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Sleep, Health, and Safety: Challenges in a 24 -hour Society

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Earth from the moon. Photo credit: NASA.

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Dr Philippa Gander received her PhD from the University of Auckland in 1980. From 1980-82, she was a Senior Fulbright Fellow in the Department of Physiology and Biophysics at Harvard Medical School. In 1983, she joined the Fatigue Countermeasures Program at NASA Ames Research Center, where she was involved in extensive field studies to assess the physiological and safety impact of shiftwork in all types of aviation operations. This led to the development of a comprehensive fatigue management programme for the US aviation industry, including worker education, improved rostering practises, and regulatory changes. She was also involved in planning circadian and sleep research to support human exploration of the solar system, and has conducted experiments in space analogue environments.

As a member of the Fatigue Countermeasures Team, she was awarded the NASA Group Achievement Award in 1993, “for providing excellent scientific products to the operational community that will enhance aviation safety”. She also served as a reviewer on a 1991 report commissioned by the US Congress entitled “Biological Rhythms: Implications for the Worker”.

She is currently directing a research program in shiftwork, occupational safety, and health in the Department of Public Health at the Wellington School of Medicine, where she is a Professorial Research Fellow.

Sleep, Health, and Safety: Challenges in a 24 -hour Society

Introduction

As we approach the end of the 20th century, the move to continuous operations in more and more areas of human activity seems unstoppable. The lure of the global market place has been added to the older incentive of keeping valuable plant operating 24 hours a day. There are no data on how many New Zealanders are currently involved in shift work, but it is estimated that about 20% of the workforce in industrialised countries work non-traditional hours.

In industries other than the emergency services, the decision to move to 24-hour operations is usually based primarily, if not entirely, on economic considerations - to increase productivity and profitability. The aim of this address is to expand the debate, particularly in light of recent scientific evidence that shift work can have significant health and safety consequences.

Much of this new evidence comes from research into sleep and sleep disorders, and into the functioning of the circadian biological clock. These are relatively new scientific disciplines, which have expanded rapidly from seminal discoveries in the 1950s and 1960s. The first two sections of this address focus on key findings in these areas. In the final section, consideration will be given to some of the scientific, moral, and political challenges that we face if we are to better manage sleep, health and safety in the 24-hour society.

Sleep: the Other Third of Life

Although we spend about a third of our lives sleeping, the scientific study of sleep only began to emerge as a discipline in the 1950s. For the preceding centuries, medical science focused almost exclusively on the brain and body during wakefulness. Sleep and sleep disorders are still far from commanding one third of research, training, or clinical resources in medicine.

A critical breakthrough came when researchers in the laboratory of Nathaniel Kleitman at the University of Chicago developed what is now the classic technique for monitoring people sleeping throughout the night. This involves recording three different electrical signals: brain activity (electroencephalogram or EEG); eye movements (electrooculogram or EOG); and muscle activity (electromyogram or EMG), from the chin. Small electrodes are attached to the scalp and face, which convey the signals from the body to a recording device for later analysis. These three measures were sufficient to reveal the existence of two entirely distinct states of sleep, as different from each other as each is from wakefulness.

Non-Rapid Eye Movement (Non-REM) Sleep

This state of sleep is characterised by a progressive slowing down in brain activity, accompanied by slowing in breathing and heart rates, and a decline in blood pressure, body temperature, and metabolic activity. Non-REM sleep is divided into four stages, based mainly on the speed of the brain waves (EEG). These slow down from 4-8 cycles per second (stage 1), to 0.5-2 cycles per second (stage 4). In contrast, during wakefulness with eyes open, the EEG can range from 15-50 cycles per second. The deeper a person goes into non-REM sleep, the more stimulation is required to wake them up. Thus it can be quite difficult to wake someone from non-REM stage 4, and they may awaken feeling disoriented and groggy. The effects of this “sleep inertia” can last for several minutes, with temporary impairment on a variety of tasks. Non-REM can be summarised as a relatively inactive brain (although it is still actively regulating other systems in the body), in a moveable body. The lack of movement is due to the lack of signals from the brain instructing the body to move.

Rapid Eye Movement (REM) Sleep

In contrast, REM sleep can be summarised as a highly activated brain in a paralysed body. During REM sleep, breathing and heart rate become irregular, blood flow to the brain increases, and brain temperature rises. Brain waves are fast and similar to those observed during wakefulness. As the name implies, during REM sleep, there are intervals when the eyes dart back and forth beneath closed lids, possibly following events in the sleeper's "dreamscape". People woken up during REM sleep are able to recall dreams about 80% of the time. Apart from occasional twitches, the large muscles of the body are effectively paralyzed during REM sleep. The cascade of instructions from the brain which would normally activate them is blocked at the level of the brainstem, presumably so that we do not "act out" our dreams.

The amount of stimulation required to wake someone up during REM sleep is very variable. It has been suggested that we may be less sensitive to stimuli from the outside world when we are busy attending to internal stimuli generated in our dreams. Dreams are usually recalled only if we awaken from them, which has led to the idea that memory may not be consolidated during dreaming.

A common analogy used to illustrate the states of sleep is “the car in garage”. Traditionally, sleep tended to be viewed as a state during which physical activity was minimal and the brain was shut down. In this view, going to bed at night was like putting your car in the garage and turning off the engine. Hopefully, it would start again in the morning. In fact, non-REM sleep can be likened to putting the car in the garage with the engine running, but in neutral. Nothing switches off, but there is no movement. In contrast, REM sleep is like putting the car in the garage with the engine running, and the accelerator and the brake both flat to the floor. The accelerator represents the active brain. The brake represents the block in the brainstem that prevents dreams being acted out.

The non-REM/REM Cycle

During sleep, non-REM and REM sleep alternate with a cycle lasting about 90-120 minutes. Sleep usually begins with a progression deeper and deeper into non-REM sleep. After 80 or so minutes, a series of body movements signals a rapid ascent back up to the lighter stages of non-REM sleep, followed by the transition into the first REM period of the night. Bouts of slow-wave sleep (non-REM stages 3 and 4) tend to last longer and be deeper at the beginning of the night. In contrast, REM sleep bouts tend to get progressively longer towards morning. The pattern of sleep across the night for a young adult is summarised in Figure 1. About 25% of sleep time is spent in deep non-REM sleep, and 25% in REM.

