Introduction to Sleep

The oldest technique used to determine whether an individual is asleep or awake involves an evaluation of behaviour and subjective experience; that is, looking at the person and/or asking, "were you asleep?" With the discovery of brainwaves (Electroencephalograms or EEG) in 1929, people were able to tell if someone was sleeping without watching or waking the person up and asking.

The electroencephalogram (EEG) is an amplified recording of the electrical activity of the brain. Originally discovered in humans by Berger in 1924 and reported by him in1929 (Berger, 1929, cited in Tyner, Knott, & Mayer, 1983), the EEG is now believed to be a recording of the "voltage summaries" of the billions of inhibitory post-synaptic potentials (IPSPs) and excitatory post-synaptic potentials (EPSPs) that impinge on cells of the cortex closest to the recording electrode (Anch, Browman, Mitler, & Walsh, 1988). It is thought that the EPSPs and IPSPs that impinge on the apical dendrites and somae of pyramidal neurons are reflected in the overall EEG pattern. **Desynchronized EEG (most visible during stages 1 and REM sleep) occurs when the number of IPSPs and EPSPs are relatively equal**, hence the small and rapid changes in the voltage summary. **Synchronized EEG (most evident during stages 3 and 4 sleep)** is produced when the number of spontaneous IPSPs and EPSPs are inequal, resulting in large and slow changes in the voltage summary.

The techniques used to record the EEG have remained virtually unchanged since the time of Berger: electrodes are affixed to scalp locations, the bioelectrical activity is amplified, and an output, called brainwaves, are recorded (usually on paper but more recently on computer disk); however, improvements in EEG recording technology and analysis have since occurred. Specifically, electrode and amplifier construction now more faithfully reproduce the bioelectrical events, and the advent of the digital computer has provided researchers with a powerful new tool which has contributed to theoretical sophistication and evolution. Despite the introduction of the digital computer within the last two

decades, the study and analysis of the EEG during sleep remains largely a "paper and eyeball" task: EEG output is visually scored for specific sleep stages according to traditionally accepted criteria (Rechtschaffen and Kales, 1968). For example, less than one in ten studies published in the journal ***Sleep*** for the year 1990 have used some form of digital computer analysis in their analysis of human EEG. The remaining studies have utilized visual sleep stage scoring, a procedure first described in 1937 by Loomis, Harvey, and Hobart. Stage scoring has been criticized for a variety of reasons, but mainly because two different people will often disagree on the sleep stage when looking at the same sleep recording. In contrast to sleep stage scoring, the EEG remains a measure of interest to sleep researchers. Researchers remain interested in EEG for the following reasons: When proper techniques are employed, analog to digital (A/D) conversion of the EEG will increase the resolution of the dependent variable and will produce a continuous measure. This continuous dependent variable is suitable for powerful parametric analysis. The EEG is a useful measure of the electrical activity of neurons, and is currently the most readily available laboratory or ambulatory technique with which to study the brain and behaviour of humans without having to open the skull.

Data Acquisition – Electroencephalography

The technology needed to faithfully reproduce the bioelectrical event occurring in the brain is impressive, and perhaps intimidating to the uninitiated. The initial link is the **electrode-electrolyte interface** (conductive gel and body fluids in the scalp both of which contain free chloride ions). This link is followed by filtration/amplification, and finally the output (i.e., paper or computer disk). Disruption at any location of the recording process will either severely reduce or eliminate the utility of the procedure; therefore, it is appropriate to begin with the electrode-electrolyte interface. The type and location of the recording electrode is not simply an arbitrary matter. The following sections will discuss this in detail.

Electrode-Electrolyte Interface

Any piece of metal affixed to the scalp (usually with collodion) with some conductive gel beneath it may be considered an electrode in the most rudimentary sense. Electrodes represent the first important junction between the generators in the brain and the EEG record itself, for it is here that the bioelectrical events are converted into electrons which will eventually constitute the polysomnogram (Tyner et al., 1983); however, any piece of metal is not adequate because the characteristics of the electrode will affect the EEG. It is important that electrodes possess minimum drift of electrode potential and a very long time constant. Consequently, electrodes constructed of particular metals (i.e., Au, Pt) or metal compounds (e.g., Ag-AgCl) possessing the quality of non-polarizability are desired. **Chloride silver disc electrodes** have the best properties of all materials and are most commonly used in research but **gold is also a useful electrode material** (they are actually gold-plated silver electrodes and not pure gold).

