Physiological Considerations of Fatigue

Dr. Mark R. Rosekind

Fatigue Countermeasures Program
NASA Ames Research Center

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Thank you Chairman Hall. On behalf of NASA, the Ames Research Center and the Fatigue Countermeasures Program I welcome all of you. We are all extremely pleased to see both the size of the crowd, which indicates the interest in this topic, as well as the diversity of the individuals that are here. And while we may be up here today, your work certainly will begin tomorrow.

The first item is to review today's program. During planning, we were pleased to have an entire day to talk about some of the scientific information that is available about fatigue. Even with an entire day available, we ran out of time when you see how much we are going to try and cover. Essentially, we have presentations in groups of three.

The first presentation today will describe the physiological considerations that underlie fatigue, and then we will talk about sleep disorders in a presentation by Dr. Allan Pack. Then, in what I think is an important bottom line, how fatigue affects human performance, presented by Dr. David Dinges.

Immediately after these three presentations, we begin addressing what strategies are available to manage fatigue in transportation. Therefore, the next six presentations will deal with specific strategies. After some introductory remarks, I will describe some basic sleep habits we believe everybody should know about, then napping strategies will be discussed by Dr. Dinges, alcohol, sleep medications and caffeine will be discussed by Dr. Tom Roth. After that, we will hear about melatonin and bright light, different strategies to try to adjust the circadian clock, presented by Dr. Charles Czeisler. This is a hot topic, yesterday's Newsweek has melatonin as a cover story, and we can not have a symposium like this and not at least address melatonin and other circadian shifting strategies.

Then Dr. Dinges will talk about technology and scheduling approaches. And we will end the day discussing educational approaches, which is what really initiated this symposium. We feel that education is really the foundation for any other activities to manage fatigue in transportation.

The very final presentation of the day will deal with a resource directory. We thought it was important that besides providing scientific information, we should provide resources for people to use after the symposium. When you go home as individuals or to your organiza-

tions, you will be able to access resources that would help you implement the information obtained over these two days.

The speakers who are here today are internationally acknowledged as experts in the field. When they come up I am going to actually be very brief in introducing them because I want them to be able to get to their content. There is more detailed information about them in the symposium binder that you have received, including how to contact them for other resources. We are very fortunate to have such a distinguished group of experts here today. I do want to acknowledge there are many other people here in the audience who are active in this area. And we are looking forward to your expertise, participation and contributions to tomorrow's working groups.

One of the things we have during the day are two 30 minute question and answer periods. In your binders you have blue index cards. If you have questions throughout the day, please write them down on the cards, pass them to the outer aisles, and individuals will pick them up and bring them to the podium so we can handle the questions off the index cards by our expert panels.

When I was thinking about the "NASA" approach to managing fatigue in transportation, I realized there were two components. The first was that our approach acknowledges that transportation is a 24 hour, global activity. It is varied, complex, and requires flexibility. And even if we did not have this symposium, transportation operations are going on now and they will go on tomorrow. The objective then, is how do we incorporate what is currently known about human fatigue and strategies to manage it, into current operations. The second component is that as you learn about how all these approaches are complex and varied, it should be clear that there is no one approach or strategy that will cure all of fatigue in transportation. Part of our agenda today is to help unravel some of the complexity and describe some of the strategies that are available to manage fatigue in transportation operations.

Charles Lindbergh wrote this about his historic first transoceanic flight crossing the Atlantic in 1927. "My mind clicks on and off. I try letting one eyelid close at a time while I prop the other open with my will. But the effort's too much, sleep is winning, my whole body argues dully that nothing, nothing life can attain is quite so desirable as sleep. My mind is losing resolution and control." He wrote this about his experience during his historic 1927 flight, and I am going to use aviation as an example, as it is one of the most "modern" forms of transportation.

In the almost 70 years since Lindbergh's historic transoceanic crossing, technology, automation, and operational demands in all modes of transportation, have evolved significantly. For example, from the five people required to fly a Pan Am clipper ship to the three required to fly a 727, and from three down to two flight crew in today's glass cockpits that are available in the 747-400 and the new 777. In the almost 70 years since Lindbergh's flight, the technology, the automation, and the operational requirements have evolved tremendously. The human operator who is in the middle of all of that has not evolved at all. What we are going to talk about first this morning is what some of the physiological considerations are that underlie fatigue.

What I want to do is start with a model that we have created to understand fatigue in operational settings. There are two major physiologi-

cal factors that I am going to talk about. One is sleep and sleep loss. The other physiological factor is circadian rhythms and their disruption. These are the two main physiological factors that underlie fatigue. When people see this model, they often ask "Well, what about diet, what about stress, what about workload?" Yes, all of those factors could affect fatigue. However, if you look at the scientific literature on what is available to understand how we could quantify those factors and fit them into this model, it is currently very small at this point. When more scientific information becomes available about how stress, diet, workload, etc., fit this model of fatigue, then it will be incorporated.

However, the two physiological factors that we have a tremendous amount of information about are the sleep and the circadian processes. We must also acknowledge that operations affect these physiological factors as well.

What is important is that all of these factors come together in the human operator, in the middle of the operation. We use the word fatigue like the word stress. Everybody can relate to it, everybody understands it. But people use a wide range of descriptors to explain fatigue --sleepiness, tired, I'm out of it, I'm gone, etc. Today we will be focusing on the word fatigue as the summation of all the possible variety of descriptors. And I will be primarily addressing these two physiological processes -- sleep and circadian rhythms.

While the focus of this material today is on its application to transportation operations, as human beings, all of us will find this information relevant as it affects us every single night when we go to bed.

A lot of people think that sleep is like taking your car, putting it in the garage at night and shutting it off. When your head hits the pillow, everything shuts off. If you are lucky, in the morning, you kick start and everything begins again. Sleep is actually a very dynamic and complex physiological state, and it actually has two specific components.

The sleep state most familiar to people is called REM sleep or rapid-eye-movement sleep, when you dream. The other sleep state is non-REM sleep, non rapid-eye-movement sleep. Non-REM sleep is like taking that car into the garage and putting it in neutral for the night. When you go into non-REM sleep everything in your body and your brain slows down; physiologically, mentally, everything slows down for the night. Non-REM is divided into four stages -- one, two three, four.

The deepest stages of sleep, at least in terms of waking someone, are non-REM three and four. This is important because if you are in a laboratory, asleep, all wired up, and I come in to wake you up in non-REM stage three or four, it is a time when your brain and your body are in their deepest sleep. If I come in to wake you up, first of all it could take one, two or three minutes to wake you up. And when you did wake up, I would say, tell me what was going on in your mind? You would probably say very little and not make much sense, this is the deepest sleep. So, if you wake somebody up in deep sleep, the individual can be disoriented, groggy, sleepy, for 10 or 15 minutes after that. This is called sleep inertia. Later when we talk about napping strategies in an operational setting, you would not want somebody waking up and being sleepy, disoriented, groggy. So understanding the basic physiology is very important.

REM sleep is like taking that car into the garage and throwing your foot on the accelerator and the brake at the same time. REM sleep is a time when your brain is extremely active, that is like having your foot on the accelerator. What is it active doing -- it is dreaming. In REM sleep, when your brain is dreaming, it is actually sending signals to your body to do whatever it is that you are dreaming about. But what's that foot doing on the brake? That foot on the brake essentially prevents those signals from getting to your body, so that you do not enact what you are actually dreaming about.

The dreaming brain is sending signals to your body to do whatever is going on in your dream. It is a very dynamic, complex state with a lot of activity going on physiologically. So while non-REM is slow, REM is a time of incredible activity. Every night when you go to sleep you go through what is roughly a 90 minute non-REM/REM cycle. You spend about 60 minutes in non-REM and about 30 minutes in REM sleep. That's a statistical average because no human being actually sleeps on a cycle that exact.

Most of the deep sleep that you get occurs in the first third of the night. So, if you are going to take a nap or a short sleep period and you want to avoid sleep inertia (that is, waking up sleepy, groggy, etc.) then the length of the nap or the sleep period is going to be critical. Again, most of that deep sleep will occur in the first third of the night. Also, REM periods occur on a more regular basis and are longer later in the night. They are also more intense physiologically later in the night.

The most dramatic changes that occur in sleep occur as a normal function of aging. As you get older, your sleep becomes less deep, more fragmented and you do not get the same total number of hours at night. Even the noise level of a 747 at 500 feet over a child's head; the child's brain does not acknowledge that the noise exists. The child would not go from deep sleep to a lighter sleep or wake up. It is as if the noise does not exist. And that blissful childhood sleep goes away with age.

As you get older your sleep gets less deep. There are some people who feel that you actually lose all of your non-REM stage three and four sleep. Sleep becomes more fragmented, and your brain's ability to give you eight consolidated hours a night goes down with age. Does that mean you need less sleep as you get older? No. And how do we know that? Because even though you sleep less at night, people start getting sleepy or napping more during the day. If you did not need the sleep, there would not be the subsequent increase in daytime sleepiness.

Also, the quality of sleep obtained can be as critical as the quantity. You can get eight hours of sleep, but if it is disrupted you can still wake up feeling fatigued and non-restored. For example, there is a sleep disorder where the leg muscles twitch. Your right leg, your left leg, or both legs twitch. Why is that a problem? Because every time they twitch, they wake you up, possibly three to 400 times a night. This sleep disorder is called periodic limb movements. It is literally like somebody coming in to your room and saying "wake up," leaving the room for 30 seconds, comes back, says "wake up" again, and continues that 300 times through the night. So you can sleep for eight hours, but in the morning, you have literally had 300 awakenings during the night. The operational equivalent is trying to sleep during the day in a hotel, or a strange facility, when people are vacuuming or other things are going on that can disrupt sleep quality. So the

quality of the sleep you get can be as critical as the quantity.

Sleep loss is a common experience in many types of operations. How do you recover? When you are recovering from sleep loss, you recover by sleeping deeper, not necessarily a lot longer. For example, there was a high school student in San Diego, named Randy Gardner. In the early 70s, he wanted to break the world's record for staying awake. At that time, the record for continuous wakefulness was 260 hours. Randy stayed awake for 11 days straight, 264 hours of wakefulness. Some people might say that since we are usually awake for 16 hours and sleep for eight hours, that represents a two to one ratio. So, to make up sleep in that ratio, after being awake for 264 hours, Randy should probably sleep 132 hours. After being awake for 11 days, Randy went to sleep and slept for about 14 hours, woke up in the middle of the night, stayed awake for 24 hours, and then slept for about 9. He did sleep slightly longer but did not make up the sleep hour for hour. He made it up by sleeping deeper, not significantly longer.

Studies in the scientific literature suggest that you need about two nights of your normal amount of sleep, at your usual sleep time to recover from sleep loss. Two nights help to restore both the night time sleep architecture and help to return your waking level of performance and alertness to roughly baseline levels.

Today, scientific research has clearly demonstrated that sleep is a vital physical need. It is as critical to human survival as food, water or air. If a human does not eat or drink or have oxygen--the individual would die. Just like these other vital physical needs, you need sleep for human survival.

Another important concept is that as you lose sleep, it builds up into a sleep debt. Currently, estimates suggest that in the United States most people get anywhere from one to one and a half hours less sleep than they actually need. What that means is that during a regular work week you accumulate a sleep debt so you are going into a weekend seven and one half hours in the red. Think about it like a bank account. When you lose sleep it builds up into a sleep debt. This is important because as you lose sleep, you get sleepy. If you do not eat you get hungry. If you do not drink something you get thirsty. Hunger and thirst are powerful and important signals from your brain that indicate your need for food or water. Sleepiness is your brain sending you a very powerful signal saying that you need sleep.

Sleepiness is such a powerful biological signal, that in an uncontrolled, spontaneous way, no matter how motivated, well trained, or professional, your brain can shut you down regardless of your situation. Even in a potentially lethal situation, your brain can shut you down to get the sleep that it needs. However, you do not have to fall asleep to have that sleepiness affect your performance. Every aspect of being a human being, every aspect of performance and capability, can be degraded with sleep loss and sleepiness. The ultimate is nodding off.

Does that mean that in every situation that involves sleep loss and sleepiness there will be an incident or an accident?" No. However, it does mean that with sleep loss and sleepiness a situation exists in which you are vulnerable to a performance problem that could end up in an incident or accident. Dr. John Lauber, a former member of the National Transportation Safety Board, has said that, "Not having an accident does not mean you have a safe operation."

There are two components of sleepiness to describe. One is physiological, reflecting an underlying biological process. You lose sleep you get sleepy. The only way to reverse that physiological need for sleep is to sleep. If you are physiologically sleepy because you have lost sleep, to reverse it, you must sleep. You can not meet this physical need by just "resting" your eyes, or rolling the window down, or cranking the radio up, the only way to reverse that physiological need for sleep is to get sleep.

But let us distinguish physiologically what you need from how you feel. Right now you could rate how sleepy you feel. For example, on a scale from one, wide awake and alert, four you are moderatly sleepy, seven, you are becoming foggy and you know sleep is coming soon. However, rating is affected by the environment you are in. If you are in an interesting, exciting environment, as time goes by you may not feel tired or readily experience fatigue. Put yourself in an environment where external stimulation is stripped away and you could fall asleep. So when someone says that a boring lecture "put them to sleep," it may not be the lecture. For example, if you need eight hours of sleep and get eight hours, before going to a boring lecture, you come to the lecture and what do you do? When it gets boring, you read, you write a letter, you do something else, you are bored. But you do not fall asleep. If you only got six hours of sleep, there will be a pressure for you to fall asleep, especially in the right circumstances. So, you go into a room for the lecture, all the lights are shut off for slides that are hard to read, maybe uninteresting, and a speaker drones on. Everything in the environment that might help you to fight the sleepiness has been stripped away. The underlying tendency to fall asleep, the pressure for sleep will emerge and you could spontaneously, in an uncontrolled way, fall asleep.

There can be a discrepancy between self-report ratings of sleepiness and physiological sleepiness. We commonly think "I know how tired I am, I've done this before, I'm motivated, well trained, I know how sleepy I am." However, human beings can be highly inaccurate, especially if already sleepy, in knowing how alert they are and how their performance is being affected.

This discrepancy can be important operationally. If you have been on a difficult schedule involving sleep loss or circadian disruption, you may believe fatigue is a factor. You look at someone next to you who has been on the same difficult schedule, and you ask them how they are feeling. When the individual says they are doing great, you may not want to fully believe their assessment. You can feel "fine and not tired" and be falling asleep within minutes. There can be a discrepancy between how people think they are doing and how sleepy they are physiologically.

There are many diverse factors that can affect sleepiness at any given moment. The human brain is programmed to make you maximally sleepy two times during the day. One window is from about three to five a.m., when most people are sleep, and the other window, is from about three to five p.m. That afternoon dip, when you start getting sleepy, is not because you just had a big lunch, or because that afternoon business meeting is boring. Your brain is programmed to make you sleepy during those times. Studies have demonstrated that whether you eat or not, you will get sleepy during that afternoon window of sleepiness. If you are at work during those times, it means that you are awake and working at times when your brain is programmed to have you asleep. If you are looking for a time to put a nap, these windows are good places to start, because they

are essentially times when your brain is programmed to have you asleep.

Next we will discuss circadian rhythms, the physiological rhythms that fluctuate on a 24-hour basis. There are many examples -- everything from the physiological to the behavioral (for example, performance) -- that fluctuate on a 24-hour basis.

There is a clock located in the suprachiasmatic nucleus, or SCN, of the hypothalamus that provides the control for these 24-hour physiological rhythms. The SCN operates somewhat like a timer that controls your lights at home or your sprinklers. If you were in a cave and could live on any schedule you want, it ends up that your internal body clock actually runs longer than 24 hours. It runs on about a 25-hour day. There is some new literature that suggests it may be closer to 24 hours.