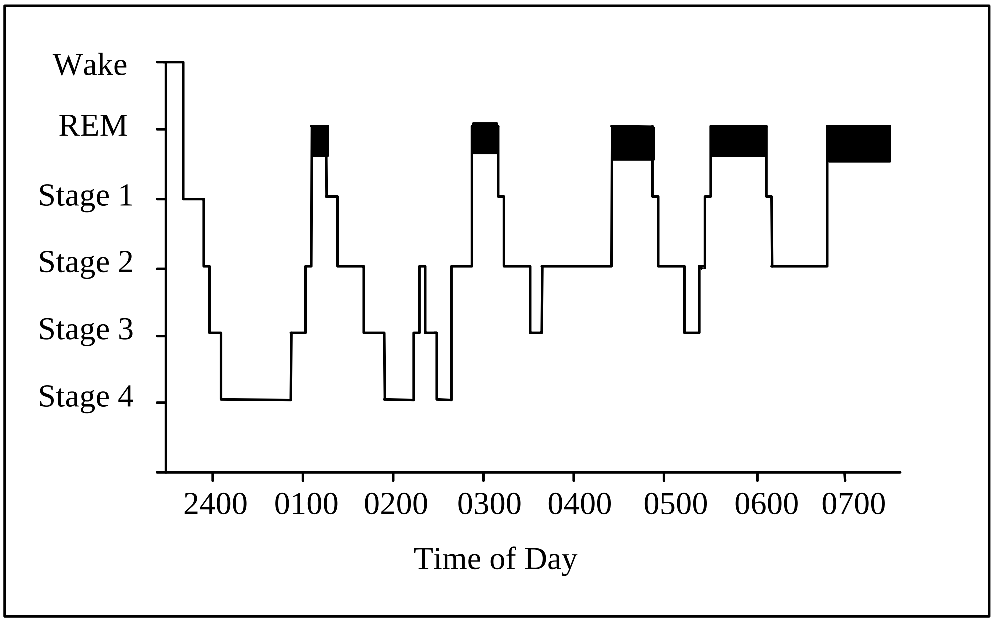

Figure 1: Diagram showing the non-REM/REM cycle across a normal night of sleep, for a young adult.

Throughout the night, the EEG may signal brief awakenings that are usually not remembered by the sleeper in the morning. The number and duration of these arousals affects how well-rested a person feels the next morning, and how sleepy they are throughout the day.

The functions of non-REM and REM sleep are still actively debated. As a gross generalisation, non-REM sleep may be associated primarily with physical restoration, whereas REM sleep may be needed primarily for mental (cognitive) restoration. There is no evidence to support the common misconception that either state is more important than the other.

Age-Related Changes in Sleep

Across the life span, there are characteristic changes in the total amount of sleep per 24 hours, and in the proportion of sleep time spent in non-REM and REM sleep. Newborns usually sleep 16-18 hours a day with half that time spent in REM, and it is not uncommon for infants less than one year old to fall asleep directly into REM. From birth, the amount of REM sleep declines gradually, reaching about 25% of the total sleep time by five years of age. It appears to remain at around this level well into healthy old age. A fascinating question is why babies dream so much. One possible explanation is that it may help to continue the development of the brain after birth. Compared to other mammals, human infants are born at a relatively immature stage of development, and with limited ability to interact with the environment. Dreaming may represent a type of internal stimulation, to complement the relatively restricted external stimulation that babies receive, to continue the processes of brain development.

The fully-developed brain wave patterns of non-REM sleep emerge over the first 2-6 months of life. The proportion of total sleep time spent in slow wave sleep is greatest in young children, and decreases by nearly 40% across the second decade of life. By age 60, high amplitude slow-wave sleep (non-REM stages 3 and 4) may be entirely absent, particularly in men.

The non-REM/REM cycle is present at birth but is only 50-60 minutes long. As all parents know, consolidated nocturnal sleep develops gradually after birth. At the other end of the life span, it is lost again. Usually in their fifties, people begin to experience more transient arousals and intermittent bouts of wakefulness during the night. Total nocturnal sleep decreases, often because people wake up earlier. It is commonly believed that older people need less sleep. However, as their nocturnal sleep becomes shorter and lighter, they also become sleepier during the day. This suggests that, rather than needing less sleep, it is the brain's ability to produce a good night of consolidated sleep that declines with age. As with many aspects of normal ageing, individual differences in sleep become much greater among older people, making generalizations more difficult. In addition, older people are more likely to suffer from sleep disorders and other health problems that may disturb sleep.

The sleep of teenagers is an area of particular concern. A recent pilot study carried out with sixth formers at Wellington High School supported international findings that this group may be chronically sleep-deprived. Students reported getting about 1.5 hours less sleep than they need on school nights, with efforts to catch up on weekends. The main reason seems to be that many teenagers move to much later times of going to bed and falling asleep, but they still have to get up for school in the morning. This change in sleep time appears to be due to a combination of factors, including homework, socialising, and after-school jobs. It may also have a physiological component, with sleep slipping to a later time in the daily cycle of the circadian biological clock. The relative importance of these different factors needs to be investigated for New Zealand teenagers. Chronic sleep loss in this age group can have far-reaching consequences, potentially affecting educational opportunities, motor vehicle accident risk, mood, and possibly alcohol and drug use.

Sleep Disorders

Already it will be clear that sleep is a complex, dynamic phenomenon. Not surprisingly, there are many ways in which it can be disrupted. The field of sleep disorders medicine has evolved very quickly in recent years. In 1990, an International Classification of Sleep Disorders was produced that lists 84 different disorders. Figure 2 shows a breakdown of the major categories of sleep disorders.

The dyssomnias include problems with sleep (falling asleep and/or staying asleep), and problems with staying awake. Some arise from causes within the body, some result primarily from environmental factors, and many are affected by both intrinsic and extrinsic factors. The most commonly diagnosed sleep disorder, sleep apnoea, is classified as an intrinsic dyssomnia. Studies in the United States suggest that it affects about 4% of adult men, and 2% of women. However, prevalence estimates vary for different groups of people, and we currently have no information on the prevalence of sleep apnoea among New Zealanders. An issue of particular concern is that the specialist clinic treating apnoea at Green Lane Hospital in Auckland has reported seeing a disproportionately high number of Maori and Pacific Island people with severe obstructive sleep apnoea.

