantly.

Factors that contribute to sleep deprivation

Though we have little control over our fixed sleep/wake cycles, we can exert some control over other factors that can contribute to sleep deprivation.

A Inadequate sleep quantity

Sleep scientists largely agree that the average working adult needs 7-8 hours of sleep every 24 hours for optimal health and well-being.

B Cumulative sleep debt

Consistently missing an hour here and an hour there of sleep creates what is called sleep debt. Sleep debt can be thought of like a bank account.

Let's say we have a high-stress job and our goal is to deposit $8 in the bank every morning, for a weekly total of $56, but for 2 days (party weekend) we only deposit $5.50 each morning. That means our weekly total is $51, and we start the week with a deficit of $5—or back to fatigue—5 hours. We then struggle during the week (especially Monday and Tuesday) to make this up.

And just like carrying a financial debt, we begin to accept this debt and its affects as normal and adjust our behavior to *it*, rather than trying to return to a balanced state.

C Awakenings or interruptions

Waking during sleep—for a few unwitting moments we can barely remember, to a full-fledged trip to the bathroom—is quite normal. But if frequent awakenings aren't attributable to environmental disturbances, they could be a sign of a sleep disorder.

Sleep apnea is by far the most common of a dozen or so conditions that can cause excessive awakenings. Fortunately, detection is more than half the battle, as most of these disorders can be effectively treated with proper medical attention.

Frequent flyer = frequent fatigue

As we've seen, our internal physiological processes are normally well-tuned to the rhythm of a 24-hour clock. But when we step onto a jet plane, and cross three or more time zones, disagreements between our internal clock and the external clock on the wall can wreak jet lag havoc.

As with any disruption of the circadian cycle, jet lag causes fatigue, irritability, and a decrease in alertness. And it just feels bad!

Even if your job keeps you grounded, you may still suffer from "social" jet lag

Social jet lag—when you go to bed and wake up later on weekends than during the week—is as bad or worse than the flying kind.

A University of Arizona study found that each hour of social jet lag is associated with an 11% increase in the likelihood of heart disease. If that weren't enough to make you forgo that all-night rave, other studies have found weekend night owls are more prone to depression, likely to smoke, and consume more caffeine and alcohol than average.

II

Fatigue at Work

The more we learn about fatigue, the more we appreciate its consequences in the workplace

In the past, the idiom “falling asleep at the switch” was used to pin responsibility for fatigue-related accidents on an individual, but rarely a societal or organizational failing.

Blame the lightbulb

Sleep historian, Roger Ekirch, has found that pre-industrial societies adopted biphasic sleep patterns, splitting their nightly sleep into a “first sleep” and “second sleep”. Each of these “sleeps” could last three to five hours, broken by a middle period of an hour or more of full wakefulness. This time was spent analyzing dreams, reflecting on the day, socializing with friends and family, and unsurprisingly, having sex. One 16th-century French doctor wrote that couples who had sex after the “first sleep”, did it better and enjoyed it more. Makes sense when you think about it.

So perhaps the 1700s marked the decline of good sex, because evidence of biphasic sleep begins to diminish in the industrial period. Artificial light, first in the form of coal oil and gas, and later electric light, made urban “nightlife” possible, gradually squeezing out the darkness once reserved for sleep.

By the 1920s, the compact electric lightbulb was in widespread use in the westernized world—arguably still the most transformational invention for the workplace. For the first time in human history, the workday no longer had to be conducted during “the day”.

Unfortunately, the night shift is here to stay

Today it's estimated that 20-25% of people work under some form of irregular hours—100% in some industries.

It normally takes a day for our bodies to adapt to just a one-hour time change. So, changing from an 8 am to an 8 pm shift, for example, would normally take 12 days. And things only get worse with rotating shifts, since a worker's circadian rhythm never gets a chance to readjust. Even experienced night shift workers typically get about two hours less sleep than the average person.

We know that shift workers are more vulnerable to accidents and injuries, and suffer from poor performance and memory, gastrointestinal problems, and other sleep deprivation symptoms. They're also at increased risk of ongoing health problems like chronic fatigue, obesity, cardiovascular disorders, depression, diabetes, ulcers, and perhaps some forms of cancer.

So how can employers protect themselves against the fatigue risks associated with shift work? Proactive scheduling and employee health and wellness initiatives are a start, but unless an employer can see and quantify fatigue in their workforce, trying to manage it is mere guesswork.

Bhopal

Chernobyl

Exxon Valdez

Three Mile Island

These catastrophic accidents all happened at night.

The risk of accidents is estimated at 30% higher on night shifts. And this risk increases with the length of shift and number of consecutive nights worked.

6 reasons to wake-up to workplace fatigue

OH&S professionals are beginning to recognize and quantify the risks of workplace fatigue—and the figures are sobering.

1 Safety

A broad 2016 US industry study by RAND concluded that fatigue results in a 13% increased risk of death, and the loss of 1.2 million workdays per year. Another study found that workers who slept less than 5 hours per day were 3.5x as likely to be injured than those sleeping 7+ hours.

30-40%
commercial trucking accidents

Driver fatigue gets a lot of the attention. According to a Massachusetts Special Comm. and an American Automobile Assoc. study, 5,000-to-8,000 US traffic fatalities per year are fatigue-related. And professional drivers are often singled out—the US National Highway Traffic Safety Admin. estimates that driver fatigue is responsible for 30-40% of trucking accidents. Perhaps unsurprisingly, truck drivers themselves put fatigue in the top ten causes of accidents, especially in long-haul operations.