The **electrolyte** (conductive gel and the body fluids) beneath the electrode is typically either NaCl or KCl; that is, a "salt bridge" which will not irritate the skin. In the past, calcium chloride has been used, but this type of conductive gel has been found to be irritating, particularly for infants. Electrodes other than those placed on the surface do not require conductive gel because the subcutaneous fluid has conducting properties. Subcutaneous electrodes should never be used for EEG recordings because of the risk of spreading Hepatitis, or other diseases.

Electrode Placement and Application

A procedure, the **International 10-20 System**, has been developed to standardize the location of recording sites for EEG (Jasper, 1958). Briefly, this system is based upon measurements made at specific scalp landmarks: nasion to inion; preauricular site to preauricular site; and skull circumference. At each step, the measurements are broken down into 10 and 20 percent amounts and appropriate marks are made on the scalp; hence the name "10-20."

There are five anterior-posterior planes:

Frontal polar
Frontal plane
Coronal plane
Parietal plane
Occipital plane

Electrodes placed in each of these planes are abbreviated "Fp, F, C, P," and "O," respectively. In addition, electrodes placed over the temporal lobes are abbreviated "T." A number placed after each of the aforementioned abbreviations is used to identify precisely where the electrode is located on each plane – odd numbers indicate the left hemisphere and even numbers indicate the right hemisphere. Lower numbers are used for electrodes which lie closer to the sagittal plane (see the list of figures). By drilling holes in the skulls of cadavers, Jasper was able to discover that the 10-20 System, a method of measurement based upon percentages, provides a means by which various laboratories are able to utilize common recording sites. This standardization has greatly enhanced the degree to which inter-laboratory findings may be compared.

Once the proper electrode locations have been identified, now in standardized notation, the area beneath the electrode must be abraded to properly record the EEG. An **impedance** of between 1 kOhms and 10 kOhms is required, but an impedance of below 5 kOhms is optimal for a polysomnogram (Stern, Ray, & Davis, 1980). This may be accomplished through the use of commercially available products; however, isopropyl alcohol, fine sandpaper, and acetone may be used. Abrasion is necessary because the epidermis is essentially an insulator, and improper or inadequate abrasion will only result in the recording of **60 Hz artifact** (i.e., the frequency of AC electricity in the power mains; 50 Hz in Europe). Overzealousness must be avoided as patient discomfort may result. Once abrasion is completed, the electrode(s) may be affixed to the scalp at the exact location marked earlier.

There are a number of methods available to affix scalp electrodes: collodion; paraffin wax; and electrode paste (McGregor, 1989). Of these methods, **collodion** is the most satisfactory because it provides the most electrode stability, thereby avoiding electrical potentials introduced by the disturbance of the electrolyte. Collodion, however, is not without its drawbacks: being a mixture of ether and alcohol, it is highly flammable and prolonged intake of its fumes is hazardous. The latter hazard applies more to the experimenter than to the subject. Clearly, a well ventilated area is needed for the application of collodion. Furthermore, the use of compressed air, rather than hot air from an electric hair dryer, is a safer technique for drying the glue.

Having properly affixed the electrodes, a single pair of electrodes (a **derivation**) must be used for each recording channel. This is necessary because differential amplifiers are used to record the EEG. For a polysomnogram, either **C3-A2** or **C4-A1** should be used to score sleep stages (Rechtschaffen & Kales, 1968), but more channels are often used to acquire additional electroencephalographic data. These additional channels are often a matter of research interest although occipital leads are frequently utilized to aid in the determination of sleep onset since alpha activity is predominant there. All derivations fall into one of two categories (Tyner, et al., 1983): (1) a bipolar derivation; or (2) a referential derivation.