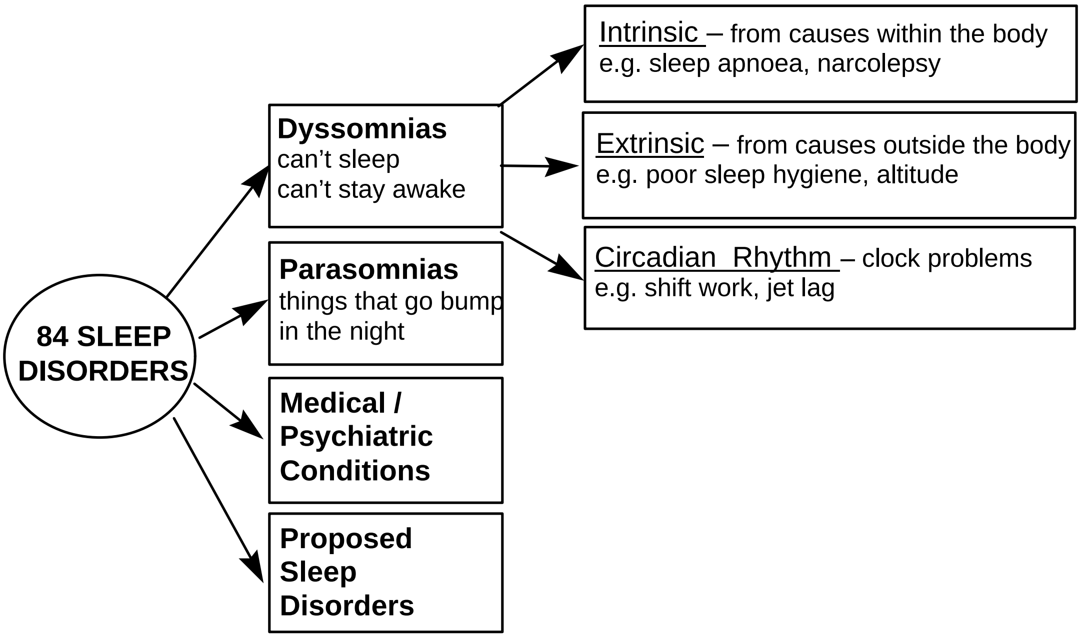

Figure 2: Different Types of Sleep Disorders

People who have sleep apnoea stop breathing when they fall asleep. This usually happens because the upper airway collapses as they relax (obstructive sleep apnea). It can also happen because the diaphragm, which helps to pull air into the lungs, stops moving when they fall asleep (central sleep apnea). It is possible to have both at the same time (mixed sleep apnea). In severe cases, the breathing pauses may last several minutes and can occur hundreds of times during the night. Sufferers have to wake up to breathe and so have very fragmented sleep and complain of daytime sleepiness. However, they often have no recollection of waking up during the night, and can be completely unaware that they have the problem. Their breathing pauses, and loud snores, snorts, and gasps as breathing resumes, often disturb their bed partner who is frequently the person who realizes that there is a sleep problem.

Treatments for sleep apnoea depend on its causes. The most common treatment for obstructive sleep apnoea is to wear a small mask during sleep, which is connected to a compressor and provides a flow of air through the nose to keep the airway open (Continuous Positive Airway Pressure, or CPAP). Other treatments include: weight loss (obesity is a very important risk factor); wearing a dental appliance at night to move the jaw forward and increase the size of the airway; and surgery to remove excess tissue in the upper airway.

Adults who have sleep apnoea have an increased chance of having high blood pressure, heart disease, and stroke. They are also more likely to have automobile accidents than non-sufferers, probably because they are excessively sleepy. These are all problems which affect Maori disproportionately. It thus seems likely that better understanding and treatment of sleep apnoea in New Zealand could help redress the differential between Maori and non-Maori in other areas of health. In children, sleep apnoea is thought to impair learning ability and to increase behavioral problems because of the increased daytime sleepiness.

Parasomnias include a range of behaviours and experiences that occur during sleep. The most common type, such as sleep walking, sleep talking, and sleep terrors, tend to happen as people are coming out of deep non-REM sleep. They appear to be awake enough to carry out complex actions, but not awake enough to be aware or able to remember those actions. These parasomnias are very common in young children, perhaps because they have so much deep non-REM sleep. Another interesting parasomnia, REM sleep behaviour disorder, is most common amongst older men, and occurs when the muscle block during REM sleep does not work completely and people act out their dreams. This can be controlled with medication. Teeth grinding during sleep, or bruxism, is also classified as a parasomnia. In general parasomnias do not require medical attention unless they are violent or may cause injury, disturb other household members, or lead to excessive sleepiness.

Medical and psychiatric disorders, which are typically diagnosed as a result of problems with waketime functioning, often have their counterpart in problems during sleep. There are a number of interesting relationships being explored between psychiatric illness and sleep disorders. For example, there are indications that insomnia may precede the onset of psychotic episodes in schizophrenia. Sleep deprivation can sometimes alleviate the symptoms of depression, and can trigger manic episodes in some patients with bipolar disorder. The study of sleep disorders may open a new window on our understanding of psychiatric illness.

Sleep Disorders in New Zealand

There are currently no data on the number of people suffering from sleep disorders in New Zealand. Extrapolating from estimates for the US population, the prediction would be that there are more than half a million people with chronic sleep disorders, with up to a further 350,000 who have intermittent problems sleeping. Sleep disorders medicine is in its infancy in this country, and most of our health care professionals have no training in this area. At present, there are specialist clinics in the four main centres, primarily diagnosing and treating sleep apnoea. However, it is likely that many New Zealanders with sleep disorders currently remain undiagnosed or misdiagnosed. Good sleep needs to be added to sensible diet and regular exercise as one of the cornerstones of good health.

Sleepiness

Sleep is now recognised as a vital physiological function, comparable to eating or drinking. Sleepiness is effectively a message from the brain that sleep is needed, similar to hunger or thirst. However, sleepiness is different in an essential way. If it is ignored for too long, people will fall asleep uncontrollably, even if this puts them in a life-threatening situation. As an example, it is estimated that one-in-five motorists in the USA has fallen asleep at the wheel.