The important point is that the natural tendency of your internal circadian clock is to run longer than 24 hours. So if you let the clock run on it's own, it actually likes to run a little bit longer.

How does the clock know what time it is? It appears that some of the most powerful cues for the clock come from the environment. One important external cue is sunlight, or bright light. There is a path way from the retina in your eye to the SCN in your brain, so that light can tell the clock the time. There are a variety of other cues from our environment that also help the clock know what time it is. What can create physiological problems is when you take the clock and put it on a new shift schedule, or put in a new time zone, it does not adjust immediately. It can take from a few days to weeks for the internal clock to adjust to a new schedule or new environmental time zone.

Shift work can involve any schedule when you are awake, active, working, at a time when your brain says you should be asleep. That situation requires that you override the biological process which has you programmed to be awake during the day and sleeping at night. One obvious conflict is trying to work during the night when you are biologically programmed to be asleep. Conversely, there is difficulty of trying to sleep during the day when you are biologically programmed to be awake. This creates a conflict between the environmental cues and internal circadian rhythms. One difficulty is that many situations involve continually shifting the clock around. For example, shift workers that go back and forth between schedules, or revert to day time schedules on their days off. Another example is crossing multiple time zones, returning home, readjusting to a home schedule, and then another series of multiple time zone crossings. Some believe that the longer one stays on a night shift that eventually the body will "adapt." The available scientific data indicates that being on an altered shift schedule, like nights, for a prolonged period of time does not lead to an adjusted internal circadian pattern. And why not? When a night shift worker leaves the job, the individual might get in the car to go home and drive in the sunlight. The sunlight tells the internal circadian clock that it is morning time and works to reset it on a day-light schedule. This provides mixed cues to the internal circadian clock and prevents physiological adjustment to the night shift.

Jet lag, of course, is a modern physiological challenge. It involves an abrupt change, taking the clock, putting it in an environment out of step with what is occurring internally. Again, it creates the situation where the environmental cues are out of synch with the internal circadian rhythms. When the internal clock

is shifted to a different schedule or a different time zone, all of the internal physiological patterns do not resynchronize all at once. Different internal circadian rhythms resynchronize at different rates. So it might be a few days for one physiological pattern to get back into synch, while others might take a week.

The different symptoms of shift work and jet lag are similar to those experienced with sleep loss. However, one that is a little different is the occurrence of stomach problems. Why would shift workers have more complaints about things like upset stomach, ulcers, etc.? This would occur when people are eating at times when their stomachs are not ready to digest.

Now, there are some factors we know of that can affect adaptation of the internal circadian clock. While some of these involve aviation examples, the factors affect shift changes, (like crossing hours), whether they be time zones or just going from day to night shift. The more time zones you cross the more difficult it is for the internal clock to adapt. Again, this is the same consideration as going from day to swing to night shift. The more hours you have to cross the harder it is for the body to adjust. There is some flexibility in the circadian clock, that allows about one to three hours of adjustment.

But there is a lot of individual difference in these factors. Such that, for some individuals the one hour time change associated with daylight savings time is sufficient to wreak havoc on their internal circadian clock.

Many people have heard about evening types and morning types, owls and larks. Owls are individuals who go to bed late, like to get up late in the morning. And the morning types, or the larks, are the ones that actually go to bed very early, like at 9:00 p.m. They are awake at 5:00 a.m., ready to face the day.

There is a very small scientific literature that suggests evening types may adapt a little bit faster than morning types to altered schedules. However, most people do not fit into these extreme categories and the distinction has not been demonstrated to be useful for any type of selection.

As a normal part of the aging process, not only does your sleep change, but your internal circadian clock's ability to adjust to schedule and time zone changes also slows down with age.

Many people have had the experience flying that suggests it is easier physiologically to adapt when you are going in a westward direction than when going easterly. Also, in shift work, it seems easier to adapt when going to a day, swing, night shift schedule than when going backwards. Why is that? Well, when living in California and flying here for this conference in Washington, D.C., involves going from a 24 hour California day to a 21 hour day on the east coast. The day is essentially shrinking. This is opposite the way the natural 25 hour rhythm of the internal clock wants to go. When returning home from the clock moves from a 24 hour Washington, D.C. day to a 27 hour day back in California (staying up three hours later). Traveling west involves lengthening the 24 hour day in the direction of the internal clock's natural tendency. This is similar to moving a shift schedule from day, to swing, to night. Therefore, it is a physiological reason that traveling west or moving a shift schedule "forward" involves easier physiological adaptation than traveling east or moving a shift schedule "backwards" across the clock. Both the quantity and quality of sleep can be affected

by the direction in which the internal circadian clock is moved. Understanding the basic circadian physiology can help to quantify, in an operational sense, what might be expected in the quantity and quality of sleep obtained during a particular schedule.

Transportation requirements clearly can affect these physiological factors. One consideration is that most transportation operations do not involve a one time occurrence. Individuals cross time zones and return, move to a different work schedule and then rotate again. There can be a continuous disruption of the circadian clock due to these changing requirements.

Another consideration in transportation is that operators can be on duty for extended periods of time. That translates to prolonged wakefulness. As all modes of transportation become more automated, as the technology evolves further, human operators are increasingly put into a passive monitoring role of these automated systems. This reduced role for the human operator raises questions about the potential for boredom and complacency to affect alertness and performance.

There are a variety of signs and symptoms that you might look for in yourself or others when trying to evaluate fatigue. For example, forgetful. When you've had to read that same passage three times, that is a sign that your memory is starting to be affected. Poor decisions, for example, Jim Danaher mentioned an extremely experienced crew making some poor decisions about a landing. Other signs could be slowed reaction time, reduced vigilance or poor communication. In the Guantanamo Bay aviation accident previously described, there were a lot of words spoken by the flight crew if you look at the transcript from the cockpit voice recorder. However, in spite of all these words, the NTSB pointed out there was poor communication among the crew. Other signs can include fixation, poor mood, and ultimately, actually falling asleep.

These are some of the physiological considerations that underlie fatigue. These basics of sleep and circadian physiology will provide an initial foundation for the information provided in subsequent presentations.

Good Sleep Habits

Dr. Mark R. Rosekind

Fatigue Countermeasures Program
NASA Ames Research Center

November 1, 1995 -- Early Afternoon Session

We have a series of three presentations in this session. I have some introductory comments and then we will talk about good sleep habits; Dr. Dinges will discuss napping strategies; and Dr. Roth will speak about alcohol, sleeping medications, and caffeine.

When I think of the NASA approach to managing fatigue, one component has to do with the 24-hour perspective on operational requirements. The other component is the approach to addressing the issue of fatigue. Once people acknowledge that fatigue is an issue and that it deserves attention, then the next request is usually to fix it. Typically the request is for a quick fix, a magic bullet, and that fix should work for everybody. This suggests that the individual does not matter, or the specific operational requirement, or the schedule--just the quick fix. And again, that quick fix should work for everybody.

There is no magic bullet to cure fatigue in transportation operations. Sleep and circadian physiology are complex, and the operational world is also complex with changing demands. It is extremely difficult to identify a magic cure for all transportation-related fatigue. People are different; their jobs are different; there are varied demands and schedules of operational settings, and a range of other factors that can affect fatigue. Therefore, it is too simplistic to suggest that a magic cure exists or would be effective.

There are a variety of strategies that are offered commercially to cure jet lag. Before using or buying a specific strategy or countermeasure there are several questions that should be considered. First, is there a physiological mechanism that can explain why the countermeasure should work? Are solid scientific data available to demonstrate the countermeasure's effectiveness? Are data available to determine how much to use, when, what should the effect be, and how long it will last? What are the adverse effects? What are the short- and long-term effects? Can the benefits and costs associated with use be determined? These are questions that should be considered before application of any particular strategy in an operational setting.

The complexity of operations and human physiology suggest that at this point in time it would be extremely difficult, if not impossible, to eliminate fatigue in operational settings. Rather than attempt to eliminate fatigue, the challenge is to manage it. Since there is no

magic cure, managing fatigue in transportation will involve examination of each component of the system. Each component should be examined for approaches that maximally incorporate the current scientific knowledge on fatigue. There are at least the following six factors to examine when trying to manage fatigue in operational settings.

The first is education and training. We believe that an educational foundation for anything you want to enact or accomplish in addressing fatigue, whether it be screening or regulations or just a particular personal countermeasure, is critical for people to understand why, and will enhance the effectiveness of any approach.

A second factor is hours of service. These are controlled by everything from Federal regulations, to contracts, to company policies, even industry policies.

A third factor is scheduling practices. You might have the perfect regulations, but scheduling practices could still detrimentally affect sleep and circadian physiology.

A fourth factor is countermeasures. There are a variety of strategies that could be used at the personal or corporate level. Many of the available strategies will be identified in subsequent presentations.

A fifth factor involves design and technology. For example, it was mentioned earlier how a highly automated system can create the potential for boredom and complacency. This raises a question about how to design these automated systems to promote and maintain alertness.

A sixth factor is research. While a large and significant amount of scientific data now exist on fatigue-related issues, there is still much that is not known. There are some specific operational questions that could be addressed by generalizing from other data sources. There are also issues that deserve particular attention and original research to answer.

We have just moved from the "no magic bullet" to a fairly broad approach to addressing fatigue in transportation. When confronted with such a task, some will believe or say that it can not be done. However, this is not just a conceptual approach. Across modes of transportation there are successful activities in each of these areas occurring right now. You will hear later about education and training. One example in the area of hours of service: the FAA has a program of activities looking at hours of service and working on possible new regulatory approaches. Regarding scheduling practice, there are several different companies in air, trucking, etc. that are incorporating some of these principles. You are going to hear about the countermeasures and the technology in subsequent presentations. Clearly, there is a lot of research currently going on, including by many of the people here in the room today.

Now, what can you actually do about this. Many of the approaches discussed will be represented as recommendations. And again, that is to indicate that there is not a magic bullet, there is no one cure all. They are provided here today as a way for you to think about how to apply them in your domain. It is critical to tailor them your specific individual needs and operational requirements.

It is also important to think about how to utilize these strategies in combinations. Not to use one, but many of them. And one of the ways to think about countermeasures, is to think about preventive strategies versus operational ones.

What are preventive strategies? Things that you use before a duty period or on a rest period that help you reduce the effects of fatigue during the subsequent operation. We differentiate those countermeasures from the operational strategies, those that you use when you are on the job, driving a truck, flying a plane, etc. to help you maintain your alertness and performance during that duty period.

The following are examples of these countermeasures. These initial examples are so general, that they apply to almost everyone whether you are on duty, flying, driving, or any other type of operation.

First some preventive strategies. At home, get the best sleep you can before a trip. There was an interesting study that was done trying to see what factors predicted the severity of jet lag. The number one factor that emerged was how much sleep had been lost just prior to the trip. So when you are home preparing to leave, and focused on accomplishing tasks, it is common to lose sleep. So any time you start a trip, again driving, sailing, flying, etc., and you have a sleep debt already in the red, then all you do is increase your chances of going further in the red or having the operational disruption create more problems. So, we recommend at a minimum try to get two nights of good sleep before you begin a duty period. Try to be well rested. If you are well rested, will that make you invulnerable to subsequent sleep loss or circadian disruption? Not at all. But instead of starting in a negative position, with a sleep debt already in the red, you will be physiologically better prepared to manage subsequent sleep and circadian disruption.

The following strategy also generalizes across all modes of transportation. There are some who feel that when they go on a duty period they need eight hours of sleep, but could get away with only seven hours of sleep during a trip. Remember that sleep loss builds up. If you need eight hours of sleep, try and get eight hours. The optimum is eight hours consolidated sleep at one time. But if you can only do it in six hours and a two hour nap, do it. There is sort of a priority system. But the key is just do not go into the operation planning to get along with less sleep than you actually need. If you need eight hours try and find a way, even through napping, etc., to get that total sleep for each 24 hour period.

While there can be a discrepancy between what you feel and what your physiology is doing, there are times you can trust your physiology. What does that mean? When you are feeling sleepy and showing signs of sleepiness (like nodding off, eyes closing, etc.) then pay attention to your brain's signal and get some sleep. Pay attention, trust the physiology.

There are also some important good sleep habits that everyone should follow to promote a good quality and quantity of sleep. First, you can train your body that it is time to go to sleep. One way to do this is to create for yourself a pre-bedtime, pre-sleep routine. Create a routine set of signals that tell your body and mind it is time to unwind and prepare for sleep. These cues might include warm milk, reading a book, whatever the routine is that you want to go through, practice it at home. You can then use the same routine and cues when away on a trip and promote sleep.

Try to use the bedroom for sleep and avoid work, worry, exercise, or other activities not conducive to sleep. Again, the bedroom should be a place where you relax and go to sleep. If you use the bed and the bedroom to have fights, or balance your checkbook if it is not in good

shape, or whatever, then the bed and bedroom become associated with being awake and anxious, and not associated with falling asleep.

Sleep time. This is especially important to people that have daytime sleep periods. Try to minimize other responsibilities; you want to keep that designated sleep time sacred. Sometimes this can be difficult, for example if you have young kids, or other kinds of family commitments.

Eating strange foods prior to bed should not give you nightmares. However, it is important that if you are hungry or thirsty, you eat a light snack or have a small amount to drink before bed.

Dr. Roth will talk about caffeine consumption later this afternoon. Operationally when using caffeine to promote wakefulness, you must also consider your ability to get sleep on your next rest period.

It is important that the environment you sleep in is quiet, dark, a comfortable temperature, and secure.

When you get in bed and watch the news, you may shut the television off, but it can be difficult to just shut your brain off and go right to sleep. Again, do not use the bed and bedroom to engage in activities that make you anxious or worried. Do activities that are conducive to sleep.

There are techniques that have been scientifically demonstrated to help you relax your mind and body. A wide range of them exist and they are skills, which means they can be taught, you can learn them, and the more they are practiced, the more expert you become. They have been demonstrated to help people unwind, relax, and get to sleep. These are skills that would always be available to you and you travel with the necessary equipment -- your body, your mind. They may be one of the most underutilized skills available to promote good sleep. You can practice the relaxation skill, become expert at home, and then use it anytime, in any hotel, in any mode of transportation.

Another recommendation is the 30 minute toss and turn limit. You can force yourself to stay awake, up to a point. You can not force yourself to go to sleep. So, if you get into bed, and you can not get to sleep within 30 minutes, do not toss and turn, get out of bed. When you do get out of bed, do something conducive to falling asleep, like a relaxation skill but do not start a 700 page novel or your favorite 2-hour video. I typically recommend reading some government reports or regulations, that should do it for you. Get out of bed when you get sleepy, get back into bed when you're tired and sleepy enough to actually be able to fall asleep.

Many of the strategies that have just been presented are good basic sleep habits, useful for all of us regardless of your situation. You do not have to be a rocket scientist (a) to understand them or (b) to use them. And yet each of us will violate many of these basic tenants every day. These preventive strategies provide an initial step to obtaining good quality and a sufficient quantity of sleep prior to operations.

The next presentation will be on napping strategies provided by Dr. Dave Dinges from the University of Pennsylvania Medical School.

Education and Training Approaches

Dr. Mark R. Rosekind

Fatigue Countermeasures Program
NASA Ames Research Center

November 2, 1995 -- Late Afternoon Session #1

Next we will be discussing education and training approaches that are available. This symposium is partially a result of a NASA/FAA education module that was created. I will be talking about other examples of educational programs that are available and also describing resources that you can access to apply the information discussed throughout the day.

The first program to be described actually begins with Dr. John Lauber, who was one of the individuals that began the NASA Ames fatigue/jet lag program in 1980. Dr. Lauber continually emphasized the importance of not conducting research in a vacuum and that worthwhile and useful results should be returned to the operational community.