Even in closed operations, fatigue takes a toll. According to a 2011 Caterpillar Global Mining report, fatigue was a factor in up to 65% of all surface mining haul truck accidents.

65%
mining truck accidents

And fatigue doesn't only affect heavy industry. An extensive 2006 Harvard Medical School study found that doctors in training, working extended shifts, committed 3-to-7 times the number of significant and serious errors, compared to their more well-rested colleagues.
As has been seen, fatigue exacts a high cost

2 Health and wellness

on human health and wellness. A survey by the US Center for Disease Control found that organizations that invest in employee wellness programs typically find absenteeism decreases by 40%, turnover by 25%, and accidents by 50%.

20%
of population suffers sleep disorders

Similar studies have yet to be done on fatigue risk management programs, but their value can't be underestimated, even simply for detecting sleep disorders. By some estimates, as much as 20% of the general population may suffer from some type of sleep disorder.

3 Productivity

Years of research in the military, aviation and emergency medicine sectors has shown that workplace fatigue leads to poor reasoning and decision making, as well as a marked deterioration in creative problem solving. Even when fatigue-related incidents don't occur, worker fatigue can pose significant challenges to smooth operation and teamwork.

4 Maintenance and asset costs

Fatigued workers can have a significant monetary impact on workplace assets. A European trucking industry study found that poor driving behaviors (e.g. harsh braking, excessive speed) can contribute 35-45% to a fleet's total cost of ownership. While not all industries can point as easily to costs such as fuel and tires, it stands to reason that a less alert worker will be more careless with the tools of their trade.

5x
accident cost

And when incidents do happen, the costs can be much greater. A US Dept. of Transportation study of railroad operators found that the average cost of accidents caused by a fatigued worker was 5x greater than a non-fatigued worker. The explanation being that longer reaction times result in greater material damage, and thus costs.

5 Insurance and liability

$$$
settlements

Several precedent-setting judgements involving fatigued workers have occurred in the last few years. In the US, perhaps none as noteworthy as the 2014 accident involving comedian Tracy Morgan and nine others hit by a fatigued tractor trailer driver. The reported multimillion dollar settlements have pushed driver fatigue into the public spotlight. In Australia, a country with a longer history in fatigue risk management, authorities are more attuned to look for fatigue as causal factor in accidents, and the courts have followed suit with harsher penalties.

And this is only the beginning. The recognition of workplace fatigue impairment is placing the onus on employers to either face increased liability and insurance costs, or mitigate against fatigue risk with effective management practices.

6 Reputation

Large organizations operate under intense public scrutiny, and preventable accidents raise red flags with employees, unions, investors, legislators, and the larger community. Proactive leadership in fatigue-related safety is now more of a priority than ever.

Microsleeps: the silent killer

“I’m OK, it’s only a few more kilometers, and I can’t be late.”

Microsleeps are momentary lapses in consciousness due to sleep deprivation. Some sleep scientists describe them as sleep temporarily winning the fight over wakefulness. We’ve all experienced them: you want to stay awake, but your eyelids get heavier, before you know it you’ve nodded off, and then suddenly your head snaps back and you’re left wondering what happened.

While in microsleep a person is entirely unaware of what is happening around them. And in a typical 3-to-4 second microsleep while driving, a lot of bad can happen. Even more alarming is that they can occur before someone feels sleepy or shows any outward signs of fatigue.