There are three main reasons that people tend to underestimate sleepiness, or deny its importance. First, how sleepy you feel is not necessarily a reliable indicator of how close you are to unintentionally falling asleep. This is because we use stimulation in the environment to help defer falling asleep. For example, a boring lecture does not make you fall asleep. It is simply an environment where there is not enough going on to help you fight your need for sleep. If you are not physiologically sleepy, you may be frustrated about wasting your time, but you will not fall asleep. Conversely, a fascinating conversation may hold your attention for a long time even when you are rather sleepy.
Second, admitting to feeling sleepy has accrued many negative connotations, such as laziness, lack of motivation, and lack of professionalism. Third, people do not recognise that sleepiness will eventually win, and that the only way to reverse it is to sleep.

The average sleep need for adults is probably around 7-8 hours a night, but there are individuals who require more, or less, than this amount to be well-rested and fully functional the next day. There is no good evidence that you can train yourself to need less sleep than your individual requirement, which may be partially genetically determined.

Reducing nocturnal sleep by as little as one hour increases physiological sleepiness the next day. Furthermore, the effects of successive nights of reduced sleep accumulate. Thus, if you need 8 hours of sleep a night and through the working week you only average 6 hours, then by Friday you are 10 hours “in debt”. As a consequence, by Friday you will be sleepier, and functioning more slowly and less reliably, than on Monday. Your mood may also become more irritable and negative. To “pay back” an accumulated sleep debt, it is not necessary to recuperate all the hours lost - you would not have to sleep 10 extra hours on Saturday in this example. Recovery sleep is deeper. In fact, so much time can be spent in non-REM stages 3-4 on the first recovery night that a second night is needed to recuperate REM sleep. In general, two nights of unrestricted sleep are enough to allow sleep to return to normal after sleep loss.

If sleep debt is allowed to continue to accumulate, eventually the brain will disengage from the environment for brief periods as it slips uncontrollably in and out of "microsleeps". During microsleeps, a person will not see, and may not hear, critical cues from the environment. One classic example was captured during an experiment in which the brain activity and eye movements of a locomotive engineer were being monitored as he drove a train at night. During a recorded microsleep, he drove through a red light on a siding and woke up too late to stop the train continuing onto the main track where he could have faced a head-on collision. Microsleeps may well be behind accidents where drivers fail to take a corner and drive straight off the road, or drift across the centre-line into on-coming traffic.

In the early 1990s, the US Congress set up a National Commission on Sleep Disorders Research. The following statement is from the Commission's 1993 Report.

> "Sleep deprivation has become one of the most important sources of error and accident throughout our society. Annual sleep-related accidents in transportation alone claim over 5,000 lives, cause hundreds of thousands of injuries, and assess a cost in the billions in health care costs, death, lost productivity, and damage to property."

This does not address the cost in terms of human suffering for victims or their families and friends.

The Circadian Biological Clock

Taking an integrated view of sleep and waketime functioning is a key step towards understanding the potential health and safety consequences of the 24-hour society. The sleep/wake cycle is itself the most obvious example of the daily fluctuations in body and brain function known as circadian rhythms (from Latin circa - about, dies - a day).

Circadian Rhythms

Circadian rhythms are an adaptation to the day/night cycle and they are found in all types of plants and animals, and in some bacteria. However, they are not simply a response to the changing environment. They have become genetically programmed and continue even when all the 24-hour cues from the environment have been carefully screened out, in a "time isolation" laboratory.

Many different circadian rhythms have been measured in the human body. Figure 3 shows some examples recorded from a commercial airline pilot on a day off, during three working days when he flew passengers up and down the eastern USA, and on two further days off after the trip. The top panel shows his circadian rhythm of deep body temperature, which descends to a daily low point around 3-5 am, and then rises to a peak in the early evening, before declining again as the cycle repeats. The second panel shows the pilot's level of physical activity, as monitored by a small accelerometer which recorded the movements of his wrist. As expected, his activity was low when he reported being asleep (shaded bars), and high and variable when he reported being awake. The lower two panels show how he felt at two-hourly intervals across the day. The first of these panels shows the circadian rhythm in his self-reported fatigue. He felt least fatigued several hours after getting up in the morning, and then became increasingly fatigued until he went to bed again in the evening. The bottom panel in Figure 3 shows how he rated himself across the day on a mood scale relating to activation. The pattern here is the opposite to that for his fatigue ratings.

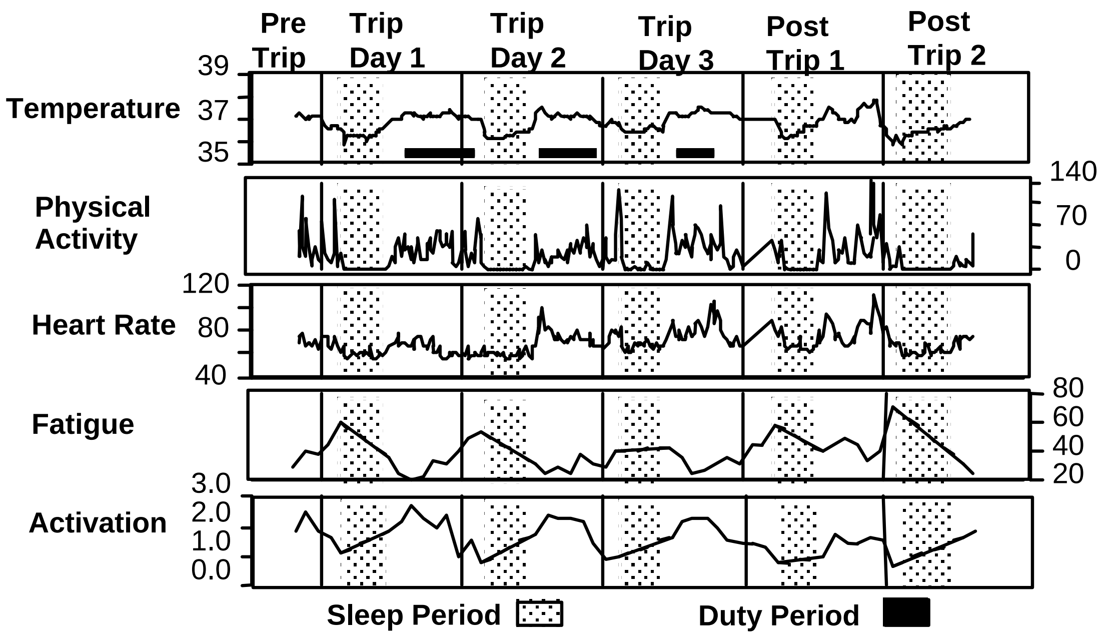

Figure 3: Circadian Rhythms of a 46-year-old Commercial Airline Pilot (data from the NASA Fatigue Countermeasures Programme).

