Discuss the biological need for sleep and describe the stages of sleep.

Despite the fact that most people spend about a third of their lives asleep, till date, the biological basis for sleep remains largely a mystery to mankind. Sleep is defined as “a state of changed consciousness, or partial consciousness, from which a person can be aroused by stimulation.” (Marieb 1995) In contrast, coma is a state of unconsciousness where even the most vigorous stimuli cannot wake a person. Over the last century, specialists in the fields of psychology, psychiatry and neurology have made great advances in the study of sleep, mainly through research conducted in sleep labs. A definitive step that made this possible was the invention of the electroencephalogram (EEG) by a German psychiatrist named Hans Berger in 1929. With his discovery, he publicly announced that not only was it possible to record the feeble electric currents generated by the brain without opening the skull, it was also possible to depict them graphically onto a strip of paper. (Sabbatini 1997)

The Electroencephalogram (EEG)

With the EEG, researchers have learnt that cerebral activity is constant. Normal brain function involves continuous electrical conduction of neuronal impulses. The EEG records these ever changing but tiny electrical signals coming from the brain through electrodes placed on the scalp. These electrodes are connected by wires to a machine that measures electrical potential differences between different cortical regions. The original brain signals are minute (measured in millionths of a volt), the EEG machine amplifies the size of these electrical signals so that they can be recorded on paper or computer. The resulting patterns of neuronal electrical activity are known as brain waves. (Marieb 1995)

Brain Wave Patterns

Brain waves vary with age, sensory stimuli, brain diseases like tumours and infections, and the chemical state of the body. As a result of different genetic predispositions as well as different experiences, every person has a brain wave pattern that is as unique as their fingerprints. These complex waves can be measured in terms of amplitude and frequency. Amplitude is the voltage between the peak and the trough of a wave, measured in millionths of a volt. Amplitude rises as consciousness falls. Frequency is the number of complete waves or cycles that take place in one second; it is expressed in hertz (Hz). Based on their frequency, brain waves are grouped into four different classes: beta, alpha, theta and delta. (Horne 1998; Marieb 1995; Thibodeau et al 1996)

Beta waves are rhythmic, low amplitude waves with a frequency of 14-25 Hz. They are found when we are awake and alert. Alpha waves are low-amplitude, slow, synchronous waves that are more regular than beta waves. They have a frequency of 8-13 Hz, and usually occur when the brain is in a calm, relaxed state of wakefulness. Theta waves are irregular, medium amplitude waves with a frequency of 4-7 Hz. Theta waves are usually only present during the early stages of sleep in an adult. Though commonly found in children, they are deemed abnormal in adults who are awake. Finally, there are delta waves, which are high-amplitude waves with a frequency of 4 Hz or less. These slowest brain waves are typically found during deep sleep from which the person cannot be easily aroused. For this reason, deep sleep is also known as slow-wave sleep (SWS). The types of brain waves determine the stages of sleep. (Marieb 1995; Thibodeau et al 1996)

Stages of Sleep

Since the early 20th century, research has shown that sleep consists of several successive stages that recur throughout the night. They include four nonrapid eye movement (NREM) stage and the rapid eye movement (REM) stage. Prior to sleep is the waking stage characterized by beta waves. It is often referred to as relaxed wakefulness because this is the stage where the body prepares for sleep. One complete sleep cycle lasts about 90 to 100 minutes; thus during the course of a night, a person will experience on average 4 to 5 complete sleep cycles. (Marieb 1995; Porth 1994; Tortora et al 2000)

Nonrapid Eye Movement (NREM) Sleep

NREM sleep is the sleep from which REM sleep emerges. During NREM sleep, brain waves associated with wakefulness and alertness disappear and are replaced by increasingly slow, deep waves of inactivity. As mentioned, there are four stages of NREM sleep – Stage 1, 2, 3 and 4. Each stage lasts from 5-15 minutes.