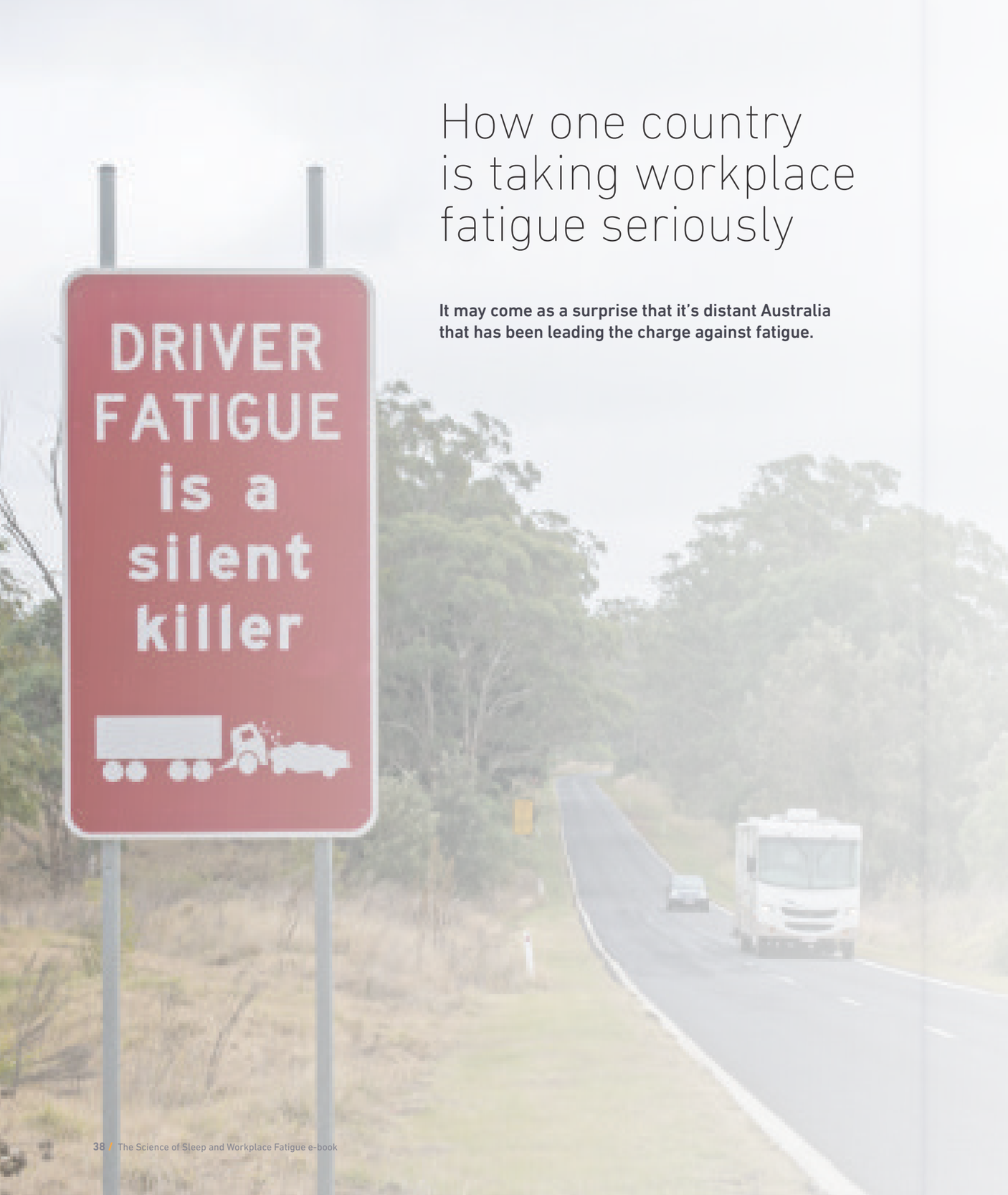
Why scheduling alone can't protect against fatigue risk

And why worker fatigue can be present even in highly regulated industries.

Given the very public nature of fatigue-related accidents in trucking, the industry has been proactive around driver hours and scheduling—most westernized countries having some type of hours of service (HOS) legislation. And it's been helped by a wide variety of technologies, such as telematics and automated driver log systems.

So, in what's already a highly-regulated industry, you'd think that driver fatigue would be a thing of the past—unfortunately, that's far from the case. As we've already noted, fatigue may be a factor in as many as 40% of US trucking accidents. So why haven't HOS regulations greatly reduced fatigue-related incidents?

HOS regulations have certainly helped, but the challenge with simply relying on HOS is that just because you've limited a driver's time behind the wheel, doesn't guarantee that they're taking advantage of the rest/sleep opportunities when they have them, or that the sleep they're getting is of consistently good quality.



How one country is taking workplace fatigue seriously

It may come as a surprise that it's distant Australia that has been leading the charge against fatigue.

A perfect storm

Australia's population is concentrated in a half-dozen large urban areas, with the bulk of its 24 million people pressed against its south-eastern coastline. Few people live in the arid interior, and many regions are only connected by one or two main highways and rail lines. Add to this limited infrastructure a hot climate and often-featureless landscapes, and you have a scenario that makes long distance travel a challenge at the best of times—mind-numbing monotony being a driver's constant companion.

Beginning in the 70's Australia's population and economic activity entered into an extended period of growth, but infrastructure development lagged. Greater volumes of traffic, especially heavy commercial vehicles, were being funneled onto an inadequate and outdated road network. Similar demands were also being made on rail networks.

And finally, Australia's labor landscape was changing. A heavily resource-based economy experienced periods of boom and bust, and industry (most notably mining and transportation), reacted with increasingly longer work hours. Ten and twelve hour shifts were becoming the norm.

Accidents will happen

By the late 80s and early 90s, road accident numbers were increasing, as was their severity; and several accidents captured the public's attention. The most horrific was a 1989 accident involving two packed tourist buses that left 35 people dead and 41 injured. The cause was driver fatigue. There were also safety concerns away from the nation's highways. Australian mines were racking up poor safety records compared to their Canadian, US and EU counterparts. The fact that some workers were averaging 50+ hours a week under rotating shift conditions (2-3 hours more than US and much higher than EU) began pointing a finger at fatigue.

Enough was enough

By the late 90s, there was a new and heightened public awareness around workplace fatigue, and fatigue in general—part of a larger shift in attitudes towards labor-related issues. Legislators were under pressure to act, and began introducing scheduling, hours-of-service, and fatigue risk management guidelines and legislation, at both state and federal levels.

Industry by-and-large took up the challenge, and when it hasn't, has found itself on the losing end of the stick. In 2016, courts awarded a mine worker almost US$1m in damages, after finding the company didn't do enough to mitigate fatigue risk in their workplace, setting a new precedent for employer liability.

Today, Australia has one of the lowest highway accident rates in the world and its mines are among the safest. While this success is attributable to a wide variety of factors, there's little doubt that a proactive approach to workplace fatigue is paying off. And the effort hasn't stopped. Australia is one of the best countries at investigating if fatigue was a causal factor in an accident, (both public and workplace), keeping statistics, and supporting fatigue research.