Many other functions could have been monitored in this individual, and each would have shown its own characteristic peak time and low point every day. There are, for example, circadian rhythms in hormone levels, cardiovascular function, responsiveness of the immune system, digestion, kidney function, reactions to drugs, and in our capacity to perform any kind of physical or mental task.

The circadian variations in performance capacity are not trivial. Depending on the task, the performance change between the daily high point and the daily low point can be similar to that caused by drinking the legal limit of alcohol.

The best time of day for doing a given task depends on the nature of the task. For example, complex problem solving or logical reasoning is most efficient around noon. Tasks which rely more on physical co-ordination are performed best in the early evening, around the time of the daily peak in body temperature. Immediate recall is better for information presented in the morning, whereas long-term retention is better for information presented in the afternoon or evening.

When performance is measured through the night, it gets to its worst on most tasks at around the time of the low point in temperature (about 0300-0500 on a normal routine with sleep at night). This is also the time in the circadian cycle when the physiological urge to sleep is strongest. In effect, at this time the brain and body are programmed to be asleep. As you stay awake longer and longer across the night, you might expect that performance would continue to get worse because of increasing sleep debt. However, anyone who has had to stay awake all night has experienced the early morning slump, when you really have to struggle hard, but then things seem to improve again. This happens as core body temperature begins to rise again in the morning, and performance improves even without sleep. The circadian clock is then driving body and brain function into wakefulness.

In the middle of the afternoon, there is a secondary slump when the physiological urge to sleep is high, and performance on some tasks again drops temporarily. This slump is more marked if you are already suffering from sleep loss. In siesta cultures, this physiological programming is acknowledged with the afternoon nap. One might argue that afternoon tea, when we usually drink stimulants of some kind, might be another way of dealing with this.

Careful research in industries where work requirements are similar around the clock, has shown that there are declines in efficiency or increases in error rates in the early hours of the morning and, in some cases, in the middle of the afternoon. This has led to the concept of “windows of vulnerability” for human error at these two times of day. Figure 4 illustrates another area of activity where the circadian variation in sleepiness and performance efficiency shows up - in fatigue-related motor vehicle accidents. This study of single vehicle accidents attributed to “falling asleep at the wheel” includes data from Israel, Texas, and New York. Interestingly, people over the age of 45 years are more likely to have such accidents in the afternoon. This may reflect the increasing sleepiness that accompanies the age-related reduction in the quality and quantity of sleep at night.

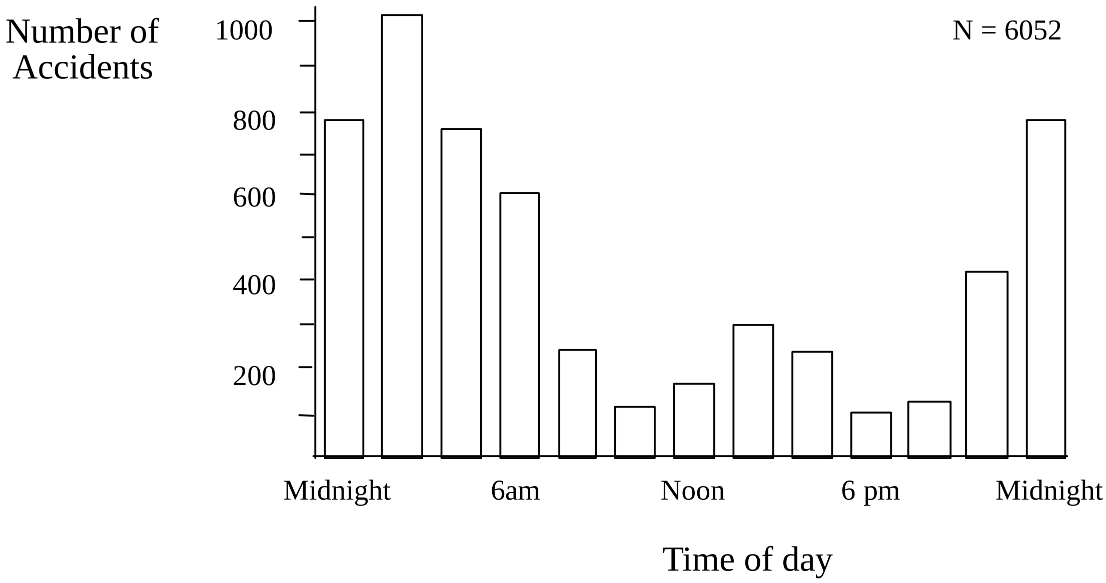

Figure 4: Timing of Fatigue-Related Single-Vehicle Accidents (source: Mitler, MM et al., "Catastrophes, Sleep and Public Policy: Consensus Report", Sleep, volume 11, pages 100-109, 1988.)

A Clock in the Brain

With so many different functions cycling up and down across the 24-hour day, a master pacemaker is needed to keep everything in step. This is the function of the circadian clock, which is localised in a cluster of neurons in the hypothalamus of the brain (the suprachiasmatic nuclei or SCN). The clock can be likened to the conductor of a symphony orchestra. Each musician in the orchestra can play his/her own part in the music, but if they do not play it at the right time, the result is not music, but cacophony. Similarly, the "internal harmony" of the body can be disrupted if different rhythmic functions do not move in step with one another, under the influence of the circadian clock.

The innate properties of the circadian clock are studied by monitoring volunteers who live for weeks or months in environments from which all time cues have been carefully excluded. In some early studies, this meant living alone in deep caves. Now, subjects usually live in purpose-built apartments that provide greater safety and comfort, as well as more measurement possibilities and convenience for the researchers. Living for a while without sunlight, clocks, watches, television, radio, or current newspapers does not seem to be too stressful for most people. In this situation of "time isolation" they begin unconsciously to live "days" that last about 25 hours. This is the length of the biological day generated spontaneously by the circadian clock.