To meet this challenge, about a year and half ago, the NASA Ames Fatigue Countermeasures Program, in collaboration with the FAA, created an education and training module. The Module is entitled, "Alertness Management in Flight Operations." The Module is a package of information about what has been learned from the general scientific literature, from NASA research, and other resources. The Module is focused on use and distribution within the aviation industry. The objectives of the Module are: 1) to explain the current state of knowledge about the physiological mechanisms that underlie fatigue, 2) misconceptions, and 3) fatigue countermeasure recommendations. Many of the specific strategy recommendations contained in the Module have been discussed throughout the day.

The Module presentation is divided into three major parts. The first part examines fatigue factors in flight operations, including the physiological considerations described earlier and how operations affect those factors.

The next section is on common misconceptions. Essentially, this is myth busting. There is a lot of information available from a variety of sources, a lot of personal experience, and many anecdotes. In this section, some common misconceptions are addressed using the scientific information provided in the first part of the Module.

The last section presents information on a range of preventive and operational fatigue countermeasures. What are the strategies that people can actually use to try and deal with performance and alertness in real world settings.

A final, important piece of the Module is discussion. We believe that it is important to not only cover the didactic information, but to spend time on concrete examples of how the information is applied. The discussion involves application to the specific requirements of that particular operational environment.

The Module was developed as a one-hour live presentation. This provides an opportunity for interaction, and the discussion focused on application. The live presentation is complemented by a NASA/FAA Technical Memorandum. The publication provides all of the slides from the presentation and supporting text. The intent was that during the presentation, instead of having to write all of the notes down, a participant has a publication with all of the slides. If you are a trainer, then the supporting text provides additional information about the content on each slide.

Dr. John Lauber wrote the preface for the publication and there are appendices on sleep disorders, NASA studies, and other general references, both specific to aviation and also general ones.

The Module was field tested extensively prior to implementation. It was presented about 30 times for several thousand people in a range of different settings so we could incorporate their comments into the final version. The NASA Ames Fatigue Countermeasures Program is a relatively small program, and it was not our intent to go out and be the primary source presenting the Module throughout the aviation industry. Instead, we developed a two-day train-the-trainer workshop. Our hope is to transfer the information in the Module throughout the entire industry. The information in the Module is relevant to anyone in a 24-hour operational settings such as flight crews in aviation, truck drivers, shift workers, flight attendants, medical personnel, regulatory agencies, accident investigators, everyone who confronts the physiological challenges. This information is relevant to schedulers and dispatchers, maintenance personnel, and across the broad spectrum of individuals involved in the transportation industry and other 24-hour settings.

The two-day train-the-trainer workshop is held at NASA Ames Research Center in the San Francisco Bay Area in California. On the first day of the workshop we provide participants with in-depth information about sleep and sleep disorders, circadian rhythms, and performance. On the second day, we provide information obtained from NASA studies, fatigue countermeasures, and provide a presentation of the Module. The intent was for workshop participants to take all of the information and the Module and transfer the information to the aviation industry. This is a NASA/FAA product and there is no cost to attend the workshop except your own travel expenses.

To date, we have held 14 workshops, for 276 participants, from 144 different organizations, from 14 countries. While it seems a daunting task to provide information to an entire transportation industry, this provides a successful model of where to start. This model is not a concept; it is currently in practice. Workshop participants thus far have represented almost every aspect of aviation. They have come from commercial, corporate, regional, general aviation, regulatory people, NTSB people, everyone you could imagine. In fact, one reason we are having this symposium is that Chairman Hall attended one of our education and training workshops in December 1994. Literally by lunch time, he was asking how to transfer the information to other modes of transportation. I would like to personally acknowledge

and thank Chairman Hall for not just asking the question, but acting on it as well. Besides aviation environments, we have also had marine operators, physicians, and law enforcement personnel attending the workshops.

Of course, the bottom line is actually getting the information to the operational community. In a survey of our workshop participants that is almost a year old, we found the NASA/FAA module is in place, functioning, and being presented at 33 organizations. Estimates, provided by the individuals presenting the module at these organizations, suggests that it will reach about 38,000 flight crew and others this year.

One of the first groups that attended our workshop was from American Airlines, and Linda Campbell who is a nurse there, has given the Module 603 times for 6,500 flight crew. There are 10,000 pilots at American Airlines. She has now covered 6,500 of them, and is in the process of extending the Module to the 20,000 flight attendants at American as well. This is just one example of the Module in use now and expanding.

The 33 organizations currently using the Module include many of the major airlines in the United States and it has been transferred internationally to many other organizations. This transfer includes not just air carriers, but also regulatory bodies and accident investigation authorities as well. There are 12 other programs that are currently in development, and these will reach at least another 10,000 individuals. Again, this is not just a concept, these are people using the information internationally throughout the aviation industry.

Participants in our workshop receive in-depth information, the NASA/FAA education and training module, a set of slides, and other resource materials that they can take back to their organizations to support implementation of the Module. One of our goals is provide enough information and resources so that participants are comfortable enough to take the Module and determine the format and forum for its use at their organization. We do not tell participants how it has to be used but instead try to support them in their implementation.

There is an important example to highlight how education lays the foundation for a tremendous amount of other activity addressing fatigue. The FAA recently has initiated a working group to develop an advisory circular on fatigue countermeasures that is essentially based on the Module. The intent is to take the information in the Module and make it even more available to flight crews across the country.

There are also other examples of educational activities currently underway within transportation. The following are some examples of these activities and is not intended to be a comprehensive listing. Other resources that are available will be described soon. So, here are a few representative, non-aviation examples of educational efforts focused on managing fatigue in different modes of transportation.

First, the AAA Foundation for Traffic Safety has a large program focused on driver fatigue. They have a great brochure called "Wake Up," and Dave Willis and Stephanie Fall provided some numbers about the distribution of this brochure. They have 1,000,000 brochures that have been printed, 800,000 that have already been sent out to the industry. They have public service announcements that are available. They are talking about an audio tape so you can listen to the information in your car, without falling asleep. One important approach they are using is to package the information

into different formats, from printed material to radio spots to audio tapes.

The National Sleep Foundation, which is now based here in Washington, D.C., has also developed an aggressive program to educate the public and professionals in different modes of transportation and in all areas of our society. They have a program called "Drive Alert, Arrive Alive" and they have now put on this program in five states with four others planned. Their model program is one initiated in New York where they had extensive participation from the Governor's office, different regulatory agencies, educational programs, all wrapped up into an implementation within New York state. These are resources available to anyone interested in obtaining this information.

We had an individual, Mr. Vincent Cantwell, from American Heavy Lift, a marine operator, who attended the NASA education workshop and has now taken the NASA module information and developed it for use in marine transportation environments. Most content in the NASA/FAA Module is generic information but it should be focused on the specifics of your training environment and operational requirements. Vincent incorporated appropriate examples to fit marine operations, translated words and content to fit shipping activities, and added new content that was appropriate to the specific operational requirements of the marine environment. The marine educational module is being field tested at several sites.

Bill Rogers from the American Trucking Association has created a parallel educational module for trucking that is in final stages of development. Again, making changes appropriate to the trucking environment, their operators and other personnel, and the diverse range of operational requirements in trucking.

Another example of transfer is Dr. Melchor Antuñano, director of medical education at the FAA Civil Aeromedical Institute, who has created a Spanish version of the NASA/FAA module, and made it available for use in South America and other places.

Another example is Lt. Colonel Sam Holoviak, Deputy Chairman of the Division of Aerospace Physiology at the School of Aerospace Medicine at Brooks Air Force Base in Texas. They have taken the NASA/FAA module and other Air Force relevant information from their own personnel, like Dr. John French and others, and created a package for aerospace physiology training. The information is in the process of implementation at 21 units and provided to about 13,000 Air Force personnel.

These are representative examples of activities currently underway in different transportation modes to provide educational materials about fatigue and countermeasures. Resources are available to transfer this information to any operational setting. One caveat that I would like to emphasize is that there are efforts to make this information readily available to any interested party, at least at NASA with the NASA/FAA module, we have tried to exert some quality control. That was part of our rationale in developing the training workshop. We bring people in, and if you are interested and motivated enough to participate through the two days of training, all the information is made available to you, and we try to support participants in their subsequent implementation.

There are some general considerations when you consider any kind of educational approach. Again, an educational program can become the knowledge base for a range of other fatigue-related activities. Often it only takes one good

idea and some effort to move an important activity forward. An example is the current FAA activity to develop advisory circular material based on the NASA/FAA education module. This activity was initiated when Al Prest, Vice President of Operations at the Air Transport Association, wrote the FAA and highlighted that the Module was already in existence and suggested creating advisory material that could be distributed by the FAA throughout the entire industry. That is an example of how straight forward it can be to initiate an activity that has potential to educate large segments of an entire mode of transportation. I acknowledge and credit Al Prest for making the suggestion and Anthony Broderick, an Associate Administrator at the FAA, for acting on it.

American Airlines was the first organization to implement the NASA/FAA education module. Eventually, it became a part of required training curriculum. In their classes, many questions were raised about scheduling. In response to those questions, American Airlines created an internal, scheduling working group to determine how to incorporate the physiological information from the Module into their regular scheduling practices. And what they have done, to their credit, is not end up in a contract negotiation, but rather in a working group that addresses these issues very effectively. These are examples of how the information can lead to further activities.

It is important that industry-specific materials be developed. Utilize whatever generic information and materials are available but you must focus educational materials for your particular audience. This is critical if the information is to be accepted and used by the operational community. There are also a diverse range of forums and formats in which to distribute educational materials. For example, while our education module was developed to be presented in a live format, we are in the process of creating some videos. These videos are intended to focus on particular environments, like short-haul, long-haul, regional flying, overnight cargo, and other specific flight environments. We also intend to create a video of the full Module for environments where the live presentation would be impractical or not available. The AAA Foundation also exemplifies this approach of multiple formats through different mediums. While a one-time educational exposure is a critical first step, you must also find ways to saturate the operating environment to get the information out. Follow-up is important to help support implementation.

And while there is a tremendous amount of information already available and useful to the operational community, it is also clear that there is much more to learn. Once new information becomes available there should be a mechanism to provide updates. This helps to keep the issue visible and highlights new information or countermeasures.

Fatigue Resources Directory

Dr. Mark R. Rosekind

Fatigue Countermeasures Program
NASA Ames Research Center

November 1, 1995 -- Late Afternoon Session #2

The last item of the day is to move from educational approaches to a product created specifically for this symposium. You will find it in Appendix H of your binder. The Fatigue Resource Directory was created by the NASA Ames Fatigue Countermeasures Program and the NTSB with support from all of you that provided inputs to the Directory. When discussing the format of this symposium, NTSB/NASA organizers believed the presentations to be the critical educational foundation of today's activities. We also believed that it would be important to provide something concrete, a product that would be available to participants to support the efforts in this area after the symposium. The objective was to provide information and access to fatigue-related resources so that you could take what you had learned today and go home and either as an individual or as an organization, apply it. So NASA and the NTSB created the Fatigue Resource Directory to meet that objective.

First, I would like to thank all of those individuals who submitted entries for this document. Second, I want to also apologize to anyone who is not included but would be interested in having an entry in the Directory. There was no intent to leave anybody out but this was our first effort to produce such a Directory and have it available at this meeting for you to take home. The Directory is separated into several categories. There are some initial introductory materials, and then sections on countermeasures, government activities, industry activities, and public interest groups. The specific entries provide information on a point of contact, activity sponsors, specifics of the actual activity, and what resources are available. You can scan the Directory and find resources on educational activities. Look in that section, you will find the AAA Foundation, the National Sleep Foundation, and many of the other examples that have been highlighted today. Throughout the day, as you have questioned how to access the individuals, organizations, or information presented, the Fatigue Resource Directory should provide a starting point.

In the section on scientific information, we tried to provide a range of resources. That section includes more details about our distinguished speakers today. My introductory remarks about these individuals were minimal because these more extensive materials about them are available in the Directory. It also provides other resources regarding scientific studies. The scientific resources are available through university libraries and there are other mechanisms for you to be able to access information that is

available. Included in that section is a listing of all the American Sleep Disorders Association (ASDA) accredited sleep disorders clinics in the United States. So when you have questions about sleep apnea and wonder who to call in your local area, the directory is in there. There is also information on how to reach the ASDA for further information about sleep disorder clinics or specialists.

We hope this will not be a static document but rather a dynamic one. Included at the end is a form to provide input to the next iteration or update of the Fatigue Resource Directory. The form requests the same content as is currently in the Directory and is an opportunity to provide new or updated entries. So if you would like to be included in the future, or you have new information to update, please fill in the form and the instructions are on the form about where to send it. At this point, the NASA Ames Fatigue Countermeasures Program is coordinating the Directory, though other Federal agencies have indicated their interest about providing the next update and maintaining it into the future.

The following caveat must be absolutely clear about the contents of the Fatigue Resource Directory -- "This document is intended as a resource directory and was compiled from input from a wide range of sources. The information provided in this Directory has not been evaluated for its accuracy or effectiveness. Therefore, inclusion in this Directory does not imply endorsement by the NTSB or NASA." That is an important caveat, so you know that just because an entry is in the Directory does not mean it has a seal of approval from the NTSB or NASA. It means that information was requested from a wide range of sources, input was provided, we performed a spell check, and standardized the format. However, that is the extent of oversight and the process did not involve scientific or other reviews of the inputs. There is a wide range of information in the Directory, and it is important for you as a consumer, to be knowledgeable about the many considerations discussed today when using this document.

Another point, which the Fatigue Countermeasures Program is quite proud of is that the Fatigue Resource Directory is available on-line. The NASA Ames Research Center has been identified as the Center of Excellence in Information Systems for NASA. So, we are pleased to provide the address to our home page where you will find the Fatigue Resource Directory on the World Wide Web. The internet address to the NASA Ames Fatigue Countermeasures Program home page is: http://www-afo.arc.nasa.gov/zteam/. All of the information in this hard copy edition of the Fatigue Resource Directory is also available on-line. I would like to acknowledge and thank Kevin Gregory, from our NASA group, who worked extremely hard right up through Friday evening before coming to Washington, D.C., to make sure that the Directory would be available and on-line at the time of this symposium. So let us know how it looks when you explore the site. The internet address is also listed in the introductory pages of the hard copy version of the Directory.

There are two other points about materials that will be available to you after the symposium. First, everyone who has attended the symposium will be receiving the proceedings. The proceedings will include the basics of the presentations provided throughout the day, and what we hope will be the concrete products from the working group activities tomorrow. Second, a video tape has been made and when you get your proceedings in the mail, it will

include information on how to obtain this video tape. The video will be made available at cost to people interested.

In the front of your binder there is a listing of all the speakers today, that includes everyone from the NTSB, the speakers during the day, and also the Secretary of Transportation who will be addressing the symposium tomorrow morning. The list provides information on how to reach these individuals.

I have some last comments before beginning the question and answer period. I would like us to acknowledge and thank a variety of people who have worked very hard to make this symposium a reality. First, my thanks to Dr. Pack, Dr. Roth, Dr. Czeisler, and Dr. Dinges. They have been most understanding of my persistence to make their presentations operationally focused and relevant, so if you will join me in acknowledging what a superb job they did throughout the day. Thank you for the excellent presentations.

I also want to acknowledge the NTSB. Chairman Hall truly was the driving force to initiate and make this event happen. Julie Beal, Director of Public Affairs at NTSB, and chair of the symposium steering committee at the NTSB, has been tremendous in her tireless efforts dealing with all aspects of this entire event. Charlotte Casey and Nancy Hill have interacted extensively with our NASA program and they have been just superb in their efforts prior to the symposium and onsite. I want to acknowledge that the NTSB had a steering committee, many of the people you will be meeting tomorrow in the working groups, but I would like to acknowledge them, as well as the many other NTSB individuals who made significant contributions to the symposium.