Stage 1 (NREM)

As we begin to fall asleep, we enter Stage 1 sleep or drowsiness. Stage 1 is a transition stage between wakefulness and sleep; it is characterized by alpha waves. Relaxation begins, breathing becomes more regular, and there are slow, rolling eye movements. Thoughts flit in and out accompanied by a drifting sensation. Vital signs like body temperature, pulse rate and blood pressure are normal. The person who is sleeping may also have hypnogogic experiences such as dream-like sensations of falling, hearing voices, or seeing flashes of pictures. If stimulated in this stage, arousal is instant. Upon arousal, the person may feel as if he or she has not slept. (Marieb 1995; Porth 1994; Tortora et al 2000)

Stage 1 comprises about 2-5% of total sleep time. This stage is dramatically increased in the case of insomniacs and people who suffer from disorders that produce frequent arousals such as apnea. In normal circumstances, it takes 5-10 minutes to progress to Stage 2.

Stage 2 (NREM)

Stage 2 is a deeper sleep and accounts for about 50% of adults' sleep time. Fragmented thoughts and images may pass through the mind, the eyes may slowly roll from side to side and there is usually very little body movement. During this stage, the EEG becomes more irregular and is typically characterized by sleep spindles and K-complexes. Sleep spindles are small bursts of brain activity that occur at 12-14 Hz and lasts only 1-2 seconds. K-complexes are bursts of high frequency and high amplitude waves, which can appear spontaneously or in response to a sudden stimulus. A sleep spindle can be part of the K-complex. At this stage, arousal becomes more difficult as the body prepares to enter deep sleep. (Marieb 1995; Porth 1994; Tortora et al 2000)

Stage 3 (NREM)

Stage 3 usually occurs 20 minutes after the onset of Stage 1. It is a period of relatively deep sleep. Heart rate and respiratory rate slow down; body temperature and blood pressure also decrease. Skeletal muscles are very relaxed and dreaming often occurs. At this stage, theta and delta waves predominate, of which 20-50% are delta and the rest, theta. The EEG displays both sleep spindles and larger, lower frequency waves. It is difficult to arouse a person in this stage. (Marieb 1995; Porth 1994; Tortora et al 2000)

Stage 4 (NREM)

Stage 4 is the deepest stage of sleep. As mentioned earlier, it is also called delta sleep or slow-wave sleep (SWS) because the EEG primarily records high-amplitude, low-frequency delta waves. During this stage, body temperature, respiration, pulse and blood pressure are at their lowest levels. Skeletal muscles are relaxed, and digestive system motility increases. It is very difficult to wake a person from delta sleep, and if awaken, he or she will most likely be disoriented and slow to react. It is normally easy for he or she to return to sleep. Bed-wetting and sleep-walking occur in this stage. Contrary to popular belief, it is SWS and not REM that is the deepest stage of sleep and the most restorative. It is also SWS that a sleep-deprived person's brain craves the first and foremost. Stage 4 NREM sleep usually occurs in the first two 90 minutes sleep cycles, following which, sleep usually does not progress beyond stage 3.

The period of Stage 1-4 NREM sleep lasts 90-120 minutes, after which, the EEG pattern changes abruptly. From the slow delta waves of Stage 4, it becomes very irregular and seems to rapidly reverse through Stages 3 and 2. At this point, instead of returning to Stage 1 sleep, we enter rapid eye movement (REM) sleep. REM sleep is distinguishable from NREM sleep in terms of observable changes in physiological states, including the characteristic rapid eye movements. (Marieb 1995; Porth 1994; Tortora et al 2000)

Rapid Eye Movement (REM) Sleep

In REM sleep, the EEG depicts a desynchronized pattern of low amplitude beta waves like those that occur during wakefulness. Heart rate and blood pressure fluctuate greatly and generally increase. Body temperature also rise, and respiration becomes irregular while digestive system motility declines. The face, fingers, and legs may twitch while in men, autonomic excitation causes erection of the penis. Intense active dreaming takes place during REM sleep as a result of heightened cerebral activity, but most of the body's muscles are actively inhibited. This mixture of encephalic states of excitement and muscular immobility is the reason why REM sleep is also called paradoxical sleep. Some researchers suggest that this muscular paralysis is a device that lets the mind explore the realms of its subconscious, while preventing us from acting out our actual dream events.