III

Technology to combat workplace fatigue

Scientists, technologists and OH&S professionals are looking for ways to detect, measure, and manage workplace fatigue.

We've now reached the point where we can confidently point to advances in workplace fatigue risk management, and the application of fatigue risk management systems (FRMS).

As we'll see, there are two distinct technological approaches to fatigue risk management—reactive systems that detect fatigue once symptoms occur, and a predictive system that uses sleep data and biomathematical analysis to predict if and when fatigue will occur.

Two technological approaches to fatigue risk management

REACTIVE

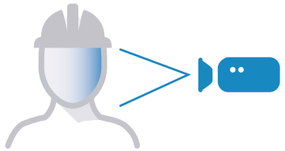
Reactive technologies detect fatigue once physical symptoms appear. They don't, however, address the root cause of fatigue—poor or inadequate sleep.

EEG monitoring

Headwear embedded sensors measure changes in brain wave activity to assess fatigue. They must be used with some type of cap, hardhat or helmet.

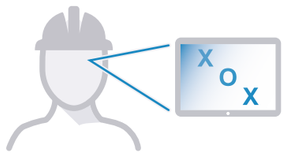
In-cab driver monitoring

In-cab devices detect fatigue from changes in body movements, such as eye-closures and head-nodding. Once these symptoms occur (microsleeps in severe cases) fatigue may have been present for some time.



Psychomotor vigilance task (PVT)

PVT testing measures a person's response to visual stimuli. It can give a fatigue snapshot at the time of testing, but unless they're given throughout a worker's shift, won't detect the onset of fatigue.



Telematics analysis

Telematics systems can detect erratic steering and braking—behaviors sometimes accentuated by fatigue. But this data is rarely precise or easily accessible, to allow for timely intervention.

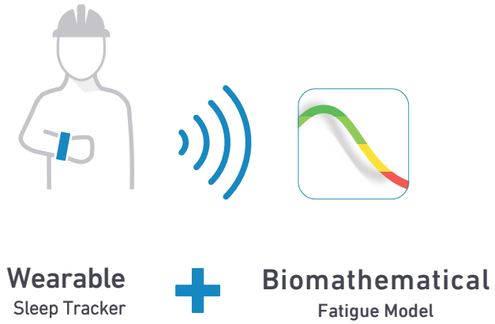
PREDICTIVE

Predictive technology analyzes a person's sleep to determine if and when fatigue will occur, providing both advance notice for appropriate intervention, and root-cause treatment.

Biomathematical modelling applied to individual sleep data

Predictive fatigue management uses bio-mathematical modelling and cloud-based algorithms to analyze the various sleep factors that can lead to sleep desynchronization and deprivation (pgs. 18-23). From that analysis, a predictive system can predict an individual's level of fatigue and its progression along the waking hours in the day ahead.

Sleep data for this analysis can be easily and reliably captured by a wearable device connected to this platform. Examples of compatible devices with validated sleep detection accuracy include the Fatigue Science ReadiBand as well as select devices from Fitbit and Garmin.



Fatigue Science is the leading provider of predictive fatigue management information systems (FMIS) to the global industrial sector. Our FMIS platform, known as *Readi*, combines validated sleep data from wearable devices with the validated SAFTE™ Biomathematical Fatigue Model to generate accurate individual fatigue predictions.

As a comprehensive suite of industrial software applications, **Readi** then delivers these fatigue data in a variety of formats tailored for daily use at different levels of an industrial organization, including separate interfaces for leadership, health and safety teams, shift supervisors, and individual workers themselves.

Readi™ /

Biomathematics is the use of applied mathematics to understand human biological systems

As technology gives us reliable tools to collect data from the human body, we're seeing a growing use of computers to analyze, simulate, and predict human behaviors.

The SAFTE™ Fatigue Model

The SAFTE Fatigue Model (Sleep, Activity, Fatigue, and Task Effectiveness) takes collected data about a person's sleep, and analyzes it within the context of what is scientifically known about human sleep and fatigue.

It's one of the few biomathematical models available to analyze human sleep and fatigue, and is recognized as the best in its category.

SAFTE was developed by the US Army Research Lab over a period of 25 years and $37 million in research, and has been extensively tested and validated by the US Military, US Department of Transportation, Federal Aviation Administration, and other governmental and industry organizations. It's one of the most applied biomathematical models of any type.