Finally, I would like to acknowledge and thank the NASA Ames Fatigue Countermeasures Program, also known as the Z Team. A sticker with our Z Team logo is provided in your binder. Three Z Team members are here: Donna Miller, Kevin Gregory, and Lissa Webbon. Lissa has sore fingers because she was the one responsible for helping create the Fatigue Resource Directory in a relatively short time. Kevin got everything on-line. Donna does everything else. All three of these people made important contributions to this symposium as part of the NASA team. Roy Smith, Liz Co, Julie Johnson, Ray Oyung, and Dr. Philippa Gander are not here but are literally holding down the fort and continue to build those scientific rockets at NASA Ames. Finally, I would like to acknowledge all the individuals who behind the scenes have been critical to creating this symposium.

Performance Effects of Fatigue*

David F. Dinges, Ph.D.

Director, Unit for Experimental Psychiatry
University of Pennsylvania School of Medicine
Philadelphia, Pennsylvania 19104

November 1, 1995 -- Morning Session

Across many industries, unintentional human performance errors, especially errors of inattention, are the most frequently identified root causes of accidents. This applies to all modes of transportation, where the vulnerability to human error poses special challenges due to both the escalating number of transport operations--many of which involve 24-hour operations)--and the growing potential for catastrophe following a human error (e.g., hazmat accidents). This paper provides an overview of the effects of fatigue/sleepiness on performance in persons who are healthy, with special relevance to transportation. More extensive discussions of these issues can be found in other recent articles (Dinges & Kribbs, 1991; Dinges, 1992; Dinges, 1995).

1. Fatigue originates in biology and erodes performance.

Fatigue-related performance impairment should be a concern in all modes of transportation, because the factors that produce fatigue, and the factors that potentiate or unmask it, are present throughout many transportation operations. Extensive scientific research in the past 40 years has firmly established that fatigue has its basis in the combined interaction of the circadian rhythm in alertness/sleepiness and the effects of inadequate sleep. Once the biological pressure for sleepiness is present in a person, it can be potentiated or unmasked by tasks that require relatively passive vigilance. Sustained attention is a key performance demand in virtually all modes of modern transportation, and it has increased in direct proportion to the use of automation in transportation systems. This phenomenon is amply illustrated in the modern automobile in which cruise control, eight-way adjustable seats, stereo sound, and climate controls create an environment that requires little more than a finger on the wheel and sustained attention.

Toss of alertness from fatigue has specific, identifiable determinants, and specific, deleterious effects on performance. Changes in brain function--often brief and uncontrollable--form the basis for the performance deficits resulting

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from fatigue/sleepiness. Early in the history of research in sleep deprivation it was discovered that changes in brain waves (EEG) were associated with the more serious failures of performance. In other words, the brain appears to be "microsleeping" during performance lapses ("lapses" refer to periods of performance in which a response is not given when it should have been, or it is given quite late relative to the stimulus). As sleepiness increases, so also do microsleeps and performance lapses. In other words, as fatigue increases, the brain appears to fall asleep involuntarily, against the will of the operator, especially (but not exclusively) when the performance demands involve sustained attention and monotony. As important as it is to recognize that the effects of fatigue on performance are based in changes in brain function, it is equally important to note that fatigue is not caused by or prevented by any known characteristics of personality, intelligence, education, training, skill, compensation, motivation, physical size, strength, attractiveness or professionalism. A common myth is that some or all of the latter factors will prevent fatigue-related performance failures. Certainly being educated about fatigue and how it expresses in performance may help you guard against it or recognize it when it occurs. But the fundamental problem of what causes the brain to fatigue and performance to fail is not lack of physical strength, or lack of intelligence, or lack of professionalism. Rather, it is a neurobiological process directly related to the circadian pacemaker in the brain and to the biological sleep need of the individual.

Four processes are considered relevant to fatigue-related changes in alertness and performance. The first is the circadian phase of the biological clock in the brain; the second and third have to do with acute and cumulative sleep loss, respectively; and the fourth involves the awakening process (sleep inertia). Each of these factors can produce performance failures, especially lapses (also referred to as gaps, pauses, or blocks), which as noted above, involve a failure to respond, or a failure to respond in a timely manner. Lapses are typically a half second to 10 seconds in duration, but this brevity hides the fundamental risk they pose to safety in transportation operations. For example, during a one-second lapse caused by the brain is microsleeping, a motor vehicle traveling at 60 m.p.h. covers 88 feet (or 5 car lengths); a train travelling at 120 m.p.h. moves 176 feet; a plan flying at 250 knots travels more than 370 feet. Thus, the distance covered during even a brief lapse is easily enough to make it impossible to avoid a collision if a sudden action is required.

Biological time of day and lapses. Controlled laboratory studies have demonstrated that each of the determinants of fatigue will increase the tendecy of an operator to experience involuntary lapses. Tn general an indevedual's circadian pacemaker (or biological time of day) opposes sleepiness during the day, but not at night (especially not between the hours of midnight and eight a.m.). Consequently, when an attempt is made to reverse this circadian rhythm in alertness, by working at night, lapses increase two- to ten-fold (during performance on a 10-minute vigilance task) across the period of night work during which sleep normally occurs, and they follow a profile similar to the major physiological marker of circadian phase (core body temperature).

Acute wake duration and lapses. The longer one is awake without any sleep beyond the normal waking day of 14-16 hours, the greater the occurrence of lapses, and the longer they become in duration. For example, there is a four- to ten-fold increase in lapsing on a brief vigi-

lance task between the hours of 10 a.m. and 10 p.m. after a night without sleep.

Chronic undersleeping and lapses. Fatigue can also affect performance through chronic undersleeping. This refers to sleeping less each day than one's biological need for sleep. It can lead to *cumulative sleep debt*, which can produce a cumulative increase in lapses, even during the daytime. Recent evidence from a study we performed on the effects of four to five hours of sleep each night for seven consecutive nights revealed that lapses on a brief vigilance task performed between 10 a.m. and 10 p.m. increased three- to five-fold, and were still increasing when the sleep restriction phase ended. Such data suggest that chronic undersleeping results in a performance deficit separate from that associated with the circadian pacemaker and with acute wakefulness.

Sleep inertia and lapses. The fourth category of fatigue-related performance impairment results from something called "sleep inertia," which refers to a difficulty achieving full, waking alertness after sleep. Alertness and performance are usually reduced upon awakening from sleep. Lapses increase during sleep inertia, especially if the sleep is very deep (as measured by intense slow wave sleep), and the awakening from sleep is abrupt. Unlike diminished performance capacity due to circadian rhythms, acute wakefulness, and chronic undersleeping, sleep inertia often can be reversed within 10-20 minutes, by activity and noise.

2. Fatigue results in a range of performance deficits.

Although lapses are a hallmark of fatigued performance and they increase in frequency and duration with each of the major determinants of fatigue described above, sleep loss and circadian rhythms also lead to negative effects in other areas of performance. There a number of basic categories of performance output that are affected by fatigue, regardless of the biological factors that produced the fatigue/sleepiness.

Fatigue increases performance variability. As sleepiness develops, performance becomes more variable. This variability is in part due to an increase in lapses (errors of omission), as described above. When not fatigued the performer is usually correct and timely in responding. As fatigue develops and worsens, performance begins to be intermittently incorrect and often untimely. This increased variability due to lapsing, especially in tasks that require sustained attention, makes performance unreliable in a fatigued person through promotion of unpredictable performance failures (e.g., missed signals). Often, a fatigued operator's reaction to lapsing and performance variability is to increase motivation and compensatory effort--it is this increasing effort needed when fatigued that prompts some persons to report that their work is both tiring and stressful. Increased motivation and compensatory effort can constraint fatigue-related performance failures, but the effect is usually short-lived and ultimately fails to prevent either lapses or highly variable performance in sleep-deprived subjects. Work contexts that involve physical passivity and sustained monitoring are especially likely to permit lapses to occur if biological pressure for sleep is present. The more automated the transportation system and the more a fatigued individual is left alone in such a system, the more

variability, lapsing, and unpredictability will characterize performance.

Fatigue slows reactions. Both the speed of physical reaction times and the speed of thought processes are slowed as fatigue increases during biological night and/or after sleep loss. Such slowing can happen even when lapsing is not occurring. The very fastest physical reaction times of a fatigued operator can slow by 5-25%. The slowing of cognitive reactions (i.e., thought processes) is generally associated with a compensatory effort on the part of the fatigued operator to remain accurate (i.e., the speed-accuracy tradeoff). Slowed reactions clearly have practical implications. They can be costly if responses are supposed to be fast in an effort to avoid a collision or to monitor a critical piece of information (e.g., signal) in order to know when to make a turn or stop.

Fatigue increases errors. Performance is generally characterized by few errors and sustained motivation to avoid errors when an operator is not fatigued. As fatigue increases, however, there is a tendency to make mental mistakes and to perseverate on ineffective solutions. The latter refers to a tired operator attempting to solve a novel problem with the same old solution used in the past. Certainly this can occur for other reasons as well, but when fatigued, people seem to fail to appreciate that their logic and judgment may be flawed, and they will waste potentially critical time and resources persuing an ineffective strategy. In this sense, fatigue appears to limit an operator's range of options. It also explicity increases errors (of omission and comission) and the compensatory effort needed to avoid them, while at the same time it can lead to a decrease in concern about making errors. This latter effect is very serious in many modern transportation systems, which are quite forgiving of certain kinds of errors at certain times (e.g., during the cruise portion of a flight), but not at other times (e.g., on approach to landing or during takeoff). Consequently, in many technology-rich transportation environments, there are periods when performance errors due to fatigue can occur with few serious consequences, leaving the false impression that there is no real cost to operating when fatigued. This is clearly an inflated sense of security.

Fatigue increases false responding. False responses (i.e., resonding when no stimulus is present) are relatively rare when a person is not fatigued, but they can increase as an operator attempts to maintain performance in the face of increased lapsing from fatigue. They are most likely to occur in situations involving a tired operator who becomes aware that he/she is missing key signals. After a lapse, an operator will begin to anticipate the signal's presence, and this can lead to increased false responses. In this sense, false responses reflect a compensatory effort to improve performance. This overemphasis that the fatigued operator places on one type of signal or piece of information can limit the operator's appreciation of other task-relevant information, which in turn can limit situational awareness.

Fatigue increases memory errors. Sleep loss also results in increased errors of short-term memory. Depending on the fatigue level, a tired operator can have difficulty recalling what was seen, read, or heard. This can result in failure to recall critical information, and uncertainty about the status of the operational situation.

Fatigue leads to viglance decrement. When an operator is not fatigued from night work and sleep loss, within a reasonable work period duration, there is little deterioration in performance as a function of time-on-task. When fa-

tigued, however, an operator may begin a monitoring task with good performance, but even relatively short work periods can be associated with a marked decrement of performance as a function of time-on-task. In other words, while both fatigued and non-fatigued operators may begin a task at the same excellent level of performance, the vigilance of the fatigued operator will deteriorate as time passes relative to the non-fatigued operator. Consequently, beginning a task proficiently, especially an attention-rich monitoring task, can give the false impression that a fatigued operator will be safe later on. Therefore, when judging the performance capability of the fatigued operator, it is unwise to rely on initially good performance as evidence that the operator will be safe 30 minutes to 8 hours later. The question is not how well is the operator performing in terms of sustained attention and ability to process information early in the work period, but rather, how safe is performance likely to be later in the work period? During biological night and after sleep loss, fatigue will make it exceedingly difficult to sustain performance. The practical implication of this inability to sustain performance with time-on-task is that performance capability can be overestimated.

This overestimation is especially likely to occur when the fatigued operator is asked about his/her level of fatigue and ability to perform prior to beginning work. The mere act of asking for this assessment can promote transient alertness (from the social interaction and significance of the question) and this brief arousal can make the fatigued operator decide he/she is fit and without performance decrement. However, depending on the magnitude of the underlying pressure for sleep, the operator can begin to experience lapses, microsleeps, slowed reactions, forgetfulness, and a marked vigilance decrement soon after beginning the task. This is one reason why people can be inaccurate judges of their biological pressure for fatigue and their vulnerability to fatigue-related performance decrements.

Fatigue leads to reduced motivation and laxity. In addition to performance deficits fatigue can result in lowered motivation to perform well. This can translate into a willingness to take risks and a laxity in safety (e.g., fatigued operator who speeds to end the trip sooner because he/she is tired).

In summary, performance of an individual fatigued by circadian and/or sleep loss factors is characterized by increased variability, lapsing, slowed reactions, errors, false responses, forgetfulness, vigilance decrements, and at times, reduced motivation and laxity in safety. From an operational perspective, deterioration in these basic parameters leads to compromised attention and vigilance, limited situational awareness, and judgement processes clouded by a failure to be able to reliably detect, appreciate, and respond to events in a timely manner.

3. Fatigue affects everyone, but the magnitude of the effect can vary.

The effects of fatigue/sleepiness on performance are the same in all operators, but the magnitude of the effects can vary as a function of a number of factors. In general, persons with sleep disorders, especially disorders that produce excessive sleepiness (e.g., sleep apnea) will experience performance deficits. Among healthy persons, everyone will eventually suffer marked performance deficits (1) when acute sleep loss is sustained (especially beyond 36 hours); (2) when sleep is chronically too short (especially less than four hours per day for mul-

tiple days); and (3) when work is performed at a time of coincidence between sleep deprivation and an individual's biological night. However, when the determinants of fatigue are less severe (e.g., during night shift work or sleep restriction for a day), individual reactions can vary markedly. It appears that in reaction to a single night of night work, perhaps half of all healthy adults who remain motivated can continue to perform reasonably well, assuming only an acute exposure and mild sleep loss. Another third of the population has a moderate level of performance deficit from this kind of exposure. The remaining 10-15%, however, have a severe performance deficit. The reasons for this latter group showing vulnerability to even mild acute fatigue are not yet known. Finally, even among those who experience mild performance deficits, sleepiness can wax and wane, and there can be periods of time in which they experience greater diffculty sustaining attention.

In summary, performance effects of fatigue have their bases in changes in brain function. This basic biological vulnerability to error is not overcome in any permanent way by personality, intelligence, education, training, skill, money, motivation, physical strength, attractiveness, or professionalism. There is no substitute for sleep. Transportation industries that increasingly rely on operators performing tasks 24 hours a day (especially vigilance-based tasks with high-consequence outcomes), should confront the challenges that biological limits placed on operators by the sleep and circadian systems. Research is ongoing to find ways to prevent the performance impairments from fatigue. Given the extensive scientific database on sleep and circadian factors that produce performance changes, and the nature of these changes, it is time to address the potential role of fatigue in transportation catastrophes involving human error, and to begin work on prevention of such catastrophes in the 24-hour operations of transportaton industries.

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Napping Strategies*

David F. Dinges, Ph.D.
Director, Unit for Experimental Psychiatry, Department of Psychiatry
University of Pennsylvania School of Medicine
Philadelphia, Pennsylvania 19104

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Napping to cope with fatigue has a very special place in the countermeasure arena, because napping has been one of the most carefully studied behavioral strategies for preventing the effects of fatigue on alertness and performance. During the past 15 years, there has been extensive scientific documentation in both academic and field settings of the benefits of naps in persons undergoing prolonged, irregular, and/or sustained work schedules. More extensive discussions of these issues can be found in other recent publications (Dinges & Broughton, 1989; Dinges, 1992; Rosekind et al., 1994; Rosekind et al., 1995).