The first period of REM sleep usually takes place 90 minutes after falling asleep, lasting 10-20 minutes. It recurs about every 90 minutes throughout the night, hence in a seven or eight hour sleep period, a person will experience three to five episodes of REM sleep. When the person is very tired and has just fallen asleep, the duration of REM sleep is short. As the person becomes more rested, REM periods gradually lengthen until the final one lasts about 50 minutes. Thus our longest dreams are in the hours just prior to waking up.

REM sleep accounts for approximately 20-25% of adult sleep. The percentage of REM sleep is highest during infancy and early childhood. As a person gets older, the duration of total sleep time and the percentage of REM sleep decreases. However, an increase in age is accompanied by the lengthening of the first REM stage; older people tend to enter REM sleep quicker and stay there longer. (Guyton 1981; Marieb 1995; Porth 1994; Tortora et al 2000)

Sleep Cycle

A typical night’s sleep alternates between REM and NREM sleep. After each REM period, we move back into Stage 2 sleep, and the cycle continues. Over the course of a night, we complete 4-5 cycles of sleep stages. Gradually Stage 3 and Stage 4 sleep are replaced with longer and longer periods of alternating Stage 2 and REM sleep. By the final sleep cycle of the night, we will spend about half our time in Stage 2 and half in REM.

The sleep cycle is variable and influenced by factors such as the quality, duration and onset of sleep. Sleep deprivation, irregular sleep schedule, stress and the environment all affect the progression of the sleep cycle. Sleep disorders, psychological conditions as well as the different forms of treatment used will also have an effect. (Marieb 1995; Porth 1994; Tortora et al 2000)

Neuronal Centres and Neurotransmitters Related to Sleep

NREM and REM sleep are controlled by two specific areas in the medulla and the pons. In addition to changes in brain wave patterns, the levels of neurotransmitters in these brain regions also change during sleep.

The REM sleep centre is located in the locus ceruleus of the pons. Researchers believe that during REM sleep, the excitation of this area is crucial in stimulating the reticular activating system, which in turn, produces the state of wakefulness. The nerve fibres from the locus ceruleus spread widely throughout the reticular formation as well as all regions of the diencephalon and the cerebrum. They all secrete the neurotransmitter noradrenaline at their endings; during REM sleep, norarenaline levels rise. Noradrenaline helps maintain alertness, and is thought to play a role in the arousal pattern of REM sleep. It is also believed to induce the temporary paralysis of REM sleep. (Guyton 1981; Marieb 1995)

The NREM sleep centre is found in the raphe nuclei in the pons and the medulla. This is a thin sheet of nuclei located in the midline. Nerve fibres from these nuclei are also distributed widely throughout the reticular formation and also upward into the thalamus, hypothalamus, and most regions of the limbic cortex. They also extend downwards into the spinal cord, terminating in the posterior horns. The endings of these raphe neuronal fibres secrete the neurotransmitter serotonin. During deep sleep, noradrenaline levels decline and serotonin levels rise. Serotonin is thought to be the major transmitter substance associated with the production of sleep. (Guyton 1981; Marieb 1995)

Substances that change the concentration of either noradrenaline or serotonin will affect the amount and type of sleep a person gets. Alcohol and most sleep medications like barbiturates suppress REM sleep but not NREM sleep. In contrast, some tranquilisers like diazepam (Valium) and chlordiazepoxide (Librium) reduce SWS much more than REM sleep. (Marieb 1995)

Stimulation of the hypothalamus can also lead to sleep, mainly in the preoptic and suprachiasmal areas.