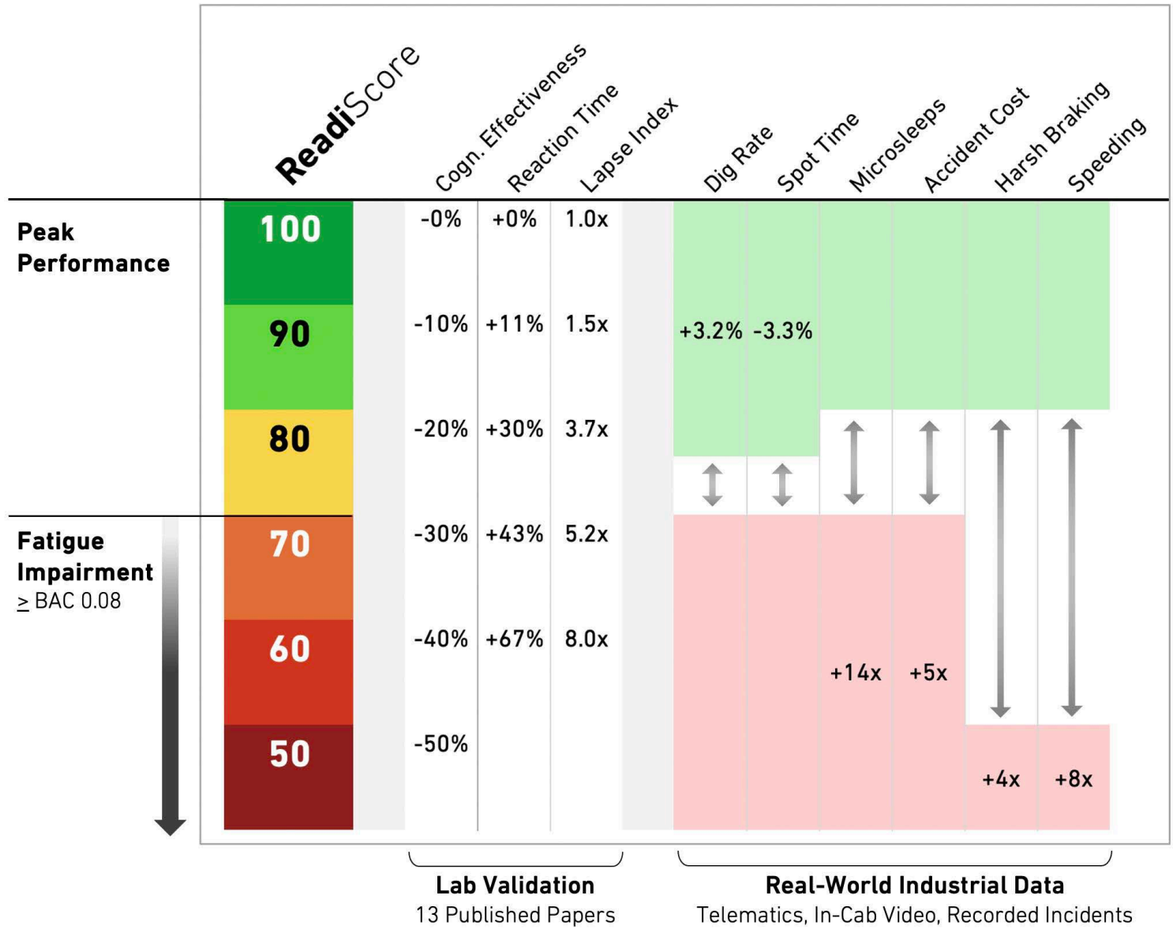
The SAFTE Fatigue Model is available exclusively from Fatigue Science and its distributors.

How a biomathematical model lets us quantify fatigue and compare it to other workplace impairments

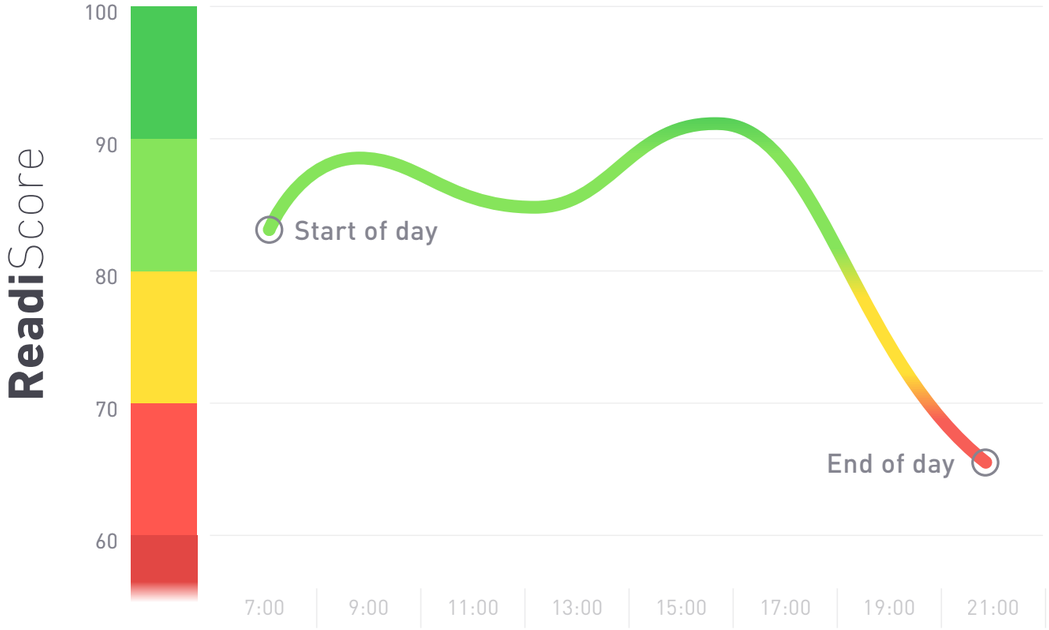
One of the challenges biomathematical models face is distilling massive amounts of complex data into useable information. In a workplace setting, that means information that OH&S managers, and even employees, can easily understand and act upon.

When given a person's accurate sleep data, collected over a period of days, the SAFTE Fatigue Model applies complex algorithms to analyze it and produce a **Readi**Score. The ReadiScore is the quantification of fatigue impairment using an easy-to-visualize 0-100 scale. With it, we can reliably compare the effects of fatigue against more commonly understood workplace impairments.