A **bipolar derivation** exists when any two active electrodes are selected and form an input into the differential amplifier. With the exception of A1 and A2 (placed either on the mastoid process behind the ear or on the ear lobe), all other locations of the 10-20 System are considered to be active sites. Typically, bipolar montages proceed in either an anterior-posterior direction (e.g., “double banana”) or a transverse direction, but circumferential, and transverse triangular montages may be used.

A **referential derivation** exists when any one active electrode site forms an input with an inactive electrode site. The electrode sites A1 and A2 are most often used as the reference sites, but the ear lobe and the chest are occasional sites. Examples of referential recording include **C3-A2**, **O2-A2**, and **F7-A1**. As indicated earlier, a certain

amount of latitude is permitted for choice of recording sites, and for the use of either bipolar or referential recording. With regard to referential recording, **ipsilateral** (e.g., P4-A2), **contralateral** (e.g., P4-A1), and **linked reference** sites (e.g., P4-A1+A2) may be used. Linking the reference electrodes is most useful when investigating hemispheric EEG asymmetries; linkage eliminates the likelihood that hemispheric differences in EEG are due to greater activity from only one of the mastoid sites (A1 & A2). Another advantage to linkages is that the **common mode rejection ratio** feature of the amplifier will eliminate any unwanted EKG artifact – a common artifact which must be avoided if the data are to be analyzed with a **signal transformation technique such as Fast Fourier Transforms (FFT) or Period Amplitude Analysis (PAA)**. Having properly located and affixed the EEG montage, the bioelectrical activity is now able to flow to the amplifiers as electrons.

Amplifiers

The EEG amplifiers must be able to amplify the incoming signal (from virtually D.C. to 50 Hz) a million times or more with little distortion, and must have an input impedance of several million ohms to prevent attenuation of the EEG signal (Stern et al., 1980). The amplifiers used to record the EEG are **differential amplifiers** (they only amplify the differences between two electrodes) and because of this, two or more electrodes are necessary to record one channel of EEG activity. Consequently, it is important that only electrodes which are constructed of identical material be utilized or an electrode potential will be introduced. For example, the electrode potential introduced when one Ag-AgCl electrode is paired with a gold electrode will be 1.28V (Tyner et al., 1983).

The modern EEG amplifier does not present any contentious issues in comparison to its predecessor of more than 60 years ago. Early amplifiers were capable of recording D.C. activity (i.e., "slow"), and to a lesser extent, the faster, more traditional EEG activity; however, the earlier amplifiers were plagued by baseline drift so a **high-pass filter** (i.e., a low frequency filter) was introduced to eliminate this problem (Gumnit, 1974). A **low-pass filter** (i.e., a high frequency filter) was also introduced to eliminate unwanted fast frequencies. As a result, the EEG range of interest in the modern, conventional sleep

study is from approximately 0.5 Hz (i.e., the **delta bandwidth**) to 30 Hz (i.e., the **beta bandwidth**). It should be noted that analog amplifier signal filtering is not exact and that frequencies both above and below the indicated filter values are affected by filtering.

Permanent storage of amplifier output has traditionally been a paper record produced by ink-writing **oscillographs**. Unfortunately, the pen **galvanometer** has electrical and mechanical limitations: the dynamic rage is determined by the maximum pen deflection (usually 25-35 mm) and by the sensitivity (the term, "gain," is used for paperless polysomnography). There is a ceiling on the rapidity with which it can be moved. Frequencies above 70 to 90 Hz cannot be properly recorded on the paper although the amplifier will amplify frequencies up to 1 kHz (Tyner et al., 1983).

With the continuing growth of microcomputer technology, many psychophysiologists are using paperless recording techniques for data storage. Such technology may offer superior data acquisition and analysis, but remains susceptible to the universal problem of polysomnograms – artifacts.