1. Operational definition of a nap: What napping is and what it is not.

Napping can mean different things, but the definition that best captures the type of "nap" that has been scientifically demonstrated to promote alertness is the following: A nap is physiological sleep of a duration less than or equal to half that of the typical major daily sleep episode of a person. In other words, by this definition, a person who sleeps eight hours a night, is napping whenever the sleep duration is four or fewer hours, regardless of the time of day the sleep is obtained. This definition also comes close to the colloquial meaning of a nap as a short period of sleep. It is important to appreciate, however, that the definition explicitly also requires that the nap involve "physiological sleep" of the same kind that defines the primary sleep period, including the standardized stages of sleep as reflected in brain activity (EEG) and behavior. In other words, there is no evidence that resting without sleep for the same period of time as a nap will reverse sleepiness and promote alertness in an operator fatigued from sleep deprivation, no matter how physically restful the rest period may be. Consequently, there is no scientific evidence for promotional claims that certain types of napping ("power" napping?) afford extraordinary recuperation because they involve special brain waves without physiological sleep. There is no substitute for sleep, and napping simply involves shorter periods of sleep. Nap sleep is regulated by the same circadian and sleep biological processes that regulate longer sleep

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periods. In summary, napping is not resting without sleep; napping is not physiologically different from sleep; napping is not a substitute for fulfilling the major need for sleep; and napping is not, therefore, a panacea for fatigue, which means it is not the only countermeasure and should not be employed as the only countermeasure in a comprehensive fatigue management strategy.

2. Napping as a voluntary countermeasure strategy.

Napping can be either *voluntary* or *involuntary* (e.g., falling asleep when the intention was to remain awake). Involuntary naps often reflect fatigue and uncontrollable sleepiness, and usually they are considered at best to be inappropriate, and at worst to be dangerous, when they occur in the work place. Voluntary naps, on the other hand, are deliberately taken to discharge fatigue/sleepiness, and these have been the focus of napping as a strategic countermeasure. It is sometimes difficult to get people to take seriously the idea that voluntary planned napping during a work cycle can be beneficial. This is primarily because many people in industrialized societies identify sleeping on the job as reflecting a lack of responsibility. This attitude is captured in phrases like "caught napping," which refers to an individual's negligence regarding what they should have been attending to. While involuntary naps may fit this negative image (despite being caused by legitimate biological forces), voluntary naps do not deserve this negative image or bias.

The major point to keep in mind is that in work systems in which people are expected to be awake when their biological clock is promoting sleep/sleepiness, and/or when they are sleep deprived, planned napping as a fatigue countermeasure may be one way in which fatigue-related performance deficits can be reduced. For this technique to be effective, however, napping strategies have to become part of the proactive planning of work activity.

Just like the tendency to feel fatigued/sleepy, the tendency to nap is regulated by two basic neurobiological processes: (1) the internal circadian pacemaker (biological clock), and (2) the homeostatic need for sleep. Evidence for the first regulatory influence comes from the fact that napping is more likely to occur at certain times of the 24-hour day, especially during the usual nocturnal sleep period (e.g., 12 a.m. to 8 a.m.) and during the midday siesta time (e.g., 1 p.m. to 4 p.m.). There is solid evidence from laboratory studies using the multiple sleep latency test and field studies of performance and fatigue-related errors, that the midday peak in sleepiness/napping tendency is reliable, especially if nocturnal sleep is shortened.

Evidence for the second regulatory influence on napping (sleep need) comes from the fact that sleep loss (whether acute or chronic) increases the likelihood for napping at all circadian times, if the sleep need is great enough. This is the case for virtually all healthy adults, even those who predict that they will not be able to nap. If the pressure for sleep is high enough, virtually anyone can take a nap. This fact makes it possible to plan napping as part of a more comprehensive fatigue-countermeasure program in persons who will exposed to night work and sleep loss.

3. Napping environment.

In order to make napping a practical fatigue countermeasure, it is necessary to know in what

kind of environment the operator will be asked to nap, and what the effects are of certain environmental factors on napping ability. Although there has not been extensive research on all the environmental factors that can influence napping, there are data on the environmental factors that affect sleep in general. To achieve physiological sleep that is continuous (i.e., not fragmented) and therefore likely to reduce sleepiness and promote alertness, naps should be taken in the same kind of environment in which healthy nocturnal sleep is usually taken. This means that when possible, the nap environment should be free of disruptive noise and vibration, it should not be too hot or too cold, it should be safe, and the sleep surface should not be uncomfortable. There is also evidence indicating that nap sleep is less fragmented if the napper is allowed to lie down, rather than merely sitting semi-recumbent. One study showed that the quality of sleep begins to erode when the angle of recline is less than 45° from vertical. This does not mean that a nap in a comfortable reclining chair cannot be beneficial in terms of promoting alertness--the benefits of a nap in a cockpit seat were demonstrated in the studies of planned napping performed by NASA (Rosekind et al., 1994). However, if the napping environment is so hostile that it severely fragments sleep (e.g., arouses the sleeper every minute), then the potential of the nap to ward off fatigue/sleepiness will be markedly reduced.

4. Nap duration.

What duration does a nap have to be to provide of some measurable degree of recovery from fatigue? Many studies show that naps of durations between one hour and three hours markedly improve alertness and performance. However, there is also evidence that naps involving sleep durations under one hour (e.g., 20 - 45 minutes) can promote alertness. In general, the longer the nap, the greater the improvement in objective indices of alertness and performance. But this relationship is not entirely linear. The greatest gain in alertness appears to be derived from the first hour of sleep (relative to subsequent hours), and it is this nonlinearity that probably accounts for the apparently disproportionate benefits of naps in terms of recovery from sleepiness. However, this does not mean that short naps will necessarily result in full recovery of alertness, or that their benefits will be long lasting. Whether the latter occur depends on how fatigued/sleepy the napper was prior to the nap, which is a direct function of the individual's pre-nap sleep debt. For example, if a person is severely sleep deprived (from acute or cumulative sleep loss), a two-hr nap will substantially improve performance, but it will not necessarily return it to baseline/optimal levels. This is one reason why napping is not a substitute for full recovery sleep. However, if the person is fatigued from mild to moderate sleep loss or night work, a nap of 20 minutes to two hours (depending on the opportunity and expected post-nap work duration) can promote alertness and performance levels close to baseline levels. The duration of the post-nap enhanced alertness can vary between one and 12 hours, depending on sleep debt and nap duration. Again, if the sleep debt of the napper is high, then the magnitude and duration of the benefits for alertness and performance will be reduced. When the sleep debt is less severe, even a 25-minute nap can promote alertness and performance to near baseline levels for up to six hours post-nap. Consequently, using napping as a strategy for coping with operationally-induced fatigue requires an appreciation of the factors that will influence the potential of a nap for reducing fatigue. Again, napping can help significantly,

but it is not a definitive solution for fatigue, and it should not be used to the exclusion of longer periods of recovery sleep.

5. Napping and sleep inertia.

It is important to recognize that napping can have positive benefits for helping to manage fatigue, but that these advantages are not realized until a significant negative effect of napping on performance is dissipated. This adverse effect is called sleep inertia, which refers to a difficulty achieving full, waking alertness after sleep. Alertness and performance are usually reduced upon awakening from sleep. This sleep inertia effect often can be reversed within 15 minutes by activity and noise. However, sleep inertia can be severe and longer lasting if the nap is taken by someone with a severe pre-nap sleep debt. This is another reason why it is best to use napping as a strategic countermeasure to prevent severe sleep debt (i.e., napping in advance of significant accumulation of fatigue).

6. Napping in advance of fatigue.

Naps appear to be maximally useful as a fatigue countermeasure strategy when they are taken in advance of, or early on during work performed at night, or during work periods that will ultimately lead to significant sleep debt. Evidence for this idea first came from studies by our laboratory on a concept we called "prophylactic napping," which refers to using naps as a kind of preemptive strike against cumulative fatigue. Prophylactic napping was intended to prevent some or all of the fatigue-related deficits in performance in persons who had to work for prolonged periods, who had to work at night, and who were going to develop sleep debts. To test it we compared the effects of naps taken before sleep loss and/or during the first night of work, to the effects of naps taken after sleep loss (both day and night). While all naps helped reduce fatigue and improve performance, the ones taken in advance of sleep loss and/or during the first night's work provided the greatest gains in terms of both the magnitude and duration of performance improvement, despite the fact that they were of shorter duration than the naps taken after significant sleep debts had developed.

Subsequent studies confirmed the benefits of prophylactic napping.

The laboratory research documenting the benefits of prophylactic napping is conceptually very close to the NASA/FAA study on the effects of "planned cockpit rest" (which was actually planned napping) in long-haul flight crews. In this important field experiment, crews were randomly assigned either to a control (no nap) condition or to a nap condition. Those in the nap condition were afforded a single planned 40-minute nap opportunity in the cockpit seat during each of four 9-12 hour flights, while the other two flight crew members operated the aircraft. The results from this experiment clearly demonstrated that a single nap (mean of 25 minutes sleep) taken by a flight crew member could markedly enhance the crew member's physiological alertness and psychomotor vigilance performance near the end of flight, when crews must be maximally alert (Rosekind et al., 1994). This study also demonstrated five other fundamentally important points about using planned napping as a fatigue countermeasure strategy: (1) It was possible to safely and effectively plan ahead of time for when a nap would be taken during a work period, rather than waiting until an operator was so tired that microsleeps and involuntary nap-

ping were occurring; (2) it was possible for virtually every operator (90%+) to fall asleep in a reasonable period of time (i.e., 5-10 minutes) during planned naps taken both in the daytime and at night; (3) sleep inertia did not pose a serious problem because 20 minutes was allowed for its dissipation prior to assuming duties; (4) as in laboratory studies, the nap improved objective measures of alertness (i.e., brain activity and probed performance) in flightcrews, but it did not eliminate their feelings of fatigue; and (5) the beneficial effects of a single nap were most evident on night flights, when control crews showed increasing fatigue relative to crews allowed a nap. This study clearly established the practical and safe utilization of napping as a fatigue countermeasure in a real-world operational setting.

7. Napping as a fatigue-countermeasure strategy: Good news and bad news.

As discussed above, there is ample scientific evidence that napping can acutely improve alertness on the job, and that napping in advance of the development of fatigue may offer the greatest benefits in terms of alertness and performance. While short naps can be beneficial, longer naps offer even more recovery, but as nap duration lengthens to an hour or more sleep, sleep inertia will worsen, and consequently, it will require more time to become fully awake and alert post-nap. Napping is not a solution to every fatigue problem engendered by work schedules and operations. It is a limited fatigue countermeasure that can be of considerable benefit if used properly, and if its limitations are recognized. These limitations include the fact that napping may not improve feelings of fatigue; napping requires dissipation of sleep inertia to be beneficial; napping will not promote circadian adjustment to night work; and napping does not significantly repay cumulative sleep debt. Rather, when used properly, napping is a stop-gap fatigue countermeasure that can promote alertness for limited periods of time in persons who must be exposed to work conditions that engender fatigue.

The good news is that napping, especially in advance of sleep loss and night work, can enhance physiological alertness and performance, depending on the nap sleep quality and duration. Viewed from this perspective, napping as a fatigue countermeasure strategy offers significant advantages in operations that otherwise rely purely on motivation and mental toughness to maintain alertness and performance during night work and sleep loss.

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Technology / Scheduling Approaches

David F. Dinges, Ph.D.

Director, Unit for Experimental Psychiatry
University of Pennsylvania School of Medicine
Philadelphia, Pennsylvania 19104

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This article discusses some of the major issues regarding the challenges of establishing standards for the burgeoning growth industry in technological approaches to fatigue management in transportation, and developing work schedules that minimize fatigue yet permit economic viability. More extensive discussions of these issues can be found in other recent articles (Gilliland & Schlegel, 1993; Dinges, 1995).

1. Challenges facing technology for fatigue management.

Virtually all of the technologies being proposed to manage fatigue in transportation are still at the conceptual, prototype, or early testing stages and consequently, their full effectiveness, implementation, and practicality remain unproven. Moreover, because many of them are being developed in a proprietary context, it is not possible to review whether they meet the scientific standards of reliability and validity (including sensitivity and specificity). Generic categories of these technologies include, but are not limited to, the following: (1) computer algorithms for designing work schedules; (2) readiness-to-perform and fitness-for-duty testing modules; (3) personal fatigue monitors; (4) vehicle-based driving performance monitors; (5) vehicle-based driver alertness/drowsiness monitors; and (6) both low- and high-technology crash avoidance systems.

No one specific technology development will be singled out for praise or criticism in the review. Rather, the classes of technology for fatigue management will be broadly discussed, and the emphasis will be on the need to maintain standards by which technologies are evaluated. One aspect of standards is the feasibility or implementation of a technology. In some areas you find an obsessional concern for implementation realities, with little regard for validity and reliability of fatigue detection. Certainly, implementation of a technology to prevent or identify a fatigued operator is critically important. There is little point to inventing something that has scientific validity that

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cannot be implemented (i.e., it fits perfectly inside a vehicle, but in fact does not measure fatigue or prevent fatigue-related performance failures). On the other hand, excessive concern for implementation without comparable concern about the scientific validity and reliability of a technology is equally inappropriate. In fact, implementation concerns should come after scientific validity and reliability have been established. In terms of the utility of technological approaches for fatigue management, it is fundamentally critical that these approaches be held to acceptable scientific standards. For example, in terms of devices that purport to detect a fatigued operator, basic data must be provided on whether the device detects what it alleges to detect (this is the validity standard), and whether it can detect it repeatedly (this is the reliability standard). Even if a device is reliable and valid, to be practically useful, it must meet additional standards of high sensitivity and high specificity. Thus, the device must detect all (or nearly all) fatigued operators (i.e., high sensitivity standard), without too many false detections (i.e., high specificity standard). A device that has high sensitivity but low specificity will detect fatigue, but may give too many false alarms to be useful. In contrast, a device with low sensitivity but high specificity will give few false alarms, but it may miss too many fatigue events to be useful.

There are also a number of ethical and legal issues that must be confronted if fatigue detection technology is to be located in the workplace. One of these issues concerns who has control over the detection technology. Another concerns the privacy rights of the individual being monitored, and the confidentiality issues of the information acquired. Related to the confidentiality question, are issues of enforcement and use of punitive contingencies when fatigue is detected. For example, from an enforcement perspective, should fatigue be viewed in the same way impairment from alcohol and drugs are viewed? What role should fatigue monitoring/detection have in assessing regulatory compliance versus providing feedback and/or education to an operator? What are the practices and policies for repeated detection of fatigue in an operator? If fatigue detection is involuntary and subject to enforcement contingencies, will operators accept it or seek to disable it? The answers to these questions are not obvious. Public policy discussion of these issues should begin now, while different technologies for fatigue detection in all modes of transportation are being developed, to allow ethical and legal policy to guide integration of the use of these technologies.

2. Operator, system, and environmentally oriented technologies.

Reviewing the different categories of technologies being proposed for management of fatigue/sleepiness in transportation modes necessarily requires some categorizations. Technologies can be arbitrarily grouped by different criteria, but at least three broad categories of fatigue-related technologies (for detection and/or prevention) include: operator centered technologies, system centered technologies, and environmentally oriented technologies. Space limitations preclude an exhaustive review of each of these categories.

System-centered technologies. These include technologies that monitor the activity (behavior) of the truck, bus, train, plane, ship, etc. Typically system-oriented technologies are designed to detect hardware performance or vehicle-environment interaction that exceed some specified profile and/or algorithm for safe operation. An example of system-oriented fatigue

technology would be a vehicle-based driver monitoring algorithm for detection of unsafe driving performance. The input to such a system is vehicle performance, not driver physiology or behavior. The latter fall under the category of operator-centered technologies. System-centered technologies that help detect unsafe driving associated with impairment (from fatigue or any other source), will likely come to fruition in the motor vehicle area in the next 10 years.