ReadiScore: Quantified Fatigue Prediction



Example: Predicted fatigue impairment

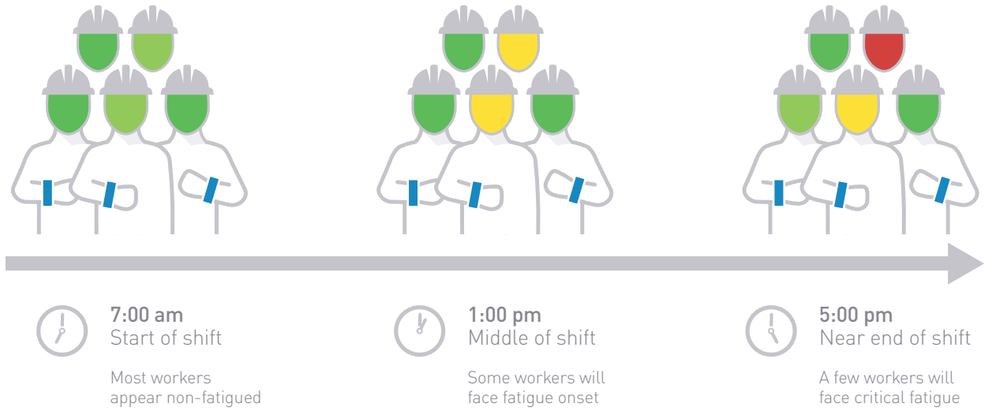


Predicting fatigue, long before it strikes

The beauty of biomathematical fatigue models is that they can help us predict biological processes and resultant human behaviors.

By applying known science about sleep—circadian rhythms, homeostatic sleep drive, etc.—the SAFTE Fatigue Model can predict a person's cognitive fatigue as it evolves over the course of a day.

This projection makes it easy to pinpoint, at the start of shift, if and when a worker will reach dangerous levels of fatigue impairment. This lets safety managers, and workers, effectively "see" fatigue before it occurs, and gives them a tool to make informed fatigue risk mitigation decisions that would otherwise not be possible.



A role for everyone

Predictive fatigue management technology empowers every member of an industrial organization to play an essential role in fatigue risk reduction

Leadership and HSE Teams

Supervisors

Operators

Technology for operators

Predictive technology for operators, such as **Readi**One, the operator-centric component of the Readi FMIS from Fatigue Science, can empower operators to be self-aware of their own fatigue on duty and before it happens.

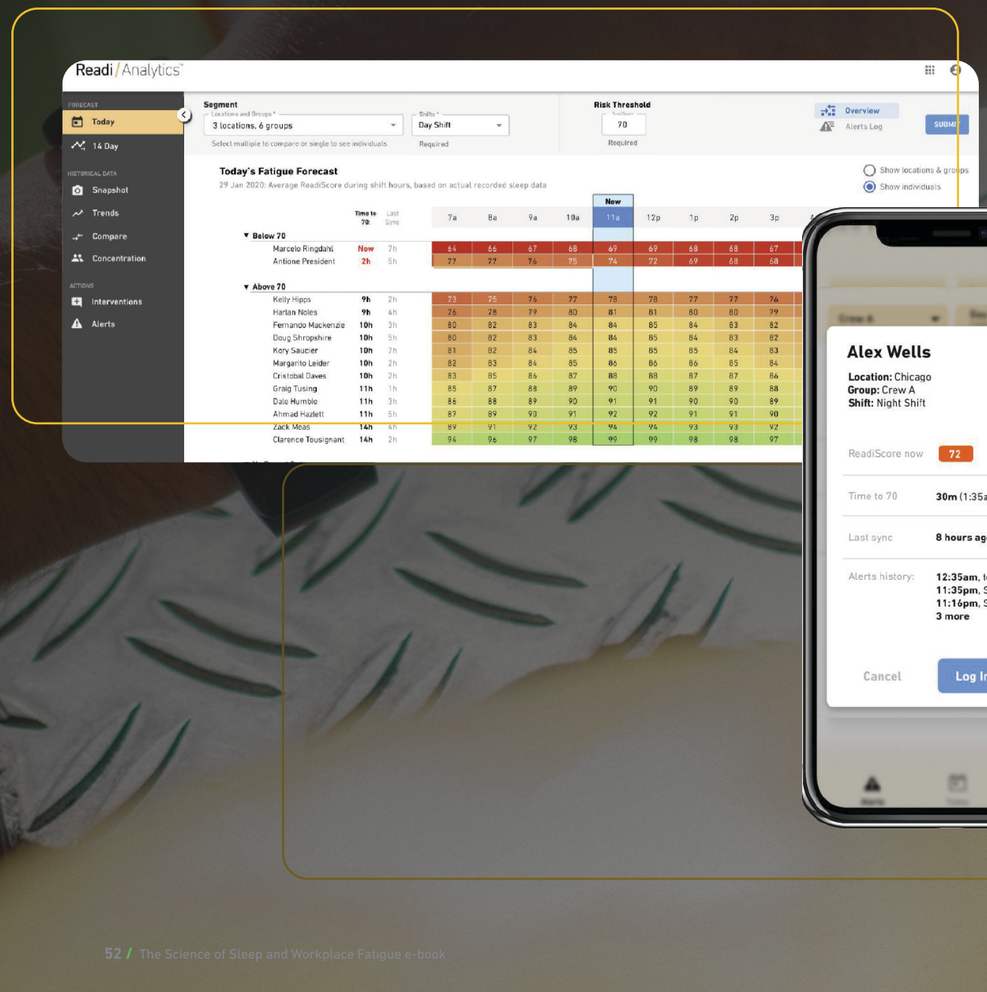
At a glance, Daily Fatigue Forecasts reveal to an operator if and when he or she will face critical fatigue on their current shift.

