inter•noise 96
25th Anniversary Congress – Liverpool

INCE: 60

EVALUATING SLEEP DISTURBANCE: A REVIEW OF METHODS

R Smith (1), R Oyung (1), K Gregory (2), D Miller (2) & M Rosekind (3)

(1) San Jose State University Foundation, USA, (2) Sterling Software Inc, USA, (3) NASA Ames Research Center, USA

1. INTRODUCTION

Overview

This paper will provide the basic principles of sleep, summarize basic sleep structure, and describe the various methods for evaluating sleep disturbance. It will also discuss the strengths and limitations of each method.

Sleep

Sleep is a vital physiological need. Like food and water, the human body needs sleep to survive. Sleep is composed of two distinct states: non-rapid eye movement (NREM) and rapid eye movement (REM). These two states are as different from one another as sleep is from wakefulness. Overall physical and mental activity are significantly reduced during NREM sleep. NREM sleep consists of four stages (1-4). Stages 1 and 2 are considered light sleep, stages 3 and 4 are deep sleep. A person awakened in stage 1 or 2 sleep, would be relatively alert and readily respond to stimuli. A person awakened in stage 3 or 4 sleep, would require a substantially stronger stimuli before awakening. Upon awakening, the individual might be sleepy, confused, disoriented, and require more time to become alert and responsive. This phenomenon is called sleep inertia. Deep, NREM stage 3 and 4 sleep is most related to physical restoration.

In contrast, REM sleep is highlighted by high levels of mental activity, bursts of rapid eye movements and motor paralysis. REM sleep involves high levels of physical and mental activation and is most related to cognitive restoration.

Episodes of NREM and REM alternate in roughly a 90-minute cycle throughout a sleep period. In a human adult with a stable sleep/wake cycle, longer periods of NREM stage 3 and 4 occur mostly in the first third of a sleep period, while longer REM episodes occur in the latter portion.

2. SUBJECTIVE METHODS

Formal subjective methods for obtaining sleep estimates have been used for decades. This method usually involves using a paper and pencil sleep diary in which an individual answers a standardized set of questions. These often will encompass both self-report measures of sleep quantity and scales for sleep quality. Some typical questions would include: (a) time in bed, (b) the time required to fall asleep, (c) total sleep time, (d) number of awakenings, (e) how restful was the sleep period, and (f) time out of bed.

Subjective measures concerning sleep disturbances related to noise might focus on the self-report of awakenings from sleep, and an assessment of sleep quality. Specific questions could focus on the number of awakenings, how long the subject was awake, and what might have caused the awakening. Questions related to the overall sleep quality could assess whether the disturbances had significantly affected the restorative nature of the sleep period. It would also be important to obtain information on any sleep aids used by subjects such as ear plugs, medications, etc.

3. BEHAVIORAL METHODS

These methods attempt to gather empirical measures of a subject's behavioral responses. The two most widely used behavioral measures are actigraphy and response measuring devices.

Actigraphy [1] provides a 24-hour estimate of the rest/activity cycle and involves the use of a small watch-like monitor known as an actigraph worn on the non-dominant wrist. The actigraph records these cycles by using a piezoelectric crystal that generates a voltage every time the actigraph is moved and stores the output to a memory chip. It is capable of collecting continuous data for several weeks and providing rest/activity data which can be used with previously established algorithms to estimate sleep-wake patterns. Actigraphic sleep estimates can provide information on time to fall asleep, total sleep time, and number and length of awakenings. Laboratory studies have found that actigraphy can provide up to 91% correlation with physiological sleep data and have shown that the actigraph is useful in distinguishing between sleep disturbed individuals and normal control subjects [2].

Other behavioral methods include the use of pressure-sensitive mattresses [3] and devices that count responses to external stimuli. Movement and respiration can be monitored by using a pressure sensitive mattress to collect the changes in pressure during the sleep period. This involves bringing a specially designed mattress into the subject's home, connecting it to pressure transducers, and outputting resultant data onto a strip chart or computer.

The mattress is divided into four zones corresponding to head, chest, hip, and legs, each kept at a prescribed pressure. Data from the pressure transducers can be stored indicating changes in pressure in each zone. The pressure changes are a reflection of movement occurring in the prescribed zone. A study comparing pressure-sensitive mattress to polysomnography for detection of sleep apnea found a high correlation between the two methods. [4]

Stimulus studies generally involve introducing a specific probe or stimuli at various times during the sleep period and measuring the behavioral response. A typical study might include a noise event at different decibels and intervals within the sleep period. The level of noise required to awaken the subject would be measured by the presence or absence of a response.

4. PHYSIOLOGICAL METHODS

Polysomnography is the gold standard method for assessing the quantity and quality of sleep. It gives the most detailed information on sleep physiology by measuring brain activity using electro-encephalography (EEG), eye movements using electro-oculography(EOG), and muscle activity using electromyography (EMG).

Polysomnography is a complex procedure performed by a trained technologist. A routine clinical polysomnogram includes the recording of brain wave activity (EEG), eye movements (EOG), muscle activity (EMG), respiration, electrocardiogram (ECG), and oxygen saturation. Special studies may include other physiologic parameters. Brain wave activity is typically recorded using electrodes attached to the head with reference electrodes placed behind the ears. Others are placed next to the eyes to record eye movement. Two sensors are placed on the chin to detect muscle tone. These three physiologic variables (EEG, EOG, EMG) are required to differentiate the states and stages of sleep. [5]

The information from these sites is collected onto a mechanical or computerized polygraph. When viewed graphically, the electrical activity resembles wave forms. High frequency, low amplitude activity is indicative of the lighter NREM stages of sleep, stages 1 and 2. Low frequency, high amplitude activity is characteristic of the deeper NREM stages of sleep, stages 3 and 4. This type of activity is often referred to as slow wave sleep.