Operator-centered technologies. These include a wide range of approaches to detecting fatigue and performance impairment. They range from assessment of performance capability prior to job engagement (e.g., readiness to perform and fitness for duty testing), to monitoring sources of fatigue (e.g., hours awake, biological time of day), to probing function during work (e.g., trace or secondary tasks), to on-line monitoring of physiology and/or behavior during work (e.g., eye blinks, gaze). There are challenges that the technological initiatives in each of these areas must meet before becoming useful measures of fatigue.

There are a large number of performance test batteries touted as candidates for readiness to perform testing (and/or fitness for duty testing). Unfortunately, many of them are aptitude and language-skill sensitive, and they almost all have rather dramatic learning curves, making them less than ideal candidates for repeated usage in a diverse population. In addition, many have not been validated to be sensitive to fatigue, are not predicated on a model of human performance failure, and do not provide criteria by which to determine when someone is dysfunctional. On the other hand, there is at least one simple performance test system that we have studied (i.e., psychomotor vigilance testing) that does not have some of the aptitude- and language-sensitive problems of other tests, and that has been validated to be sensitive to sleep loss and circadian variation, suggesting that there is potential for this approach, both as a readiness to perform test and a way of probing functional capability while on the job. Performance testing is one of the easiest areas to create a technology, and it will therefore likely be one avenue by which fatigue management is undertaken in transportation modes.

Another subclass of operator-centered technology includes those devices that seek to monitor *sources of fatigue,* such as how much sleep an operator has obtained or the operator's biological phase of alertness/sleepiness. Such information is then used to predict when future periods of increased fatigue/sleepiness will occur. To do this, a monitor will have to be predicated on a biomathematical model of human alertness. Interestingly, electronic miniaturization has increasingly made it possible to unobtrusively monitor sleep/wake cycles, making this approach increasingly likely. However, much more work is still needed in predicting when an operator will be fatigued, and more precisely when the fatigue level is most likely to be associated with unsafe operation.

Another area currently receiving much attention in terms of the development of technologies is that of biobehavioral monitoring of an operator's fatigue. Examples of proposed portable measures include brain waves (EEG), eye blinks (number, speed, duration), eye closures, eye movements, direction of gaze, facial characteristics, pupilometric responses, heart rate, electrodermal responses, and body movement. Some of these techniques have been validated to be sensitive to fatigue (e.g., some aspects of EEG signals) but have not yet been made totally practical, while other measurements (e.g.,

facial characteristics) have not yet been validated. As importantly, few of these measures have validated algorithms for *interpreting* the information acquired, even when they acquire fatigue-related information. Finally, even among those biobehavioral measures that have been validated to be sensitive to fatigue, and for which algorithms exist that meaningfully integrate and interpret the information acquired on-line, there are only limited data on their practicality.

Many devices must acquire, interpret, and feedback information in real world contexts. Consequently; a demonstration that a biobehavioral measure can detect fatigue in a controlled measurement context of a laboratory does not ensure that the device will work as well in a real world scenario, where an operator can be active. There is, therefore, still a great deal of progress required in the area of biobehavioral monitoring of fatigue, and in the area of on-board fatigue countermeasures. In the latter area, there are an equally large number of claims of efficacy that have not been demonstrated (at least not in the public domain) to be scientifically valid (e.g., that certain odors will reverse fatigue for any sustained period of time). Clearly, biobehavioral monitoring of fatigue is a promising area, but one that also needs to meet reasonable scientific and practical standards. A great deal of harm can be done if invalid and/or unreliable devices are quickly and uncritically implemented. This will result in wasted resources and provide only a false sense of security relative to performance-impairing fatigue.

Environmentally-centered technologies. There is also a range of environmental technologies associated with preventing fatigue-related performance deficits and catastrophe. These can include sleep environments in the work place, which refers to the comfort, quiet, lighting, and related environmental facets of sleeping quarters in planes, trains, ships, and trucks. Such on-board sleeping environments are intended to promote recovery from fatigue. However, if the environment is not conducive to sleep (or is under-used), it may be of little value as a fatigue prevention system. There is a great deal of variability within and among transportation modes in on-board sleeping facilities, but little research on the topic. Laboratory data suggests that a comfortable (thermally, posturally), quiet, safe sleeping environment in which the sleeper can lie down is more likely to promote consolidated sleep and recovery than is one in which these factors are not present. More research of the kind that NASA has recently conducted on on-board crew rest facilities in longhaul aviation is needed to identify the most effective sleeping environments in the workplace (i.e., those that afford the best recovery from fatigue).

There is also emerging environmental technology associated with promoting alertness in the workplace. Bright light is an excellent example of such a technology--it has been much more extensively investigated than some of the other environmental countermeasures to fatigue. Some of the newer environmental technologies being developed include error detection systems and feedback technologies, and intelligent systems technologies (e.g., so-called intelligent highways). Shoulder rumble strips are also an example of an environmental technology intended to prevent catastrophic outcome.

One of the greatest concerns raised about environmental technologies, especially those that provide feedback on the operator's interaction with a system or the environment (e.g., should rumble strips), is whether these technologies do nothing more than encourage people to be-

lieve that it is safe and acceptable to continue operating in a fatigued state. As an example of this concern, consider the problem of whether or not to install shoulder rumble strips along millions of miles of highway, especially sections with high run-off-road crash rates. The concern would be that shoulder rumble strips may not actually reduce crashes, but rather merely permit crashes to "migrate" from a highway area in which shoulder rumble strips have been added, to an area without rumble strips, further down the road. Presumably the environmental technology (in this case, shoulder rumble strips) prevented some crashes at one site by merely shifting them later in time, because many of the impaired drivers did not actually stop operating their vehicles upon encountering the technology. While there is very good evidence that shoulder rumble strips do reduce run-off-road crashes, migration has also been observed. Consequently, any environmental technology designed to promote alertness and prevent fatigue-related catastrophes must also be implemented in a manner that ensures it does not simply encourage even more unsafe practices. Therefore, as these technologies become implemented, research will be needed on exactly how people use them, and how effective they are at preventing fatigue-related outcomes. The same type of research will need to be performed on system-centered and operator-centered fatigue countermeasure technologies.

3. Challenges facing scheduling and the management of fatigue.

On the scheduling side, developments have been much slower. Scheduling is much more than "hours of service," which form the backdrop or platform on which scheduling is supposed to occur across transportation modes. Scheduling involves the thousands of different types of schedules that now exist in the world. A huge number of which are not circadian, meaning they do not even approximate a 24-hour work-rest period that would permit some adjustment by the circadian biological clock regulating alertness in humans. Two other critical challenges to scheduling technologies include the problem of work being done during non-work or rest hours, and work that is job related but that is classified as "voluntary" and, therefore, considered outside the scope of regulated hours. In terms of performance impairment, the brain does not care what caused the sleep loss or circadian loss of alertness leading to fatigue. The biology reacts the same way, regardless of whether someone remained awake for a prolonged period of time because he/she was working overtime, or was working a second job, or was caring for a sick relative. This means that everyone (worker, company, regulator, and public) share responsibility for ensuring that dangerous levels of fatigue on the job are not engendered either by poor work schedules, or by life style, or by voluntary work opportunities (excessive overtime).

The challenge of scheduling to manage fatigue is that with the full scale utilization of 24-hour operations in virtually all modes of transportation, has come a concomitant proliferation of work schedules (e.g., split shifts, flexitime, and compressed work weeks). Moreover, federal regulations governing hours of work in all major modes of transportation are dated, and uninformed by modern scientific data on the biological causes of fatigue and its effects on performance. In addition, these regulations are often out of line with actual industry practices. A significant issue that will continue to confront industries and governments involved in global economic competition is how to meet

the escalating demands to operate around-the-clock, often internationally and/or intercontinental, in a cost-effective manner, while ensuring that operators remain alert on the job. Interpretation of current U.S. federal statues and regulations governing work-rest scheduling vary widely across transportation industries (e.g., the range in total hours of work allowed by law varies by more than a factor of two, mandated days off in a two-month period range from zero to 24, and attitudes about the need to enforce the regulations range from serious concern to casual disregard). In recent years there have been growing interest in the United States and Europe toward revision of the work-rest regulations to reflect industry/government economic needs, parity among labor constituencies, the public's perceptions of what they want to have regulated (this can vary markedly across industries), and the scientific data accumulated on the causes and consequences of performance-impairing fatigue. Whether this level of agreement is feasible is unknown, but to even approach it, constructive efforts from all parties will be essential.

While developments in scheduling technologies have lagged behind those for systems, operators, and the environment, there is currently at least one initiative underway to base changes in federal regulations dealing with limits on scheduled work hours in a transportation mode on scientifically derived principles and guidelines about fatigue/sleepiness (Dinges et al., in press).

4. The ultimate challenge is not a technological one.

Some technologies will eventually prevent or limit certain catastrophic outcomes due to fatigued performance. There is clearly great potential for improving the safety margin with technologies and better scheduling. However, such developments should not be a substitute for setting standards for the functional capability of a transportation operator. This point is perhaps best made with an analogy to another risk factor. Imagine if a device was developed that could absolutely prevent 98 percent of all drunk driver crashes, and that it was to be installed in all modes of transportation. With this super device in place, would we, as a culture, accept the premise that henceforth it was acceptable for people to drive drunk? This is the ultimate issue we face in the fatigue area as well. Technologies may eventually prevent or limit certain catastrophic outcomes due to fatigued performance, but technologies are not substitutes for setting societal standards for the functional capability of an operator.

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Dr. Charles A. Czeisler

Harvard Medical School/Brigham and Women's Hospital
Melatonin, Bright Light and Overnight Operations

November 1, 1995 -- Afternoon Session

Thank you very much, Dr. Rosekind. Chairman Jim Hall from the NTSB jokingly suggested that he had arranged for a melatonin pill to be on the cover of Newsweek today as a kickoff for this workshop.

It is a pleasure to have been asked by the NTSB and by NASA to make a presentation today. I am going to concentrate in this presentation on the countermeasures that can be used to try to correct some of the abnormalities associated with misaligned circadian phase, in particular on use of the hormone melatonin and on exposure to light.

The operational demands within the transportation industry, as has been already reviewed today, are quite disruptive to a number of the physiologic systems that control the timing of sleeping and waking and hence, affect alertness and performance. Transmeridian travel across multiple time zones, of course, causes a mismatch between the biological time of day, on the one hand, and the local time at which individuals are trying to operate on the other. This is often exacerbated by the extended work hours that are needed to travel due to the inherent nature of the transportation industry. Much transportation work is also done at night and requires a high degree of alertness on short notice, often punctuating long intervals of relative boredom. Furthermore, we know from survey data that there is a high rate of near-miss and actual accidents in round the clock industries. In a survey of about 2,500 rotating shift workers, we found about 20 to 25 percent of rotating shift workers reported personal injuries and procedural errors, near misses, or even accidents, associated with sleepiness in the preceding year. Furthermore, about 28 percent of them report an actual or near-miss automobile accident due to sleepiness within the preceding year. Ninety-eight percent of those reported automobile accidents or near misses due to sleepiness occurred on a work day, with over 90 percent of those reportedly occurring while driving home from work after having worked the night shift. Indeed, the early morning hours represent a critical zone of vulnerability for individuals in the transportation industry. In fact, it was reported years ago that there is a 16 fold increase in the risk of a single vehicle truck accident due to sleepiness at that time as compared to the middle of the daytime (Figure 1).

So why is this particular time within the 24-hour day the most vulnerable? We have already heard from Dr. Dinges and Dr. Rosekind explanations of the physiologic bases of this vulnerability, and Dr. Dinges spoke extensively

about lapses of attention which occur under this circumstance. Figure 2 shows EEG recordings by Torsvall and Åkerstedt in Swedish train drivers on an overnight trip from Stockholm to Malmö in the south of Sweden. It is rare to have actual EEG recordings of individuals during the night shift, although Dr. Rosekind and Dr. Dinges have recorded similar tracings in airplane pilots. The upper panel of Figure 2 illustrates two tracings of the EEG from an alert driver. As you can see, the eye movement tracing indicates many eye blinks. The low voltage mixed frequency signal in the EEG tracing indicates an awake and alert individual. The lower four tracings illustrate data from a sleepy individual driving a train. The eye movement tracing from this sleepy driver indicates that his eyes are rolling around in their sockets. He also has episodes of synchronous activity in the EEG, as occurs during sleep. Midway through this record, the train driver passes right through a pre-stop signal and fails to apply the brakes until about 20 seconds later. Suddenly, the driver's heart rate jumps just at the point when he applies the brakes. This sluggish response illustrates the cognitive slowing that Dr. Dinges described in the sleepy individual. Actually, there was not another stop signal in the 20 second interval between the time the engineer first passed the signal and when he applied the brakes. Yet it took 20 seconds for the signal to pierce the consciousness of the train driver, and for him to realize that he had seen a stop signal some time ago but had not yet applied the brakes.

Why do such lapses tend to happen at night when we are at an adverse circadian phase? Because, as you remember from Dr. Dinges' lecture, one of the primary determinants of alertness and performance is circadian phase, which is determined by a light-sensitive pacemaker or clock located in the brain.

We can monitor individuals in the laboratory to find out what happens to their physiologic functions when they remain awake all night. The body temperature cycle reaches a nadir just before the regular wake time of the individual, and then the body temperature rises again. Subjective assessments of alertness drop to their lowest level at about the regular wake time. Those of you who have remained awake all night will often feel a surge of energy in the early morning hours just after dawn.

Many times, if exposed to the external light/dark cycle, people staying awake all night will think that it is the sunrise that has woken them up. Alternatively, one might guess that interaction with colleagues coming into work in the morning might provide this surge of alertness. But actually, even if we keep subjects in a lab where they are shielded from changes in the outside world, and we keep them in a constant posture with meals evenly distributed throughout day and night, a daily surge of alertness still occurs a few hours after their regular wake time. This surge is being driven by an internal biological clock. However, the peak drive for sleep is very close to the regular wake time of the individual, not at bedtime as you might imagine.

The release of the hormone cortisol continues its robust oscillation, even in this state of continued wakefulness. Daily variation of urine output, which is normally lowest at night when we are asleep and highest during the daytime when we are ordinarily awake persists even during a two day vigil of extended wakefulness.

Even the release of the hormone melatonin, which Dr. Richard Wurtman at MIT has called the hormone of darkness, continues to occur during the night. In nature, it is used to mea-

sure daylength, by sending a signal to the brain which allows seasonally reproductive animals to determine whether or not it is the appropriate season for breeding. In animals that do not normally reproduce during the winter, high levels of melatonin occur when the days are short and the nights are long, inducing testicular regression with a 90% loss of testicular weight, so that the animals are unable to breed during the winter. This was not mentioned in the Newsweek cover story on melatonin, although it was reported that decreased sex drive was one of the side effects recorded by some of the individuals taking melatonin. In the spring, when the days are long and the nights are short, there is less melatonin released because melatonin is inhibited by exposure to light. Inhibition of melatonin secretion is then associated with a recrudescence of the testes, followed by reinitiation of reproduction in those animals.

Cognitive performance, as measured by the speed of completing simple addition tasks, reaches a nadir just after the habitual waketime, in parallel with short term memory performance. In the short term memory task, the subjects are read a passage and then tested for simple recall of that information, without any cognitive reasoning required. At the nadir of the temperature cycle, near the habitual wake time, performance on that task is significantly degraded as compared to the daytime.