Artifacts

The EEG is assumed to be a measure of brainwave activity but frequently unwanted signals, both physiological and nonphysiological, are amplified and recorded during the overnight session. These unwanted signals are known as artifacts and they are capable of distorting the EEG record to the point of worthlessness. Physiological artifacts originate within muscle, the heart (EKG and Pulse artifact), the eyes, the tongue, sweat glands, and the respiratory system. Nonphysiological artifacts may be caused by 60 Hz AC activity in the power mains, electrode **"popping"**, and electromagnetic interference from radio or television waves.

With regard to the physiological artifacts, electrode placement and technique is a crucial component in avoiding this unwanted activity. Fortunately, artifacts are more frequently encountered during EEG recordings than during Polysomnographic recordings – the tongue, muscle, and eye blinks intervene less during sleep than during wakefulness.

Artifact due to EKG interference (encountered more often in overweight individuals due to greater fatty deposits on mastoids) is eliminated through the use of **double referencing** (i.e., A1+A2); both sudorific and respiratory activity may be eliminated from the EEG signal by increasing the high-pass filter, although this procedure will attenuate the amount of delta activity that is recorded.

As stated earlier, 60 Hz artifact is due to 60 Hz AC in the power mains. Ensuring that electrode impedance is below 10 kOhms (preferable below 5 KOhms) prior to recording will virtually eliminate this artifact. A good **patient ground** will also aid in eliminating 60 Hz artifact because a low resistance pathway will carry excess electrical activity. Electrode **popping** is due to either drying electrolyte, a dirty electrode, or to an old and damaged electrode. In such a case, the electrode needs to be reapplied, cleaned, or replaced, respectively. Electromagnetic interference is more difficult and expensive to rectify – the entire sleep chamber often needs to be shielded from this outside interference (Most high quality sleep chambers are shielded as a foresight). If one adheres to the above recommendations, the EEG data would be successfully recorded, and would be ready for analysis.

Data Acquisition – Phenomenology

The acquisition of phenomenological data for the measurement of sleep is much less technologically sophisticated than its bioelectrical counterpart. This approach involves questioning the individual regarding their experience, and obtaining responses in one form or another. For example, data may be gathered from either the administration of sleep logs, pencil and paper questionnaires, responses to verbal queries, or from behavioural tasks.

With regard to sleep logs, the investigator has the subject record lights-out time, sleep onset latency, number of night-time awakenings, final morning awakening time, and any other relevant information on a chart for several days or weeks. One advantage of a sleep log over paper and pencil questionnaire – and over in-lab recordings – is that the sleep log inexpensively provides the investigator with information on day-to-day variations in

sleep over a prolonged period. Unfortunately, a sleep log requires greater cooperation because it must be maintained on a daily basis (Johns, 1971). The sleep log is often used in conjunction with both the paper and pencil questionnaire, and with lectrophysiological measures.

Concerning paper and pencil questionnaires, it is standard protocol for sleep laboratories to administer sleep questionnaires (e.g., post-sleep or sleep history questionnaires) to acquire additional information about an individual's nocturnal experience. Post-sleep questionnaires frequently ask subjects to estimate sleep onset latency, total sleep length, restfulness or soundness of sleep, number of awakenings during the night, and perhaps how their sleep differed from home. With regard to sleep, the utility of paper and pencil questionnaires has been demonstrated in the literature. Monroe (1967) and Kuderian, Ogilvie, McDonnell, and Simons (1991) successfully differentiated the Polysomnographic and behavioural sleep, respectively, of "good" and "poor" sleepers based on their responses to a sleep questionnaire.

Verbal responses may be obtained either during the recording period or following the night's sleep. The former is more commonly used in experimental situations. An example of this would involve questioning the subject over a loudspeaker, "Hello SUBJECT, were you asleep or awake just before I called your name?" at the first sign of stage 1 sleep, or immediately following the first sleep spindle.

Obtaining data from behavioural tasks is typically accomplished within one of three paradigms: a **passive system** (as in "dead" switch) in which the loss of tonus either releases or depresses a thumb-switch. An **active, uncued signal system** in which the subject actively indicates perceived wakefulness by the depression of a palm-mounted thumb-switch. An **active, cued response system** whereby the subject responds to faint stimuli (usually sound) with the depression of a thumb-switch. These paradigms are most frequently used to evaluate sleep-associated alterations in EEG coincident with behavioural phenomena.

