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CHAPTER 3

An overview of polysomnography

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3.1. Introduction

The term 'polysomnography' (PSG) was proposed by Holland, Dement, and Raynal in 1974 to describe the recording, analysis and interpretation of multiple, simultaneous, physiological parameters. As a tool, PSG is essential in the formulation of diagnoses for sleep disorder patients and in the enhancement of our understanding of both normal sleep and its disorders (Dement and Kleitman, 1957; Dement and Rechtschaffen, 1968; Dement et al., 1973; Raynal, 1976; McGregor et al., 1978; Weitzman et al., 1980; Broughton, 1987; Guilleminault, 1987; Keenan, 1992, 1999; Guilleminault et al., 1993, 1995; Springer et al., 1996; Butkov, 2002; Carskadon and Rechtschaffen, 2000). It is a complex procedure that should be performed by a trained technologist (ASDA, 1998). Today's sleep laboratory continues to undergo technologic evolution, particularly in terms of the increased reliance on digital systems (Wong, 1996; Hirshkowitz and Moore, 2000; Penzel and Conradt, 2000) and the collection of data outside of the traditional sleep laboratory setting (ASDA, 1994; Fry et al., 1998). This evolution requires sophisticated knowledge of equipment and procedures.

This chapter is a review of the technical and clinical aspects of PSG. The reader is directed to the references (Block et al., 1985; Martin et al., 1985; ATS, 1989, 1996; AEEGS, 1994; ASDA, 1994, 1995, 1997, 1998; AARC-APT, 1995; Reite et al., 1995; AASM, 1999, 2003; IOSET, 1999; AASM, 2000; Terzano et al., 2001; AAP, 2002) for current indications and standards of practice original sources.

3.2. Indications for polysomnography

Polysomnography is used to investigate the relationship between changes in physiology, impact on sleep, and consequences of waking function, performance and behavior. Issues such as shift work, time zone change, or suspected advanced or delayed sleep phase syndrome should be taken into consideration when scheduling the study. The PSG should be conducted during the patient's usual major sleep period, to avoid confounding circadian rhythm factors.

Questionnaires regarding sleep–wake history and a sleep diary that solicits information about major sleep periods and naps are useful adjuncts to PSG (Douglas et al., 1990; Johns, 1991). Questionnaires can be used to identify and triage patients prior to laboratory testing (Hoffstein and Szalai, 1993; Flemons et al., 1994; Maislin et al., 1995; Alexander et al., 1996; Chervin et al., 2000).

A full medical and psychiatric history should be completed and made available to the technologist performing the study. Without this information, the technologist is at a loss to understand how aspects of the medical or psychiatric history may affect the study or to anticipate difficulties. Technologists must also understand what questions the study seeks to answer. This enhances the ability to make protocol adjustments when necessary, and guarantees that the most pertinent data are collected.

3.3. Prestudy questionnaire

It is not uncommon for patients, particularly those with excessive sleepiness, to have a diminished capac-

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ity to evaluate their level of alertness (Thorpy, 1992). In addition, many patients with difficulty initiating and maintaining sleep often report a subjective evaluation of their total sleep time and quality that is at odds with the objective data collected in the laboratory referred to as sleep state misperception, an ICSD diagnosis classification (ASDA, 1997a or b). For these reasons it is recommended that subjective data be collected systematically, as part of the sleep laboratory evaluation.

The Stanford Sleepiness Scale (SSS) (Appendix 2) (Hoddes et al., 1972, 1973) is an instrument used to assess a patient's subjective evaluation of sleepiness prior to the PSG. The SSS is presented to the patient immediately before the beginning of the study. It offers a series of phrases, from which to choose the one that best describes their state of arousal or sleepiness. Patients respond by selecting the set of adjectives that most closely corresponds to their current state of sleepiness or alertness. The scale is used extensively in both clinical and research environments; however, it has two noteworthy limitations. It is not suitable for children who have a limited vocabulary or for adults whose primary language is not English. In these situations a linear analog scale is recommended. One end of the scale represents extreme sleepiness and the other end alertness. Patients mark the scale to describe their state just prior to testing (see Appendix 2).

Another instrument, the Epworth Sleepiness Scale (Johns, 1991) lends information about chronic sleepiness. Patients are asked to report the likelihood of falling asleep in situations such as riding as a passenger in a car, watching TV, etc.

Patients are also asked about their medication history, smoking history, any unusual events during the course of the day, their last meal prior to study, alcohol intake, and a sleep history for the last 24 hours, including naps. Involvement of the patient in providing this information usually translates into increased cooperation for the study. A technologist's complete awareness of specific patient idiosyncrasies, in the context of the questions to be addressed by the study, ensures a good foundation for the collection of high-quality data.