In everyday life, the circadian clock effectively tracks time cues in the environment to keep it in step with the 24-hour day. One of the most powerful of these cues is sunlight. (Indoor room lighting has a similar, but much weaker, effect on the clock because of its lower intensity). The response of the clock to sunlight changes across its cycle. Thus, sunlight in the morning tends to speed the clock up. Theoretically, the right amount of sunlight every morning would speed a 25-hour circadian clock up just enough to keep it on a 24-hour cycle. This process is analogous to getting up every morning and resetting a watch or an old pendulum clock that runs a bit slowly. Sunlight in the middle of the day has very little effect on the circadian clock, and sunlight in the evening slows it down. Again theoretically, the right amount of sunlight every evening would slow down a 23-hour circadian clock just enough to keep it on a 24-hour cycle.

The actual role of sunlight in synchronizing the circadian clock is no longer very clear. With the widespread availability of cheap artificial lighting, the introduction of shift work, and jet air travel, our patterns of exposure to sunlight have become very erratic. Thus the clock must rely on other types of cues if it is to stay in step with a 24-hour day. Importantly for the shift worker, these other cues include the patterns of work and rest, and contact with other people. How these social factors exert an effect on the clock in the brain is still poorly understood.

The Clock and Sleep

As might be expected, sleep is profoundly affected by the circadian clock. The part of the clock cycle in which you try to sleep will affect how long it takes to fall asleep, and the length and quality of sleep that you can obtain. Some key relationships between sleep and the circadian clock are summarised in Figure 5. In this figure, the rhythm in core body temperature, with its low point around 3-5 am and its peak in the early evening, is used as a reference for the cycle of the circadian clock. (The clock itself could only be measured directly by implanting an electrode in the brain.) On a normal night of sleep, people usually fall asleep about five hours before the low point in core body temperature, and wake up several hours after temperature begins to rise again.

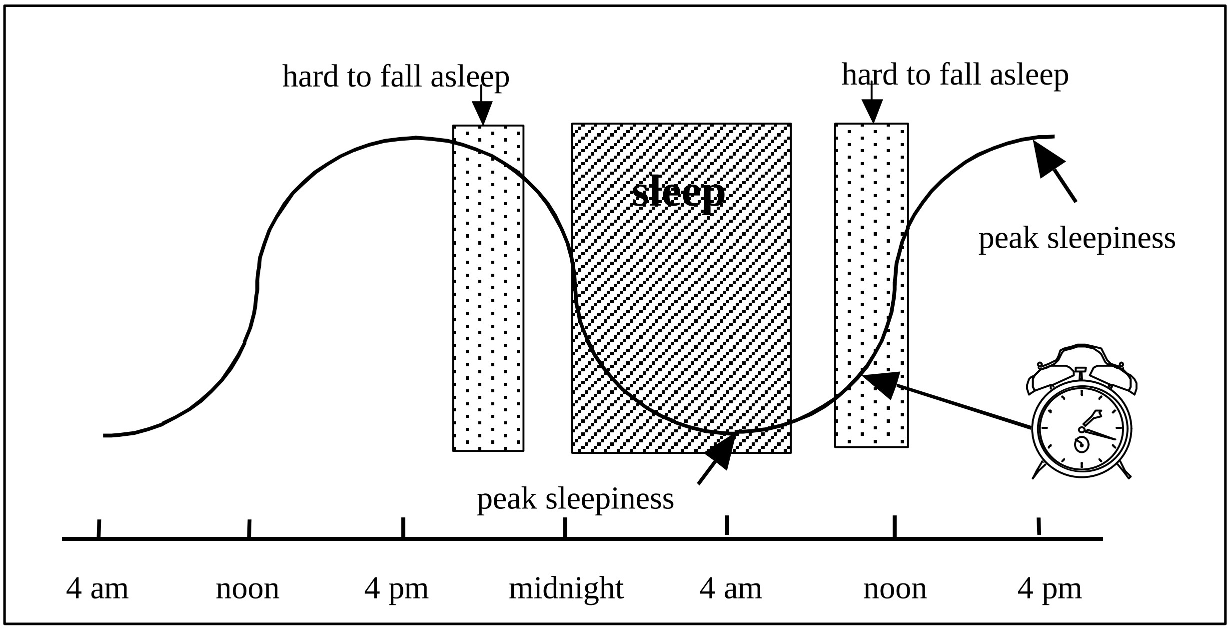

Figure 5: Effects of the Circadian Clock on Sleep

As already discussed, there are two times in the clock cycle when it is easiest to fall asleep - around the time of the temperature low point, and again about 9-10 hours later, during the afternoon nap window. Conversely, there are also times when the brain and body are programmed to be awake, and it is very difficult to fall asleep, even if you are suffering from moderate sleep loss. These are known as "wake maintenance zones". One occurs several hours before your usual bedtime. This can be a problem if you know that you must get up extra early. You cannot force yourself to fall asleep several hours earlier than usual, in anticipation of the fact that your sleep will be cut short in the morning. The possible function of this evening maintenance zone is not clear, although it may contribute to a more regular pattern of sleep at night. The other wake maintenance zone is centred about 6 hours after the low point in temperature, or in the late morning. At this time the circadian clock is programming the body and brain for wakefulness. In fact, about six hours after the low point in temperature an "internal alarm clock" goes off that can wake you up, if you are already asleep. This wakeup call from the circadian clock can be very inconvenient if you have only been in bed for a few hours after coming off night shift.

REM (or dreaming) sleep is tightly linked to the circadian clock cycle. REM sleep is entered fastest, and REM bouts last longest, just after the low point in temperature. This link to the clock explains why REM bouts are longest towards morning in a normal night of sleep (Figure 1). In contrast, deep non-REM sleep (stages 3-4) seems to be much less dependent on the circadian clock. The amount of time spent in deep non-REM sleep is linked to the duration of prior wakefulness, and perhaps the amount of activity during wake. Most deep non-REM sleep occurs in the first couple of non-REM/REM cycles in a sleep episode, regardless of when in the circadian cycle sleep occurs.

The Shift Worker's Dilemma

Shift work requires trying to override the temporal programme dictated by the circadian clock for sleep at night and wakefulness during the day. It is very difficult to move the clock away from this preferred orientation, because, regardless of the shift pattern, the day/night cycle and the activities of the rest of day-oriented society do not change. Thus the clock, in trying to pick up cues to stay in step with the 24-hour day, gets mixed messages. For example, the clock of a night worker is influenced by the demands of the work pattern effectively indicating that activity should be reprogrammed to night time. However, when he/she drives home in the morning, the sunlight is a major cue to the clock that activity should be occurring during the day. Similarly, the routines of family and friends who are not night workers can be strong cues to the night worker that daytime is the time to be active, not to sleep. As a consequence, the circadian clock almost never adapts fully to shift work. Even people working permanent nights do not become physiological "night people". Days off usually represent another re-orientation exercise for the circadian clock of the shift worker, since most people revert to sleeping at night on their days off.