Data Analysis

The entire field of electroencephalography is based upon alterations in **voltage** (i.e., changes in amplitude on the y-axis) and/or **frequency** (i.e., changes in time which a single wave occupies the x-axis). The analysis of EEG data is accomplished visually and/or with a computer quantification/analysis program. Although a number of signal transformation techniques are available for use with a computer, visual analysis of the EEG during sleep is typically accomplished by classifying the data into a series of discrete stages according to the procedures outlined by Rechtschaffen and Kales (1968). There are advantages and disadvantages associated with both visual and computer analysis, and these will be discussed in the following sections.

EEG Bandwidth Frequencies

Human electroencephalographic frequencies are typically classified using the five following bandwidths: Delta: 0.5 Hz to < 4 Hz, Theta:4 Hz to < 8 Hz, Alpha: 8 Hz to < 12 Hz, Sigma: 12 Hz to < 16 Hz, Beta: 16 Hz to 30 Hz. Other infrequently used bandwidth frequencies found in the EEG are: Gamma 30 – 50 Hz. Undefined activity 55 – 66 Hz (60 Hz artifact). Although much remains unknown or uncertain about the neurophysiological origin of particular EEG bandwidth frequencies (Pedley & Traub, 1990), all electroencephalographers would agree that "the cerebral cortex generates all brainwaves recorded by conventional scalp EEG" (p. 130). Due to the focus of the present discussion, a description of EEG bandwidth frequencies would be much more relevant than a detailed elaboration of the putative subcortical origins of EEG during sleep and wakefulness. Suffice it to say that research has not identified any particular sleep center in the brain, but several sleep initiating areas in the forebrain and brainstem are connected to the cortex via ascending and descending projections. Research has found evidence to suggest that the solitary tract nucleus in the medulla, the nonspecific thalamic nuclei, and the anterior hypothalamus-preoptic area and basal forebrain are some of the areas involved in cortical synchrony and behavioural sleep (Jones, 1989).

Electroencephalographic research during the past 60 years has produced a greater understanding of EEG wave patterns than of their genesis (Stern et al., 1980). The scalp,

skull, and meninges are located between the electrode and the brain, but it is acknowledged that brain tissue, with billions of neurons and myriad synapses beyond that number, is responsible for the generation of the surface potentials recorded (Pedley & Traub, 1990; Speckmann & Elger, 1993). In addition to nerve cells, glial cells and cerebral spinal fluid are present. The exact function of glial cells is unknown, but they are thought to provide mechanical support, are known to generate a resting potential, and are believed to play an amplifying role in the production of the EEG.

At one time (circa 1936), the EEG was believed to be formed by action potentials in cortical neurons, but this concept was abandoned because of the improbability that spikes with a duration of 1-2 milliseconds could be synchronized to produce waves with a duration of tenths of a second or more. A subsequent proposition was that the EEG represented synchronous impulses traveling in a thalamocorticalthalamic loop. Presently, the most commonly accepted model of the origin of the EEG involves the generation and summation of PSPs (Tyner, Knott, & Mayer, 1989).

As mentioned earlier, the EEG is believed to be a recording of the "voltage summaries" of the billions of IPSPs and EPSPs (usual duration from 10-300 milliseconds) that impinge on cells of the cortex closest to the recording electrode. It is thought that the PSPs that impinge on the apical dendrites and somae of pyramidal neurons are reflected in the overall EEG pattern (Anch et al., 1988; Speckmann and Elger, 1993). These PSPs are influenced by the nerve impulses that arrive in a given area of the cerebral cortex from ascending subcortical inputs (e.g., solitary tract nuclei of the medulla, midbrain, thalamus, hypothalamus, preoptic area, basal forebrain-septum, and hippocampus) as well as by corticocortical circuits (Jones, 1989). Desynchronized EEG occurs when the number of PSPs are relatively equal, hence the small and rapid changes in the voltage summary. Synchronized EEG is produced when the number of spontaneous PSPs are inequal, resulting in large and slow changes in the voltage summary.