Polysomnography allows for the evaluation of disturbances in an individual's sleep by observing changes in the EEG, EOG, and EMG. Depth of sleep continuity can be defined by threshold responses to auditory stimuli. The effects of auditory stimuli on sleep patterns using polysomnography have also been studied [6]. It is possible to document changes in brain wave activity, eye movement, and muscle activity due to changes in environmental noise. For example, noises in the environment may have little effect on a subject in deep sleep as compared to a subject in light sleep or REM. It is important to be able to determine the stage of sleep during a noise event and document any subsequent stage changes. A noise event may cause an individual to go from deep to light sleep or have an awakening.

5. STRENGTHS AND LIMITATIONS

Subjective Methods

One advantage with subjective data is the flexibility in self-administration. A set of instructions included with a questionnaire or diary can be sent to each subject to define the parameters of the study, explain how to fill out the information, and state any deadlines for its return. They are portable, easy to use, and easy to produce. Researchers can draw on a well-established line of standardized questions. This methodology also involves minimal costs.

It is important to note that research has often found a poor correlation between subjective reports and objective measures. One of the first such studies, conducted in 1976 [7], found that insomniacs tended to overestimate sleep onset latency, misjudge the amount of time awake after sleep onset, and underestimate the amount of total sleep time. These findings have been confirmed many times. Studies of non-complaining subjects have found similar results [8].

Reporting arousals due to noise can be difficult. Commonly, the subject may not be aware of what caused the awakening. In some cases, the subject may move from a deeper stage of sleep to a lighter one without an awakening and therefore be subjectively unaware of the disturbance.

Behavioral Methods

Movement based measures can also be portable, easy to administer and more cost effective than polysomnographic methods. These measures are non-invasive and little effort is required from the subject to gather data. Many clinical and research studies have shown that the actigraph is useful in distinguishing between sleep disturbed individuals and normal control subjects. Generally, actigraphy can provide a reliable estimate of sleep quantity and quality.

These methods also have some limitations. When sleep disturbances are detected by movement, the reasons or underlying mechanisms remain unknown without a full laboratory study (i.e. polysomnography, video, etc.). Since these methods are based solely on activity, there is a chance of misclassification. If a subject is in bed, motionless, trying to fall asleep, but is physiologically awake, this inactivity may be misinterpreted as sleep. Subjective measures are often used in conjunction with behavioral methods and provide an important context for data interpretation.

Another problem in correlating these movements with disturbances due to sound is that the subject may not awaken or move due to the noise. For example, there may be a change in sleep stage, from deep to light sleep, or an arousal in the EEG, but without an accompanying movement. Physiological measures used with behavioral methods may provide more information for complete interpretation.

Physiological

Polysomnography is the most precise methodology for measuring the quantity and quality of physiological sleep. It is the only approach that physiologically identifies the moment of sleep onset, distinguishes sleep stages, detects arousals or awakenings, and quantifies total sleep time. While physiological measures have generally been limited to the sleep laboratory setting, recent technical advances in ambulatory monitoring equipment have made field research effective and reliable.

Polysomnography is the most costly to administer and the most labor intensive of the methods discussed in this paper. It requires a high degree of expertise in the administration and operation of the monitoring equipment. One subject's sleep data may contain over 100 pages of wave form activity, and special expertise is required to interpret the extensive data. Additionally, the multiple sensors placed on an individual's body can introduce some discomfort or interference that could affect the individual's sleep.

6. CONCLUSIONS

Subjective, behavioral, and physiological methods are available to measure disturbances in sleep due to noise. Although subjective methods are easy to administer, studies have shown a poor correlation between subjective and objective measures. The cost effectiveness, ease of administration, and flexibility afforded by actigraphy has supported its use in many clinical and research studies. However, these movement-based measures have their limitations. When sleep disturbances are detected by movement, the reason or underlying mechanisms remain unknown without a full laboratory study. Since these methods are based solely on activity, misclassification may occur. Polysomnography is the most comprehensive method for assessing the quantity and quality of physiological sleep, though it is more costly and labor intensive to administer than the other methods discussed herein.

It is critical that the method used to determine sleep quantity, quality, and disturbance provide the data necessary to address the study questions. By learning what methodologies are available, how different devices operate, and where strengths and limitations exist, a more informed decision can be made when constructing a study. In some cases it may be prudent to use a combination of subjective, behavioral, and physiological methods. This approach will often yield more complete results and provide a better understanding of the issues under study. For instance, the use of a subjective sleep log or diary in conjunction with an actigraph will result in a more comprehensive picture of subject rest/activity patterns than when either measure is used alone. When questions arise during actigraphic data analysis concerning why an awakening occurred, the diary may reveal substantial answers. Subjective measures are also useful for gathering preliminary study data which can then assist in the design of a more comprehensive study with behavioral or physiological measures.

It is worthwhile to check available local resources to support research activities. Most countries have accredited sleep laboratories and clinics. These are usually affiliated with local hospitals or universities and have qualified individuals who can assist with sleep related research efforts.

REFERENCES

1. Kripke et al.,. Electroencephalogr Clin Neurophysiol 44:674-678 (1978)
2. Sadeh, a. et al., Ambulatory Monitoring 1[3]:209-216 (1989)
3. Thoman EB, Glazier RC,. Sleep 10:122-129 (1987)
4. Nino-Murcia, et al., Sleep Research p.432 (1991)
5. Rechtschaffen & Kales, U.S. Government printing office, (1968)
6. M.H. Bonnet, Sleep, 1, 161-168 (1978)
7. Carskadon et al., Am J Psychiatry; 133:1382-8 (1976)
8. Lewis, SA. Br J Psychol;60:203-8 (1969)