Incomplete Circadian Adaptation and Safety

Figure 6 illustrates the effects of night work on the clocks of a group of overnight cargo pilots, who were permanent night workers. They were monitored before, during, and after an 8-day roster that involved night flying up and down the eastern and central USA (maximum time zone change 1 hour). In the figure, 24-hour days are plotted consecutively down the page. The shaded area indicates the approximate time of local night. The small black boxes indicate the times of the flights operated by the pilots each night. The small open boxes indicate the times of flights on which the pilots were passengers. They were still on duty, but were being flown to and from home, where they had a night off after three nights of flying. The crosses mark the average times of the temperature low point for 12 pilots. Prior to going on night duty, the average time of the temperature low point was 5:20 am. If the circadian clocks of these pilots had adapted completely to night work, it would have moved to 5:20 pm. In fact, it only moved to an average time of 8:08 am.

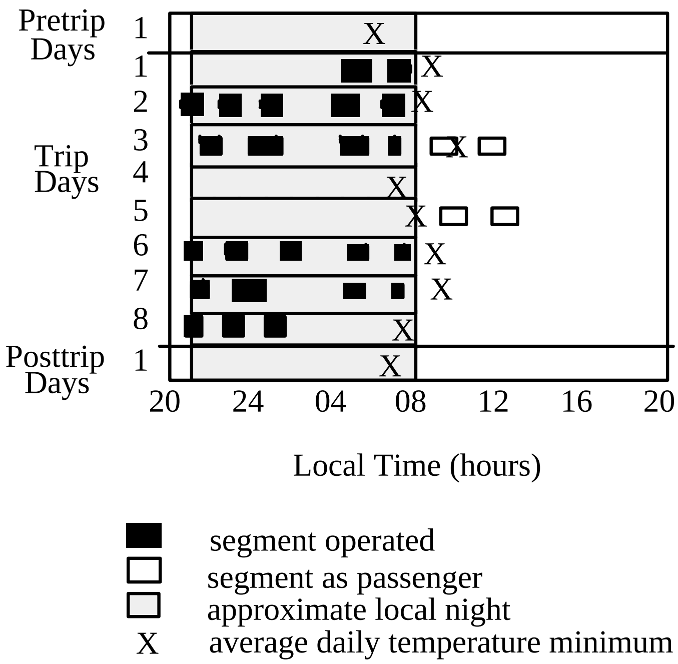

Figure 6: Effects of Permanent Night Work on the Circadian Clocks of Overnight Cargo Pilots (data from the NASA Fatigue Countermeasures Programme).

From the point of view of safety, there are two main reasons why the incomplete adaptation of the circadian clock to night shift could be a problem. First, pilots were often coming in for the last landing of the night during the time when their circadian rhythms in performance capacity were at their lowest ebb of the day, and when they were most vulnerable to falling asleep inadvertently. They had also been up all night, and so were operating with an acute sleep debt. Both these factors increase their risk of making errors.

Second, they could not go to sleep at the usual time in the circadian cycle (about 5 hours before the temperature low point - see Figure 5), because they were on duty at that time. When they finally got to bed in the morning, their temperature rhythm was just beginning to rise again. They were still trying to sleep when their “internal alarm clock” went off 6 hours after the temperature low point. On average, these pilots woke up at 2:13 pm, 6 hours and 5 minutes after the temperature low point, and reported that they did not feel well-rested. Depending on what time they went back on duty the next night, they were sometimes able to have a second short sleep in the evening. Nevertheless, they still slept about 1 hour 40 minutes less per 24 hours than they would have on a day off. As a result they accumulated a sleep debt across the 8-day roster. This would also progressively increase their risk of making errors.

In summary, because the circadian clock did not adapt to night work, these pilots were working when all the physiological factors that increase error vulnerability were operational - they had been awake for a long time, and were working through the circadian low point in performance capacity, with an accumulating sleep debt. The safety margin would have been reduced at these times. No major errors were observed in this study. However, there were also no unusual or emergency situations which would have tested the pilots' performance capacity.

There are a number of well-known major industrial accidents where emergencies did arise on the night shift, and the shift workers made significant errors that exacerbated the disaster. These include the nuclear accidents at Chernobyl and Three Mile Island, and the toxic chemical release in Bhopal, India.

Shift Work and Health

Given the growing number of people involved in shift work, there is a pressing need to identify possible effects of shift work on health. It is difficult to do scientifically rigorous research in this area. One obvious problem is the people who stay in shift work for a long time are probably those who can tolerate it best. More attention should perhaps be focused on people who leave shift work for health reasons. A second problem is that, to clearly demonstrate an effect of shift work on a workforce, it is really necessary to have a very similar group of day workers for comparison. This is rarely possible. Third, other factors in the workplace may contribute to health consequences. For example, a worker in a large industrial plant, who is exposed to toxic solvents and high levels of noise for 20 years, might be expected to show different health effects to an air traffic controller working comparable shifts for the same period of time.

Given these difficulties, it is not surprising that research in this area is sometimes inconsistent and even contradictory. Nevertheless, there is sufficient evidence to indicate that shift work has a number of health consequences. Shift workers, and particularly rotating shift workers, have higher incidences of sick leave, more frequent visits to health care facilities at the work site, and more general health complaints than day workers. The most common complaints are sleep disruption and gastro-intestinal problems (everything from flatulence to peptic ulcers). There is growing evidence that shift workers may have a higher incidence of cardiovascular illness. In some industries they may be more prone to mental health problems, including depression and anxiety disorders. There is also increasing concern that the reproductive health of women shift workers may be adversely affected, resulting in more menstrual cycle irregularities and poorer pregnancy outcomes (low birth weight and pre-term births). Currently, there is very little understanding of what aspects of shift work cause these problems. Possibilities include the following.

- The continuous challenge to the circadian clock of work patterns that are out of step with the day/night cycle, and the process of constantly trying to readapt to changing work patterns and days off.
- Spending much of a working life in sleep debt.
- Circadian rhythms in disease symptoms and in the body's responses to medications, that may compromise a shift worker's efforts to follow treatment programs for health problems.
- Stresses on family life, and the competing time demands that shift workers often face between work and home.
- Reduced opportunities to take part in sports and other leisure activities with people who are not shift workers.