In normative human sleep, neuronal systems are involved in a progression from wakefulness to NREM sleep to REM sleep with 90 minutes (approximately) ultradian

NREM-REM rhythms thereafter. As indicated earlier, the EEG remains the physiological parameter most used to identify and define human sleep stages (e.g. delta sleep occurs during slow wave sleep stages 3 & 4). As a result, sleep stages (Rechtschaffen & Kales, 1968) and EEG bandwidths will be jointly discussed and will be considered as interchangeable. Prior to discussing EEG frequencies and sleep stages, the importance of synchrony will be considered.

Synchrony is used in the literature to refer to the summation of PSPs produced by neurons acting in unison. The greater the neuronal synchrony (unity) the greater the number of neurons operating in simultaneity, and the greater the energy/power/amplitude which is produced. An analogy may be useful: desynchronized EEG may be likened to a number of conversations occurring at the same time in a room; a phenomenon indicative of activity in different parts of the brain. By contrast, synchronized EEG is analogous to the occurrence of only one conversation in the room; fewer conversations, therefore less information is processed which explains why EEG synchrony is typically considered to indicate inactivity or rest whereas desynchrony indicates activation (Carlson, 1986).

Sleep Stage Scoring

When EEG data are recorded only on paper, visual scoring is the sole analysis option. Visual sleep stage scoring involves scanning each epoch (typically a page of 30 seconds duration recorded at a paper speed of 10mm/sec) and assigning the epoch to one of seven categorical variables: Wakefulness, Stage 1 sleep, Stage 2 sleep, Stage 3 sleep, Stage 4 sleep, Stage REM sleep, and Movement time (record is obscured by movement and is immediately preceded and/or followed by EEG-defined sleep).

An epoch is assigned a sleep stage score when 50 percent or more of the epoch is consistent with the criteria for that particular sleep stage (see below). When phasic events, such as **sleep spindles** and **K-complexes**, are required for a given sleep stage, these events must occur prior to the midway mark of the epoch. The reader should note that electro-oculographic (EOG) and electromyographic (EMG) measurements are made in conjunction with EEG recordings, and that these additional parameters are used to

assist in the identification of certain sleep stages such as REM sleep (Rechtschaffen & Kales, 1968).

Wakefulness, as defined by the EEG, consists of either high-frequency, low voltage desynchronous activity (beta waves, 16 Hz to 30 Hz) or 8 Hz to < 12 Hz sine wave activity known as alpha waves. Alpha waves and beta waves were first identified and name by Berger in 1929. The alpha rhythm is most prominent over the occipital cortex (Oz, O1, O2, according to 10-20 system) when the individual is relaxed with eyes closed.

The disappearance of the alpha rhythm (prior to midpoint of epoch and comprising less than 50% of total epoch) heralds the onset of stage 1 sleep; the 8 Hz to < 12 Hz activity gives way to low-voltage, mixed frequency brainwaves of 4 Hz to < 8 Hz called theta waves. At one time, the theta frequency band was subsumed within the delta range, but early researchers considered an intermediate frequency band to be necessary (Niedermeyer, 1993). As a result, the term "theta" was chosen to describe EEG within the 4 Hz to < 8 Hz range because of the presumed thalamic origin of this brainwave frequency. Vertex sharp waves may be seen in addition to the low-voltage, mixed frequency activity. Stage 1 sleep usually occupies 5-10 percent of the entire night's sleep.

After a few minutes of stage 1 sleep, a transient phenomenon such as a **sleep spindle** or **K-complex** will occur thus defining stage 2 sleep. A sleep spindle consists of 12-14 Hz EEG activity with a minimum duration of .5 seconds. A well-delineated negative component (tradition has dictated that negative is up in the world of EEG) followed immediately by a positive deflection describes the morphology of a K-complex. According to Niedermeyer (1993), sleep spindles are also known as sigma waves or sigma activity (12 Hz to < 16 Hz), and are typically characterized by a group of rhythmic waves which gradually increase and decrease in appearance (similar in appearance to a football). Unfortunately, the waxing and waning 12 Hz to < 16 Hz waves are often poorly formed. Sleep spindles are only observed in the EEG of healthy adults during stage 2 sleep, which comprises about 40-50 percent of a night's sleep. Functionally, sleep spindles and K-complexes remain a mystery with some suggesting an endogenous

arousal significance (Niedermeyer, 1993), and others suggesting evidence for bona fide sleep and loss of consciousness (Steriade & McCarley, 1990).