The Biological Need for Sleep

Despite decades of enquiries into sleep, most researchers would agree that they have barely scratched the surface where the significance of sleep is concerned. The biological need for sleep remains largely an enigma. Nonetheless, several postulations have emerged with regards to the biological need for sleep. Of these, the most widely accepted would be the restorative theory. Writing in the 1970s, researchers Hartmann and Oswald saw NREM sleep or SWS as restorative of the physical structures of the body, while ascribing to REM sleep psychological restorative functions. In line with this theory, recent studies suggest that NREM sleep contributes to physical rest, and is essential for normal and healthy cell growth. It may bolster the immune system and be related to the rhythms of the digestive system. In contrast, REM sleep is believed to contribute to learning, psychological rest, the normal functioning of the nervous system, and long-term emotional well-being. It may also bolster memory. (Porth 1994; Webb 1979)

The Functions of NREM Sleep

One study that has attempted to elucidate the restorative function of NREM sleep showed that the secretory pattern of human anterior pituitary hormones is closely related to the sleep-waking cycle. There is a close association of hormonal secretion with a specific stage of sleep in some hormones. More specifically, studies have shown that the secretion of growth hormones (GH), responsible for general growth and protein synthesis, are directly related to SWS. GH is secreted during sleep, after meals, physical exercise and psychological stress. "However, the highest peak of plasma GH concentrations in a 24-hour period always occurs during Stage 3 and 4 [sleep]." (Takahashi 1979) This was found to be true in more than 90% of normal subjects of both sexes between 5-50 years old. The only times when this relation between GH secretion and SWS was dissociated was in pathological conditions and drug administrations. From these findings, researchers believe that SWS plays an integral role in the production and regulation of certain hormones. (Takahashi 1979)

In terms of the restorative function of sleep, there has also been another study that has shown the correlation between Stage 4 sleep and cerebral shutdown. It is said that of the various brain regions, the part most likely to need sleep would be the cerebrum. Unlike many other organs of the body, the cerebrum is unable to really rest during wakefulness. It continues working at a high rate on a state of 'quiet readiness' – always vigilant and ready to respond quickly to new situations. (Horne 1988)

Through EEG, the cerebral cortex showed significant changes during sleep. The delta EEG waves of SWS sleep, specifically Stage 4 sleep, reflected a recovery role. It is the sleep that showed the most cerebral shutdown and isolation. During this stage of sleep, the cerebrum is finally able to disengage from the sudden and random "fight or flight" demands imposed on it through environmental conditions and physical activity. In fact, it has been shown that when brainwork and cerebral metabolism have been raised during wakefulness, then the biggest impact on sleep is a need for more Stage 4 sleep. (Horne 1988)

The Functions of REM Sleep

While some sleep researchers maintain that achieving SWS is the primary reason for sleep, others would be quick to propound the need and importance of REM sleep. Volunteers constantly deprived of REM sleep have been shown to become irritable, emotionally unstable and even psychotic. Thus it can be assumed that in some unknown way, REM sleep restores both normal sensitivities and balance among the different parts of the central nervous system.

For one, through the process of dreaming, REM sleep may provide the person with the opportunity to analyse the day's events and to resolve emotional problems. Throughout history human beings have sought to understand the meaning of dreams. The ancient Egyptians believed dreams possessed oracular power while other cultures see dreams as inspirational and curative tools for increasing self-awareness and self-healing. In 1900, Sigmund Freud proposed in "The Interpretation of Dreams" that dreams were the "royal road" to the unconscious; that they revealed in disguised form the deepest elements of an individual's inner life. (Marieb 1995; Winson 1997)