There is a pressing need for careful, comprehensive research in this area.

Future Challenges

There is every indication that more and more industries will move to 24-hour operations, and therefore that increasing numbers of people will be involved in shift work. Scientific understanding of the potential consequences for sleep, health, and safety, is rapidly expanding but still very incomplete. Nevertheless, the available evidence is sufficiently compelling to warrant a careful review of the costs and benefits of the 24-hour society.

Challenges to Science

There are two areas of shift work research that I see as being particularly critical.

1. Why do some people apparently cope well with shift work, while others do not?
2. What causes the additional health problems experienced by shift workers, and how can they be minimised?

Figure 7 outlines a current model of how these issues might be linked. Traditionally, the first (and often the only) approach to problems with shift work was to reorganise the rosters. Innovative approaches to rostering may provide some improvement, but regardless of the roster, some individuals will have more problems coping with it than others. This individual variability has been recognised for a long time. To date, much of the research trying to explain it has focused on personality profiles and characteristics of the circadian clock. For example, some studies found that neurotic extraverts, and people who were evening-type rather than morning-type, did better on various measures of adaptation to shift work. However, overall, this focus on characteristics of the individual has yielded findings that are inconsistent, at best. Even when statistically significant relationships were found, they explained very little of the observed differences between individuals. The one consistent finding was that shift workers often experience more problems as they get older, particularly after they reach 45-50 years of age. This may be associated with age-related changes in sleep and the circadian clock.

More recently, the focus of attention has moved to so-called “situational factors” - aspects of a person’s life outside of work that may affect how they cope with shift work. The traditional stereotype of a shift worker, outside the emergency services, was a male working in a blue-collar job, and receiving significant shift allowances as compensation for the inconveniences of shift work. If he had his own family, he had a wife at home with full time responsibility for childcare and running the household. All aspects of this stereotype are outmoded. Shift work is spreading to all spheres of economic activity. With the major entry of women into the (non-domestic) workforce, many shift workers now have working partners, and sometimes shift working partners. This adds a great deal of complexity to the organisation of such areas of life as childcare and household responsibilities, and reduces the time available for the relationship between partners. Opportunities for socialising may be limited, particularly if a shift worker is not part of a large team who have the possibility of enjoying their leisure time together. Family and community support for shift work may be important mediating factors affecting coping. Commuting long distances to and from work can significantly reduce the amount of time available for sleep, and all the other activities of life outside of work.

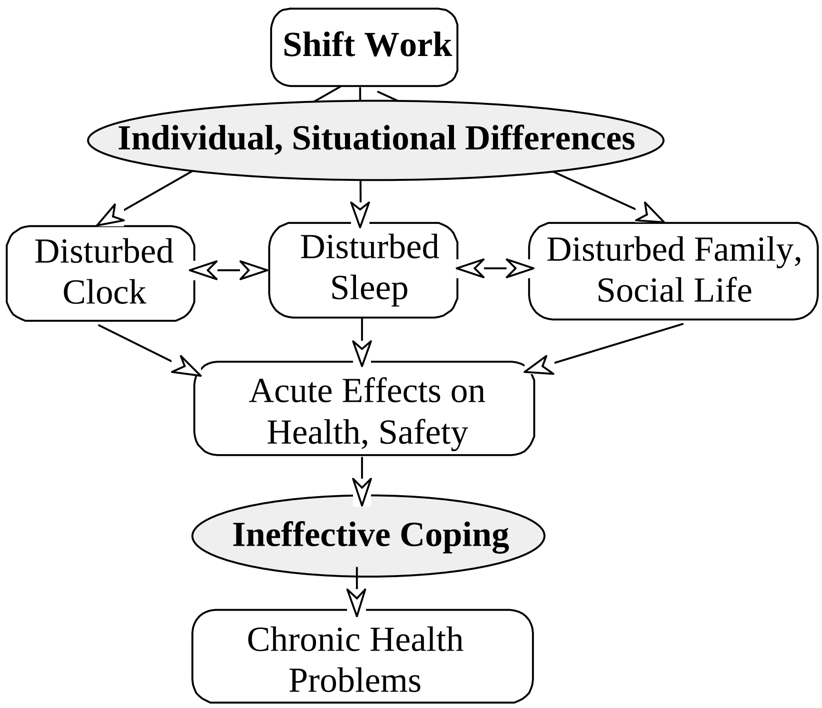

Figure 7: Possible Links Between Shift Work, Health, and Safety Outcomes

Whatever the roster, and their individual characteristics and life circumstances, shift workers will experience some disruption to the circadian biological clock, sleep, and family and social life. At times, these disturbances will have an acute effect on health and safety. Very little is understood about why these acute effects develop into chronic problems for some people, and not for others. A major multi-disciplinary research effort is needed to better understand the factors that improve people's ability to cope with shift work, in order to provide constructive support for shift workers. It is a truism that shift work is not a job, but a way of life.

I believe that another important challenge for scientists is to step across the gap, and perhaps out of their comfort zones, from the well-controlled research environment to the messy problems of the real world. Relevant scientific knowledge and expertise is often inaccessible to non-scientific people for whom it could be very valuable. I would argue that pooling the expertise of all interested parties - shift workers, managers, health and safety specialists, regulators, and researchers - is the approach most likely to lead to workable solutions. It requires a willingness to listen and a commitment to communicating clearly.

Challenges to Society

The traditional justifications for moving to 24-hour operations (except in the emergency services) have been primarily economic, to increase productivity and profitability. This paper focuses on what might be considered hidden costs that are currently transferred to individual workers, their families, and ultimately to society as a whole. They potentially include higher accident rates, poorer health, more troubled family and social lives, and an increased risk of major industrial accidents. While there may be broad agreement that these represent "costs", translating them into dollar amounts is extremely difficult, and does not capture their impact in terms of human suffering. It is my contention that the debate about the costs and benefits of the 24-hour society must be expanded to include these broader considerations, and the moral and political issues that they raise.

At the root of these problems lies the circadian biological clock, the genetic imprint of our 24-hour rotating planet. Looking forward to the new millennium, which will see human exploration of the solar system, this evolutionary heritage will continue to challenge us, whether in the 28 earth-day light/dark cycle of the Moon, the 24.6 hour day of Mars, or the timelessness of interplanetary space travel.

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