Now, what can we do about a biologic system in which the brain is gearing down to be asleep during the night time hours, even if that is the time an individual needs to be active and awake in order to fly an airplane or drive a train? Well, planned exposure to light can actually reset this internal biological clock, shifting it so that we are alert and awake at night and asleep during the daytime. The brain contains the internal biological clock or circadian pacemaker in the suprachiasmatic nucleus of the hypothalamus, or SCN for short. There is a direct connection between the retina in the eye and this pacemaker or clock in the brain. Animal studies have demonstrated that even after transection of the pathways necessary to mediate conscious vision in the brain, resulting in behavioral blindness, the internal clock of those animals can still be reset with exposure to light. It is not necessary to be consciously aware of the light in order for it to reset our internal clock. We have since confirmed those observations in a subset of blind humans.

One of the things that we have shown is that if we determine what time of day it is in an individual's body by charting a physiologic function, and we expose that individual to several consecutive days of bright light at night and darkness during the day, then within a few days the pacemaker can be reset. Such light exposure can reset the pacemaker by up to 12 hours within 2-3 days.

On the other hand, if we are exposed to darkness during our new daytime, our internal biological clock will not adapt to a change in time zones, even though we have shifted the timing of when we sleep and wake, along with our entire meal schedule, our social interaction schedule, and all the other things that go along with changing time zones.

It is not just the timing of the body temperature cycle that will shift in response to light exposure, but also the timing of the release of the nocturnal hormone melatonin. If we expose an individual to bright light, we can shift the body temperature cycle so that the nadir occurs at an earlier hour, and we can also then shift the release of the hormone melatonin so that instead of being released during the hours from 10:00p.m. to 8:00a.m. it is released in the

afternoon and evening hours. The resetting response of this biological system to light depends on the time at which the light stimulus is given. Just as Dr. Roth was indicating a moment ago with regard to pharmacologic agents, you need to plan both the timing of the light exposure as well as the dose to induce a desired response.

In response to the timing issue, if you give the light exposure in the middle of the day it will have little resetting effect. For example, if you were to go outside and be exposed to very bright light at 4:00p.m., that would minimally reset your internal biological clock. Whereas if you were to be exposed to that same light stimulus in the middle of your biological night at 4:00a.m., such as might occur if you were piloting an aircraft from Washington, D.C. to Tokyo, then several consecutive days of bright light exposure could reset your biological clock by up to 12 hours, depending on the exact timing of the light exposure.

We have done some studies in the laboratory to determine the potential use of this approach among shift workers who are regularly working at night. Subjects from our control studies began their first night shift when their body temperature cycle was reaching its nadir during the shift. As a result, they were very sleepy during the scheduled work time on this first night. After they worked for a week in standard room light, then at the end of that week, on the sixth night shift, they were still reaching the nadir of their body temperature cycle at that adverse phase, because the internal biological clock was not adjusted to a night work schedule. In fact, people can work at night for years and fail to adjust to their night work schedule. Exposure to bright light in the outdoor world on the way home from work sends a signal to the brain indicating that it is daytime. That daytime light exposure overpowers the impact of the much dimmer artificial light to which they are exposed while working at night, and keeps them on a schedule in which they are fighting the brain in order to stay awake at night and then fighting the brain to try to sleep during the daytime.

On the other hand, if you enhance the exposure to bright light during the night shift, and protect the day time sleep so that it occurs in darkness, then you can essentially trick the brain so that it adjusts to night work. People can then be at their peak during night work, and at their nadir during the subsequent day sleep. In our study, none of the subjects in the control group adapted to the night shift schedule, whereas all the subjects in the treatment group successfully adjusted to their schedule of night work and day sleep. If we examine their body temperature, alertness, cognitive performance, kidney and hormone activity, it is evident that the group that received the treatment were at their peak of alertness during the night shift instead of at their nadir, and they were at their low point of alertness during they day sleep, which is appropriate. In contrast, those in the control group did not adjust physiologically to working at night, and continued to reach their temperature, alertness and performance nadir during the night shift hours, even after a full week on the schedule.

The subjects in the control group slept an average of 5.7 hours per day, so that over the course of a week they lost a full night of sleep. In other words, they lost at least eight hours of sleep over the course of a week of night shift. As Drs. Dinges and Rosekind pointed out, such chronic partial sleep deprivation leads to deterioration of alertness and performance and increased risk of error or lapsing of attention. In contrast, the individuals in the treated group,

who were exposed to enhanced lighting in the work place, slept an average of two hours more per day and avoided the potentially dangerous loss of a full night of sleep during the week of night work.

Our first application of the use of bright light to the workplace was in the transportation industry, albeit in an unusual mode of the transportation industry, among the crew of NASA's space shuttle Columbia. The shuttle was scheduled to launch at night and the crew therefore had to invert their sleep-wake schedules by 12 hours in order to be prepared for night activity and day sleep. The crew were then expected to remain on that schedule throughout the ten or 14 days of the mission, with some minor variations. The particular crew of the first shuttle (STS35) with whom we worked in 1990 were on that inverted schedule for weeks prior to the mission, since that was the mission that was delayed because of hydrogen leaks for many weeks. Throughout that time, the crew kept trying to stay awake at night and sleep during the day time. We installed enhanced lighting in the pre-launch quarantine area for the crew members. The commander of that mission reported that on the first night of augmented light, the crew accomplished more than in the previous several weeks, when they were trying to stay awake at night in ordinary room light. We put them on a schedule in which they were exposed to enhanced light intensities during their anticipated day, and darkness during their anticipated night sleep. By the time they were ready to launch, the timing of the release of melatonin was inverted, such that it was being released during their day time sleep instead of during their waking night.

There has been speculation and some scientific evidence that direct melatonin administration could be used to reset the internal biological clock in humans. It has been reported that daily melatonin administration for four consecutive days can reset the melatonin rhythm by up to an hour or two. However, in those studies, subjects were living in the outdoor world and their exposure to natural outdoor light was not controlled. Since light can reset the biological clock by up to 12 hours within a few days, it is not known without controlling for light whether or not melatonin is really in and of itself effective as a phase resetting agent in humans.

In fact, in blind individuals, the results from clinical studies indicate that although it appears to aid sleep in some blind individuals, it does not appear to be able to entrain or reset the rhythmic markers that we use to track the output of this internal biological clock in the absence of light input to the pacemaker. So, in my view, notwithstanding today's cover story in Newsweek, it is not clear whether or not melatonin is effective at resetting the human biological clock.

Apart from circadian phase, one of the main determinants of alertness and performance is the amount of time that we are awake during the waking day. To study the interaction between the time of day and the lengths of time awake, Dr. Derk-Jan Dijk and I have used a protocol that was developed by Professor Nathaniel Kleitman more than 50 years ago, when he spent a month in Mammoth Cave in Kentucky. When he went into Mammoth Cave, Dr. Kleitman put himself on a schedule that transmeridian travelers would find to be quite a nightmare. He put himself on a schedule in which every day he crossed anywhere from three to four times zones, and he did that for a week. In one case he lived on a 28 hour day, going to sleep four hours later each day, as if he were travelling westward by four hours. In

one week, even though he only had six sleep episodes on this 28 hour schedule, he still had seven cycles of his body temperature. In another experiment, he put himself on a schedule where every day he went to bed three hours earlier, the equivalent of flying eastward three times zones each day. Although he had eight 21 hour days during a week on that schedule, he still had seven cycles of his body temperature. We have taken that paradigm and extended it for a month. Under these circumstances in the lab, the internal biological clock begins to oscillate at its own intrinsic period, which as Dr. Rosekind mentioned is a little longer than 24 hours. Dr. Theresa Shanahan has shown that the timing of the release of the hormone melatonin and the timing of the body temperature cycle continue to oscillate with a near-24-hour period, in synchrony with each other. This protocol allows us to study what happens to individuals sleeping and waking at all different phases of an internal biological clock. By looking across days on that 28-hour schedule, we find that even within the normal waking day, there is a substantial decline in alertness and performance that occurs within the first 16 to 18 hours of our regular waking day. Our alertness and performance are actually declining between 8:00 a.m. and 10:00 p.m., due to the length of time that we have been awake. We do not usually notice that because our internal clock is timed to peak in the latter half of our waking day. As our alertness declines because we have been awake longer, and as our performance would otherwise be deteriorating, our internal clock is actually improving our alertness throughout the waking day. Thus, the internal clock promotes alertness as the day goes on, opposing the decline of alertness which would occur if we remain continuously awake. Those two forces normally interact to allow us to maintain a stable level of alertness throughout the day.

But if you schedule an individual to begin driving at 10:00p.m. and continue driving all night, this precisely timed system is turned upside down. So instead of working in concert, interacting to maintain a high level of alertness, circadian and homeostatic factors make alertness in the latter half of the night worse, and worse, and worse. That is probably why there is that 16 fold increase in the risk of single vehicle truck accidents in the hours from 3:00 to 6:00 in the morning (Figure 1). To make matters worse for the night driver, it is then difficult to sleep during the day time, because these same two systems control the ability to sleep.

One is the homeostatic drive for sleep, which depends on how long you have been awake. While you will have plenty of homeostatic sleep drive if you have been awake all night, the circadian clock is actually poised to make it difficult for you to sleep during the day time.

When individuals try to sleep at an adverse circadian phase, particularly in the afternoon and evening hours, there is a great deal of waking that intrudes upon their scheduled sleep episode. We estimate that on average, 25-50 percent of the time they will be awake if they try to sleep at an adverse circadian phase, depending on their age. This is very discouraging to people. They lie down and while they may fall asleep, they can't stay asleep (Figure 3).

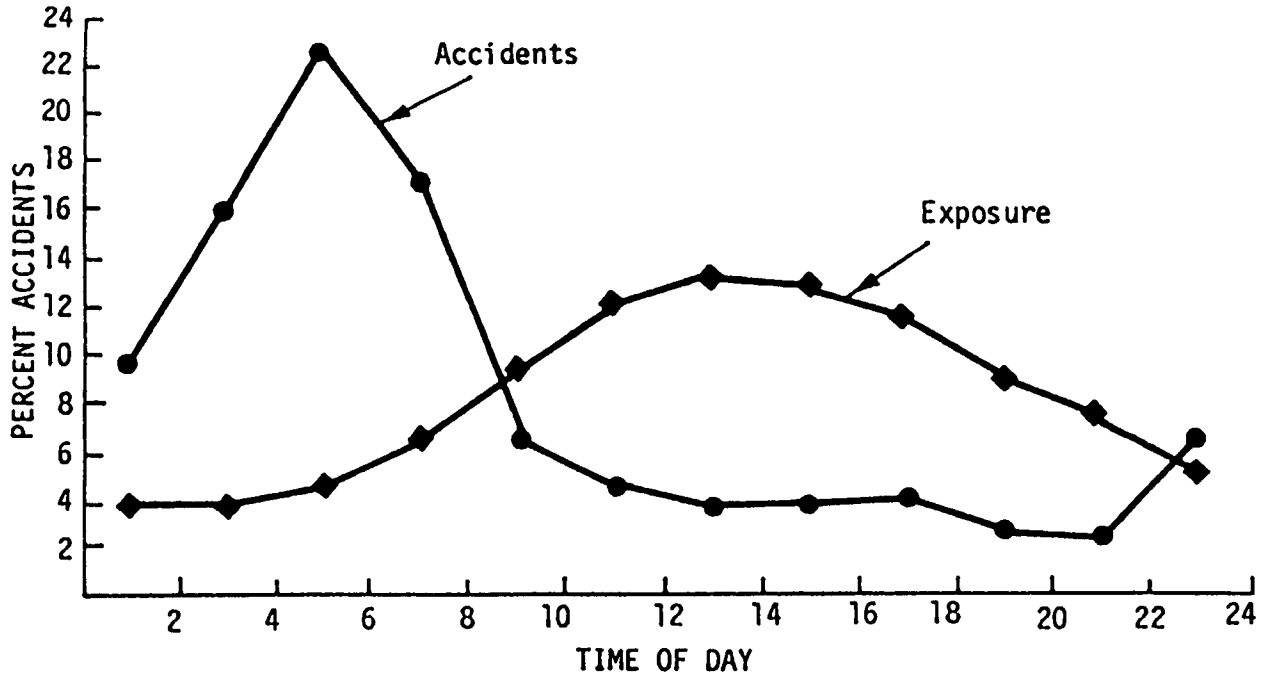
This is where the hormone melatonin may help some day. Rather than shifting the biological clock, some data indicates it may help to promote sleep at adverse times when melatonin is not naturally being released. If you give the hormone melatonin during the day time, a 1994 study reported that it can help to promote sleep during a 10-minute nap.

That 10 minute nap experiment has driven the most intensive public relations promotion of melatonin that I have ever witnessed for any compound. Newsweek said something pretty striking in the article on melatonin in today's issue. They reported that in early August, something happened to cause a dramatic increase in the sale of melatonin. Perhaps it was related to the fact that the day after their August article on melatonin appeared, sales rose more than ten fold in health food shops across the nation. Now Newsweek has a second article reporting on this melatonin craze, on the front cover of the magazine. Well it seems to me that if Newsweek looked inward they would realize that they are driving this "melatonin craze" with all of this publicity. No other hypnotic has been allowed on the market with so little clinical trial data collected. In my opinion, it is really much too early to promote melatonin as a sleep promoting hormone. If after controlled trials, it does turn out to be effective, it could be used to help promote sleep during the time of day that we do not ordinarily sleep and that we do not ordinarily produce this hormone.

Finally, I believe that the transportation industry desperately needs an educational campaign on sleep and circadian rhythms. Such an educational campaign could prevent the kind of situation that I found prevailing in Albany a few years ago. I spent three years flying from Boston back and forth to Albany testifying because the chief of the fire department there wanted to set a limit on shift duration for the paramedics driving the ambulances in Albany. He wanted to limit them to no more than 24 hours of service. But since the employees were paid premium overtime for each additional 24 hours that they worked, they were suing the City of Albany, arguing that they should be allowed to work longer by a contract that was established 40 years ago, which allowed up to 72 consecutive hours of service.

The remarkable thing to me, after three years of testimony, was that in the end the City of Albany had to pay all the back wages to all those individuals who were not allowed to work up to 72 hours in a row, and the fire chief was forced to change his scheduling practice so that individuals were again scheduled for service as paramedics working up to 72 hours in a row. I find it remarkable that in a civilized society -- given what we know about the dangers of sleep deprivation -- such a practice is allowed and even mandated by the legal system to continue. I do not think anyone who has a heart attack would want to have an IV line placed by someone in the field in their 70th hour of work, or to be driven from the scene of the incident or accident across our Nation's highways to the hospital by a paramedic who has been on duty for 70 hours. Yet we have no policies in this country which prevent that kind of abuse from happening. I believe that an effective educational campaign could improve such situations. We also need Federal guidelines limiting the number of consecutive hours of service allowed in all industries in which performance degradation can cause accidents. People in such jobs should not be allowed to work such inhuman hours. Unfortunately, the risks they now choose to take are not just their own lives.

Thank you very much.