Another postulation is that REM sleep is reverse learning. In 1983, Francis Crick of the Salk Institute and Graeme Mitchison of the University of Cambridge proposed the idea that the cortex when overloaded with vast amounts of incoming information, may develop false, or "parasitic" thoughts that would jeopardise the true and orderly storage of memory. According to their theory, REM sleep served to erase these accidental and meaningless communications on a regular basis, resulting in erasure or unlearning of the false information. In this way, the process maintained an orderly and efficient thinking system and reduced fantasy or obsession. (Marieb 1995; Winson 1997)

In addition to these, there is also the ontogenetic hypothesis that REM sleep stimulates the developing cerebrum. It has been observed that REM sleep is predominant in the foetus, and some researchers believe that it is here where its functions really lie. They believe that because there is little sensory stimulation in the developing foetus, REM sleep, being so akin to wakefulness, acts as a substitute to aid the development of the cerebrum. They propose that in an adult, the reduced levels of REM sleep continues to keep the sleeping cerebrum in a state of readiness so that it can react quickly when awoken once again. (Horne 1988)

Conclusion

While research and conjectures about the biological need for sleep range far and wide, there is perhaps nothing more indicative of its importance as when we are not getting enough of it. Most of us experience lack of sleep in the form of poorer concentration and diminished performance at work. However, its effects may actually be more serious. "Sleep deprivation can reduce attention and vigilance by 50 percent, decision-making ability by 50 percent, communication skills by 30 percent, and memory by 20 percent," says Mark Rosekind, board member of the Washington D.C. National Sleep Foundation (NSF). Furthermore, a 2001 survey conducted by NSF has linked sleep deprivation directly to several medical conditions, including depression (83 percent), nighttime heartburn (82 percent), diabetes (81 percent), hypertension (79 percent), and heart disease (78 percent). They also found that sleep deprivation could accelerate the aging process, lead to obesity and increase the risk of memory loss. In addition, The British Medical Association reiterates the higher levels of stress, anxiety and depression among the sleep-deprived. (Hassen 2002) Moreover, since sleep loss is cumulative in nature, sleep debt occurs. For every minute of sleep you take away from your body, your body will find a way to retrieve it. Prevention is important. Sleep is the only cure.

~ END ~

References

Guyton AC, 1981. Textbook of Medical Physiology, 6th edition. W.B. Saunders Company, Philadelphia.

Hassen F, 2002. "Sleep Deprivation: Effects on Safety, Health and the Quality of Life". Department of Radio-TV-Film, California State University, Fullerton [web page online]. Available from URL: <http://communications.fullerton.edu/facilities/tvfilm_studios/content/safety/sleep.htm>. Accessed 24 September 2002.

Horne J, 1988. Why We Sleep: The Functions of Sleep in Humans and Other Mammals. Oxford University Press, New York.

Marieb E, 1995. Human Anatomy and Physiology, 3rd edition. Benjamin Cummings Publishers, Redwood City.

Porth C, 1994. Pathophysiology – Concepts of Altered Health States, 4th edition. JB Lippincott, Philadelphia.

Sabbatini RME, 1997. "The History of the Electroencephalogram". Brain and Mind Electronic Magazine on Neuroscience [web page online]. Available from URL: <http://www.epub.org.br/cm/n03/tecnologia/historia.htm>. Accessed 24 September 2002.

Takahashi Y, 1979. "Growth Hormone Secretion Related to the Sleep and Waking Rhythm". In: Drucker-Colin R, Shkurovich M, Sterman MB (editors). The Functions of Sleep. Academic Press, New York. pp 113-145.

Thibodeau G, Patton K, 1996. Anatomy and Physiology, 3rd edition. Mosby, St Louis.

Tortora JT, Grabowski SR, 2000. Principles of Anatomy and Physiology, 9th edition. John Wiley & Sons, Inc., New York.

Webb WB, 1979. "Theories of Sleep Functions and Some Clinical Implications". In: Drucker-Colin R, Shkurovich M, Sterman MB (editors). The Functions of Sleep. Academic Press, New York. pp 19-35.

Winson J, 1997. The Meaning of Dreams. Scientific American 7:58.