Fatigue Alerts, for when it matters most: Operators receive vibrating reminders on their wrist and phone when they are approaching a period of critical fatigue.

Technology for supervisors

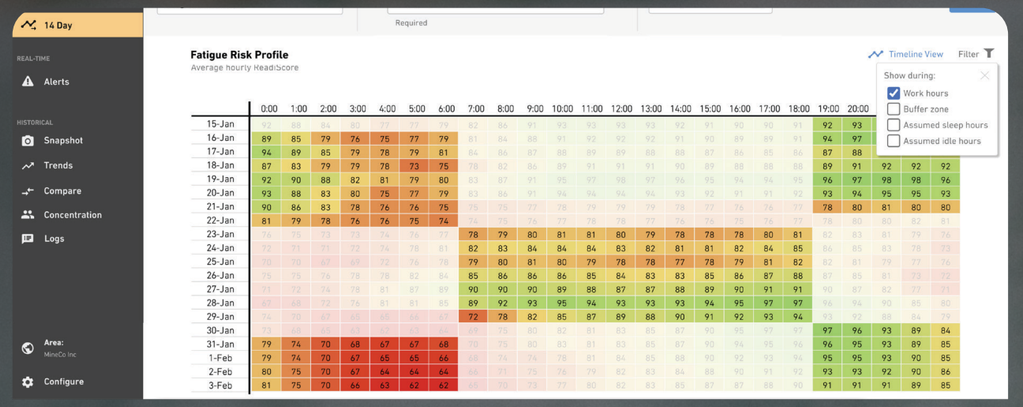
Predictive technology, like **Readi**Supervise, the component of Readi for designed for shift supervisors, can provide real-time **Crew Fatigue Alerts** to allow supervisors to monitor critical worker fatigue and access a dashboard of all likely upcoming risks.

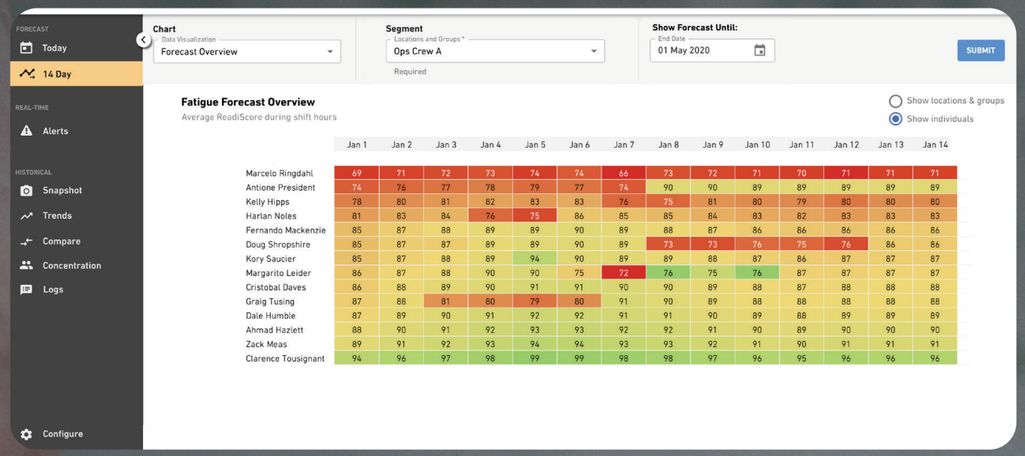
Integrated Intervention Logging is another important feature to look for, as it enables seamless tracking of any critical fatigue interventinos that a supervisor makes.



14-Day Fatigue Forecasting is the most recent addition to Readi's site of predictive technology. Leveraging schedules, machine learning, and individual sleep profiles, 14-Day Fatigue Forecasting allows supervisors to see a projection of the "who, when, and where" of crew fatigue up to 14 days in advance.

With these insights, supervisors can plan critical tasks for the right worker at the right time, identify likely fatigue hotspots in their shift pattern, and plan interventions for critical fatigue even further in advance — with ample time to make adjustments.