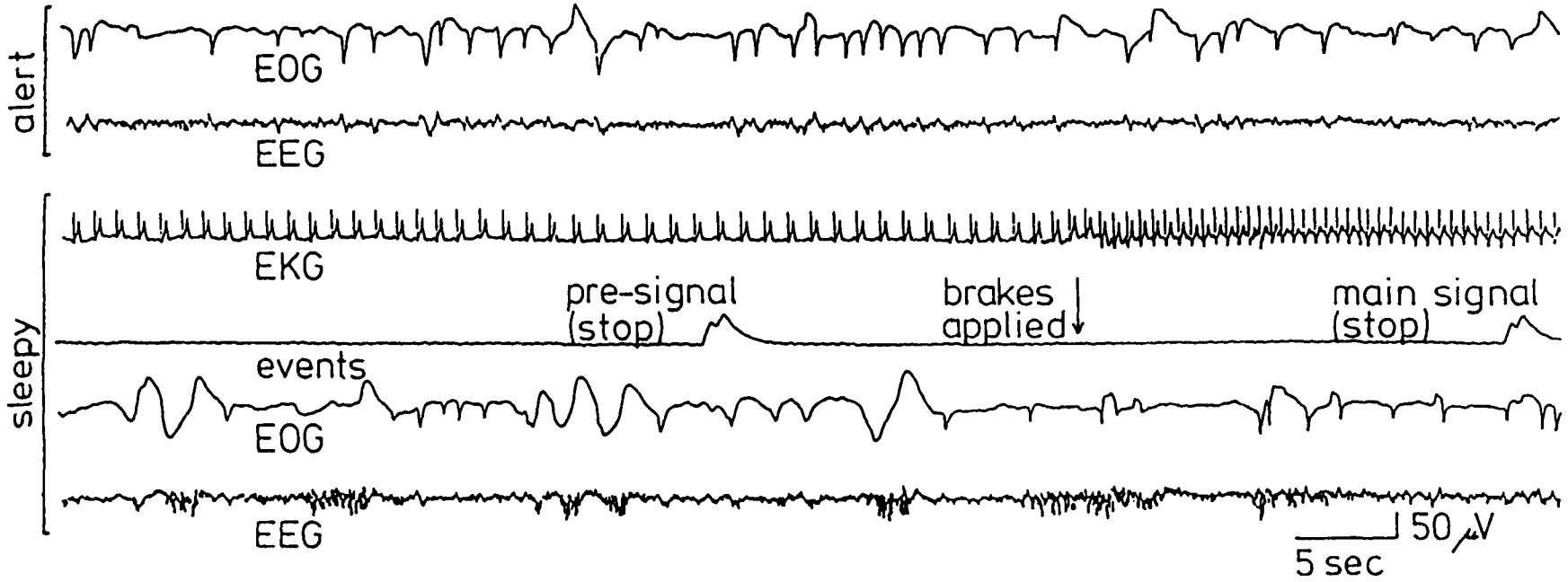


Percentage of accidents by time of day for dozing drivers and normalized percentage of trucks on the highway for a random sample of interstate drivers (exposure).

Reproduced from: W. Harris "Fatigue, Circadian Rhythm, and Truck Accidents" in Vigilance: Theory, Operational Performance, and Physiological Correlates edited by R.Mackie, New York: Plenum Press, 1777.

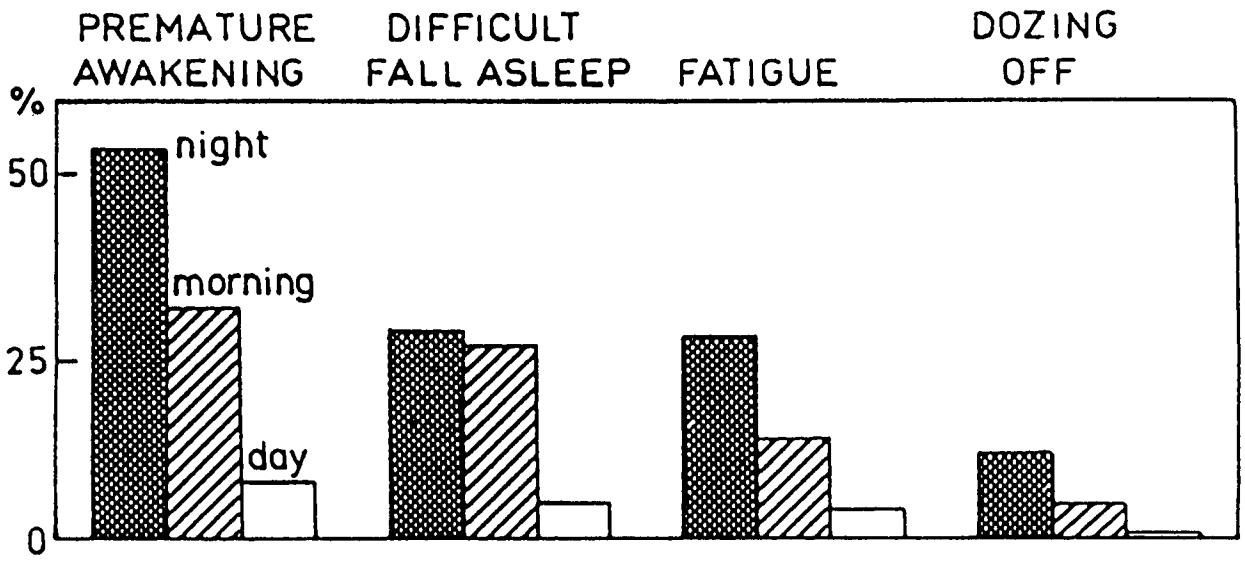
Figure 1

Figure 2



Above: detail of the EEG and EOG (ECG added) record during an alert part of the night journey. Below: detail of the record around the first performance lapse.

Reproduced from: Torsvall et al. "Sleepiness on the job: continuously measured EEG changes in train drivers" Electroencephalgraphy and clinical Neurophysiology, 66:502-511;1987.



Percentage of a sample of 1000 train engineers reporting four sleep/wake problems to occur "sometimes" or "most of the time" in connection with night, morning, and day work.

Reproduced from: Åkerstedt et al. "Sleepiness and Shift Work: Field Studies" Sleep,5:S95-S106;1982.

Figure 3

Allan I. Pack, M.D., Ph.D.

Center for Sleep and Respiratory Neurobiology
University of Pennsylvania Medical Center

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Sleep disorders are common in America society.[1] There are a large number of sleep disorders[2] but there is more information about some. Thus, in this presentation I will limit myself to discussion of three sleep disorders—chronic insomnia, narcolepsy, and sleep apnea. There are studies on the impact of these conditions on transportation. But this literature is almost exclusively related to transportation by car. There are some studies related to commercial surface vehicles, i.e., trucks, but not to my knowledge to other modes of transportation.

Insomnia and Transportation

Insomnia is a condition in which there is difficulty initiating or maintaining sleep. Individuals with this disorder will complain of the following: difficulty in getting to sleep; waking up in the middle of the sleep period and being unable to reinitiate sleep; waking up too early. Many individuals with this problem will have more than one such complaint. Insomnia can be transient, e.g., associated with bereavement of a close relative or other stressful situation, or it can be long-lasting. Chronic insomnia is considered to be a condition in which the insomnia lasts for more than three weeks.[3] Survey studies show chronic insomnia affects 9-10% of the American population.[4,5] A recent Gallup survey conducted on behalf of the National Sleep Foundation found that 12% of Americans had frequent, chronic difficulty sleeping.[6] Difficulty sleeping can impact daytime performance. A 1991 Gallup survey found that individuals with chronic insomnia reported twice the crash rates of individuals without this problem.[7]

Narcolepsy and Transportation

Narcolepsy is another sleep disorder which is associated with an increased crash risk. It is a much less common condition and it is estimated that it affects 250,000 Americans.[8] It is a disorder that usually begins in adolescence.[9] There are four main clinical features but not all individuals with this disorder will have of necessity all of the features.[9] The features are: a) excessive daytime sleepiness. Individuals with this disorder can be very sleepy during the day; b) cataplexy. Here individuals with narcolepsy can have sudden loss of muscle tone precipitated by emotional events. Loss of muscle tone normally occurs as part of rapid eye movement (REM) sleep (dream sleep). Thus, in narcolepsy this aspect of REM sleep can be triggered by emotion. The most common emotion that triggers cataplexy is laughter, although other emotions can also do so.[9] Severe catapletic attacks can result in individu-

als falling to the ground; c) hypnagogic hallucinations. This feature is related to the abnormalities in REM sleep in patients with narcolepsy. They may experience vivid dreams at sleep onset when they seem still to be awake; d) sleep paralysis, which is the experience of being unable to move when one wakes up. This occurs intermittently in about 10-12% of the normal population. It is, however, a more common phenomenon in individuals with narcolepsy. Sleep paralysis is likely to be caused by the loss of muscle tone that is found in REM sleep being continued for a period after the individual wakes up.

Narcolepsy is a chronic condition. It lasts throughout the individual's life. It does not usually get progressively worse but rather there is a variation in the intensity of symptoms. The basis for this variation is unknown. The disorder can be managed by medications to combat the sleepiness. Such medications are stimulants that include amphetamines. There is a new medication—modafinil—that is currently used in Europe. It is awaiting approval by the Food and Drug Administration (FDA). It is a medication that acts in a different fashion than amphetamines and has no abuse potential. Naps can also be extremely useful in narcolepsy since they ameliorate the sleepiness.

Narcolepsy is, not surprisingly, associated with an increased risk of vehicular crashes when untreated.[10] There are, however, no data about whether individuals once treated with narcolepsy have an increased crash risk. This is an essential piece of information to guide appropriate public policy. Currently there are limitations of driving privileges of individuals with narcolepsy in certain states and some countries.[11] The regulations vary, however. In general, for the non-commercial driver the regulations propose denying driving privileges on diagnosis with the driving license being restored when the condition is controlled for a period, e.g., 3-12 months. In certain localities, e.g., Texas, United Kingdom, Canada, Australia, individuals with narcolepsy can never be drivers of commercial vehicles.[11] There are to my knowledge, however, no studies of crash rates of commercial drivers with narcolepsy. This is not surprising and there are not likely to be. Narcolepsy is a relatively uncommon condition and it would seem likely that individuals with this disorder would not seek employment as commercial drivers.

Sleep Apnea and Transportation

Sleep apnea, on the other hand, is a much more common disorder. There are considerably more data about this disorder. In this condition the upper part of the airway narrows and may even completely close (apnea) during sleep. As a result oxygen levels in the blood decline, a change which is sensed by the brain. The brain produces an arousal, i.e., a brief awakening from sleep, during which the muscles of the throat open the upper airway. As a result sleep in this condition is considerably fragmented and is not as restorative as normal sleep. Hence individuals with this disorder are excessively sleepy during the day.

The condition is extremely common. If one uses criteria to make the diagnosis based on presence of daytime sleepiness, night-time symptoms and breathing abnormalities during a night-time sleep study, it affects 4% of middle-aged men and 2% of middle-aged women.[12] If the diagnosis is only based on the results of the sleep study alone then these numbers rise to 9% of middle-aged men and 4% of middle-aged women.[12] There is, however, a continuum of abnormality. There are many

individuals with mild disease but fewer with the most severe forms of the disorder. It is important to keep this in mind when designing public policy. Mandating testing would identify many individuals with milder forms of disease in whom the significance for the transportation industry is currently not known.

Since sleep apnea interrupts sleep and causes individuals to be excessively sleepy, it is not surprising that sleep apnea is associated with reduced driving skills and an increased risk of vehicular crashes.

Sleep apnea results in impaired driving performance. This has been shown in studies in driving simulators[13] and in the divided attention task that has been extensively used to study driving impairment produced by alcohol.[14] Patients with sleep apnea may perform as poorly as individuals who are above the legally acceptable blood alcohol concentration.[14] Patients with sleep apnea also have an increased crash rate,[15] although the studies showing this were based on a small sample of individuals. Retrospective analysis showed that patients with sleep apnea have approximately a three times increase in crash rate in the previous five years as compared to all other drivers in the state of Virginia, where the study was done.[15] There is some suggestion that sleep apnea is more common in commercial drivers.[16] This is likely because obesity is more common in this group;[17] obesity is the major risk factor for sleep apnea.[12] Commercial drivers with sleep apnea had twice the crash rate in a recent study,[16] a result widely reported in the press in the United States. But this statement is misleading since there was no significant difference in crash rates in commercial drivers with sleep apnea as compared to those without apnea.[16] Thus, currently there are no definitive data that commercial drivers with sleep apnea have an increased crash risk. It would seem likely that this is the case but studies are required to examine this question.

There are treatments available for this disorder (for review see 18). The most commonly used treatment is nasal continuous positive airway pressure (CPAP). During sleep the individual wears an attachment, e.g., mask, that connects their nose to a small machine that delivers pressurized air through the nose to the back of the throat. This pressurized air acts to push open the walls of the upper airway thereby preventing snoring and upper airway collapse. It is an extremely effective treatment. There are, however, problems with patient compliance. About 40-50% of subjects starting this therapy use it very intermittently.[18] There are some data that when CPAP is used as a treatment for sleep apnea, crash rates are reduced.[19,20] Other treatments that are include an intra-oral device which is worn during sleep.[21] This device pulls the jaw forward and enlarges the upper airway thereby making collapse and snoring less likely.[18] Surgical treatments are also available (for review see 18).

What Needs to be Done?

The issue about sleep disorders and transportation is complex. The biggest single issue is related to sleep apnea both because it is so common and it is the disorder about which we have the most data. There are already strongly held opinions, albeit not based on scientific study, about the steps we need to take. This author is in favor of an incremental approach to the problem based on sound scientific investigation. As we move forward we need to address the following questions: a) should sleep apnea be screened for as a condition of employment in transportation?; b) if so, how do we do so cost-

effectively? Routine expensive laboratory sleep studies at a cost of around $1,000 per study, which is advocated by some, is not, in my view, a viable public policy; c) if sleep apnea is diagnosed in, for example, a commercial driver and that individual cannot continue employment, should he/she be given disability payments? Again we could be facing staggering economic costs if we moved in this direction; d) what is the responsibility of the employer and the employee in the event that a major accident is attributed to untreated sleep apnea? Each of these are difficult issues will, over the next several years, presumably be the subject of much public and scientific debate.

For the present, the first step that we need to take is, in my view, increased awareness of the issue. We need to put programs in place to inform employers, employees, families of employees, and safety officials about sleep apnea and in particular, how to recognize it and treat it. We particularly need to carry out aggressive education of physicians who are responsible for pre-employment physical examinations of employees and for their annual physicals. Since sleep disorders is a relatively new field of medicine with little formal teaching in medical schools,[22] there is limited knowledge or expertise about sleep apnea among practicing general physicians.[23] A sustained educational effort should lead to increased case recognition and treatment of individuals with this disorder. Methods to track case recognition following implementation of such educational programs should be put in place. Employers can reasonably assume that somewhere between 4 and 9% of their work force will have this disorder.

To compliment this educational effort, forms etc. that are used for medical evaluation should include questions that elicit symptoms of sleep apnea, i.e., loud, frequent snoring; witnessed apneas; snorting and gasping during sleep, as well as complaints related to excessive sleepiness. Obesity is a major risk factor for sleep apnea, in particular fat in the neck area. Thus, neck (collar) size should be documented since this is the best physical measure to help determine whether sleep apnea is present. We know that the prevalence of sleep apnea in individuals who snore and have a collar size above 17 inches is around 30% (T. Young, personal communication).

As these educational activities are being put in place, we need to do research to establish and evaluate cost-effective ways to screen for sleep apnea. Such approaches could include a two-stage process involving first filling out a questionnaire and then having a simple test performed at home. The most likely test to be used for screening is measurement of overnight oxygen levels using a simple device attached to the finger, i.e., oximeter. There is some evidence of its efficacy as a screening tool[24] and a single test is likely to cost of the order of $50. Research needs to be done of the efficacy of this approach in transportation companies. It is to be realized, however, that this concept of screening for sleep apnea will likely lead to a number of new medical companies proposing that they can fill this need. Employers should be concerned about the quality of these efforts and whether the approach being advocated has been validated in rigorous studies.

As these technological developments are taking place, there will also be a need to develop fora to discuss the difficult issues that these disorders raise. Legal experts and experts in public policy need to be attracted to the issue so that the debate is fully informed with all different perspectives being involved.

In conclusion, sleep disorders likely represent a common but treatable, and hence preventable, cause of operator impairment. They, therefore, represent an opportunity for the transportation industry to improve performance. It is an opportunity that the various components of this industry should work together to take advantage of.

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