During stage 2 sleep, delta waves (.5-2 Hz with a minimum peak to trough amplitude of 75 μV according to Rechtschaffen & Kales, 1968; .5 Hz to < 4 Hz herein) gradually increase in occurrence with a predominance in the frontal cortex. The high-voltage, low-frequency, delta activity is the most synchronized brainwave frequency and is commonly referred to as slow wave activity. When the delta activity occupies more than 20 percent of the epoch, but less than 50 percent, the epoch is considered to be stage 3 sleep; stage 4 sleep is scored when the amount of delta activity surpasses 50 percent. Delta waves are not typically detected in the EEG of awake, healthy individuals, but occur during the "deep sleep" of normal humans. The term, "deep sleep," is derived from the heightened auditory thresholds required to elicit wakefulness from stages 3 & 4 sleep (Bonnet & Moore, 1982; Rechtschaffen et al., 1966), and make up about 10 to 25 percent of a night's sleep. Ontogenetically, human slow wave sleep develops during childhood and young adulthood, and declines with increasing age (Anch et al., 1988). Slow wave sleep is considered to serve a cerebral restorative function (Borbely, 1986; Horne, 1988), but the object of restoration has yet to be determined. The aforementioned cutoff points for stage 3 and 4 sleep are clearly arbitrary and reflect poorly on the concept of a sleep as a continuum. Indeed, it has become common practice for many researchers to combine stage 3 and 4 and simply to refer to this type of sleep as **slow wave sleep**.

Approximately 90 to 120 minutes after stage 1 sleep (following stages 2, 3 and 4), REM sleep makes its first appearance and occurs roughly every 90 minutes thereafter. The EEG of REM sleep is similar to that of stage 1 sleep: low-voltage, mixed frequency EEG. Indeed, if it were not for the additional EOG and EMG measurements, one might erroneously assume the individual to be in stage 1 sleep; hence, the commonly applied term paradoxical sleep. Early researchers (e.g., Blake, Gerard, & Kleitman, 1939) were aware of this additional, unusual stage of sleep which they termed the "null" stage, but it would be left of Aserinsky and Kleitman (1953) for identification.

With regard to the EOG and EMG measurements mentioned earlier, the EOG is characterized by slow movements during stage 1 sleep; rapid movements during stage REM sleep; and relative inactivity for the remainder of the sleep stages. The EMG is at its highest point during wakefulness and progressively decreases from stage 1 through to stage 4 sleep. The EMG is at its lowest during REM sleep, which is characterized by atonia.

Visual sleep staging, while a standardized methodological technique for describing and comparing human sleep, presents limitations (Haustein et al., 1986; Hoffmann et al., 1979). For example, visual sleep staging relies on the categorization of multiple physiological events into a small finite set of categories. Consequently, a considerable amount of information is lost in the reduction of electrophysiological data to stage categories (Hoffman et al.). Moreover, the resultant categorical data are not amenable to powerful parametric analyses. Intra-and inter-rater reliability have been reported to be less than satisfactory causing some to suggest that visual stage scoring is more of an art than a science (Kim, Kurachi, Horita, Matsuura, & Kamikawa, 1992; Monroe, 1969). The ubiquitous usage of stage scores, accompanied by terms such as "sleep architecture," has caused many researchers and clinicians to consider stage scores more as a biological fact than as a methodological convenience (Haustein et al.). In light of these shortcomings, some (Haustein et al.; Moffitt & Hoffmann, 1987) have recommended the use of digital computers which would allow the researchers to avoid some of the problems listed above.

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