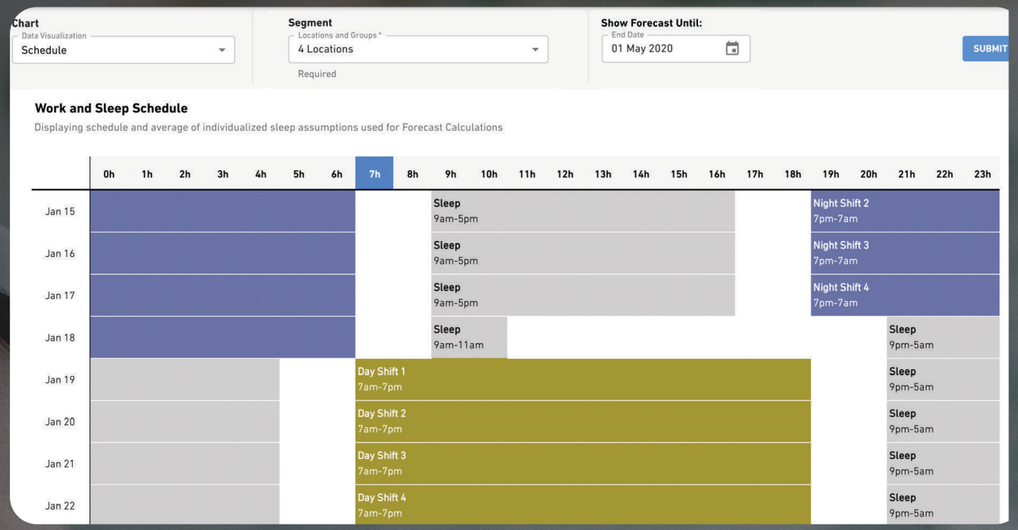


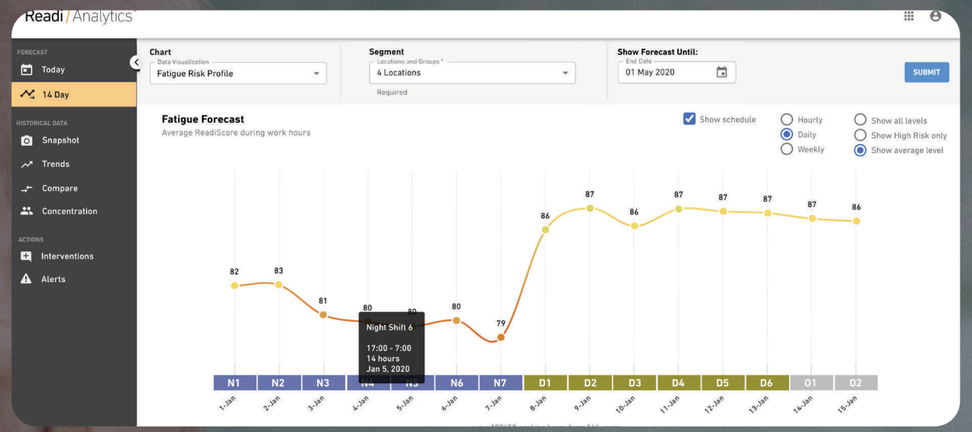
Technology for leadership and HSE

Predictive technology, like **Readi**Analytics, the analytics software component of Readi, can inform critical management decisions to reduce fatigue risk and improve productivity across an industrial organization.

Analytics tools such as ReadiAnalytics leverage predictive fatigue data to provide aggregated fatigue insights at a group-, shift- or site-wide level. Leadership and health & safety teams can establish a quantifiable fatigue baseline for their operation, then identify problem fatigue areas within it. With this baseline in place, they can then implement specific fatigue reduction initiatives targeted at areas of concern, and use the ongoing analytics from *Readi* participants to measure the efficacy of these efforts (and adjust course as necessary to ensure success).

Moreover, schedule analysis and forecasting tools within ReadiAnalytics enable HSE teams and schedulers to simulate the real-world fatigue impacts of potential schedules. These insights are based on based on the unique and anonymous sleep profile of each participant in an operation, allowing for a much clearer picture than hypothetical scheduling tools can provide. These insights can provide an understanding of the degree to which a certain schedule is an underlying cause of fatigue (versus other factors, such as sleep health), and can help inform schedule optimization decisions.





Thank you.

We trust that this eBook has given you some insight into the science of sleep and workplace fatigue, but it really is only the beginning.

In this eBook, we've learned that:

- Both poor sleep, and schedules, can be a root cause of cognitive fatigue.
- Fatigue is an unavoidable consequence of our production-driven society, and its prevalence will only increase.
- Cognitive fatigue is a serious workplace impairment that impacts safety, productivity and employee health and well-being.
- Technology exists to not only quantify and manage cognitive fatigue, but to predict its onset as well.
- Leading industrial firms are now using predictive fatigue management technology to manage fatigue as a shared responsibility across all levels of the organization
- Effective fatigue management can ultimately reduce risk while increasing organizational productivity.

Fatigue Science, and our *Readi* fatigue management information system, is at the forefront of this new era of predictive fatigue management technology.

By combining validated science with data from wearable devices into a comprehensive enterprise software platform, we help individuals at all levels of the industrial organization, from operators, to supervisors, to HSE teams and leadership to do their own part in mitigating workforce fatigue and optimizing industrial performance.

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About Fatigue Science

Fatigue Science is the leading provider of predictive fatigue analytics and human performance insights for heavy industry, elite sports, and military. Headquartered in Vancouver, Canada, we provide organizations *Readi*, a 360° Fatigue Management Information System, delivering historical, real-time, and forecasted insights into workforce fatigue.

Our technology is built on scientifically-validated biomathematical models that quantify and predict the effects of sleep disruption on reaction time and cognitive effectiveness, key elements of fatigue.

High performance organizations use our software to optimize operations, reduce risk, and increase productivity — both at an individual- and enterprise-level. With a proven return on investment and significant traction in heavy industry, military, and elite sports, Fatigue Science serves cutting-edge organizations who understand the importance of sleep as well as the value of data-driven decision-making.