3.4. Nap studies

A proposed alternative to PSG has been the nap study (to be distinguished from the Multiple Sleep Latency Test (MSLT)) (Carskadon et al., 1986; Carskadon, 1989; Thorpy, 1992). The rationale is that if a patient has a sleep disorder it will be expressed during an afternoon nap as well as during a more extensive PSG. The nap study approach has been used most frequently for the diagnosis of sleep-related breathing disorders and was proposed in an effort to reduce the cost of the sleep laboratory evaluation. The short study in the afternoon avoids the necessity of having a technologist present for an overnight study. There are serious limitations to the use of nap studies, however, including the possibility of false-negative results or the misinterpretation of the severity of sleep-related breathing disorders if the patient is sedated or sleep deprived prior to the study. When a nap study is performed it should follow the guidelines as published by the American Thoracic Society (1989):

> *Although minimal systematic data exist on the value of nap recordings, nap studies of 2 to 4 hours' duration may be used to confirm the diagnosis of sleep apnea, provided that all routine polysomnographic variables are recorded, that both non-REM and REM sleep are sampled, and that the patient spends at least part of the time in the supine posture. Sleep deprivation or the use of drugs to induce a nap are contraindicated. Nap studies are inadequate to definitively exclude a diagnosis of sleep apnea.*

3.5. Data collection

Data are collected using a combination of alternating current (AC) channels and direct current (DC) channels.

Equipment for recording polysomnograms is produced by a number of manufacturers. Each may have a distinctive appearance and some idiosyncratic features, but there is a remarkable similarity when the basic functioning of the instrument is examined.

Equipment preparation includes an understanding of how the filters and sensitivity of the amplifiers affect the data collected.

The amplifiers used to record physiologic data are very sensitive, so it is essential to eliminate unwanted signals from the recording. By using a combination of high- and low-frequency filters, and appropriate sensitivity settings, we maximize the likelihood of recording and displaying the signals of interest and decrease the possibility of recording extraneous signals. Care must be taken when using the high- and

low-frequency filters however, to ensure that an appropriate window for recording specific frequencies is established and that the filters do not eliminate important data.

3.6. Alternating current amplifiers

Differential AC amplifiers are used to record physiologic parameters of high frequency, such as the electroencephalogram (EEG), the electro-oculogram (EOG), the electromyogram (EMG) and the electrocardiogram (ECG). The AC amplifier has both high- and low-frequency filters. The presence of the low-frequency filter makes it possible to attenuate slow potentials not associated with the physiology of interest; these include galvanic skin response, DC electrode imbalance, and breathing reflected in an EMG, EEG or EOG channel. Combinations of specific settings of the high- and low-frequency filters make it possible to focus on specific band widths associated with the signal of interest. For example, breathing is a very slow signal (roughly 12–18 breaths per minute) in comparison with the EMG signal, which has a much higher frequency (approximately 20–200 Hz or cycles per second).

3.7. Direct current amplifiers

In contrast to the AC amplifier, the DC amplifier does not have a low-frequency filter. DC amplifiers are typically used to record slower-moving potentials, such as output from the oximeter or pH meter, changes in pressure in positive airway pressure treatment, or output from transducers that record endoesophageal pressure changes or body temperature. Airflow and effort of breathing can be successfully recorded with either AC or DC amplifiers.

An understanding of the appropriate use of filters in clinical PSG is essential to proper recording technique (Cooper et al., 1974; Tyner et al., 1983; Wong, 1996; Penzel and Conradt, 2000). Table 3.1 provides recommendations for filter settings for various physiologic parameters.

3.8. Calibration of the equipment

The PSG recording instrument must be calibrated to ensure adequate functioning of amplifiers and appropriate settings for the specific protocol. The first calibration is an all-channel calibration. During this calibration all amplifiers are set to the same sensitiv-

Table 3.1

Recommendations for filter and sensitivity settings for various physiologic parameters.

Channel[a]	Low-frequency filter (Hz)	Time constant (s)	High-frequency filter (Hz)	Sensitivity
EEG	0.3	0.4	35	50 (μV/cm)
EOG	0.3	0.4	35	50 (μV/cm)
EMG	5[b]	0.03	90–120	20–50 (μV/cm)
ECG	1.0	0.12	15	1 MV/cm
Index of airflow	0.15[c]	5[b]	15	[†]
Index of effort	0.15[c]	5[b]	15	[†]

Source: Modified from SA Keenan. Polysomnography: technical aspects in adolescents and adults. J Clin Neurophysiol 1992; 9:21.
EOG = electro-oculography; EMG = electromyography; ECG = electrocardiography.

[a] EEG includes C3/A2, C4/A1, O1/A2, and O2/A1. EOG includes right outer canthus and left outer canthus referred to opposite reference.

[b] If shorter time constant or higher low-frequency filter is available, it should be used. This includes settings for all EMG channels including mentalis, submentalis, masseter, anterior tibialis, intercostal, extensor digitorum.

[c] Because breathing has such a slow frequency (as compared to the other physiologic parameters) the longest time constant available, or the lowest setting on the low-frequency filter options, would provide the best signal. It is also possible to use a DC amplifier (with no low-frequency filter, time constant = infinity) to record these signals.

[†] It is common in clinical practice to index changes in airflow and effort to breathe by displaying qualitative changes in oral/nasal pressure, temperature, and chest and abdominal movement. It is well recognized that quantitative methods (such as endoesophageal pressure changes) provide a more sensitive and accurate measure of work of breathing. Ideally, a multi-method approach is used to increase confidence in detecting events of sleep-related breathing anomalies.

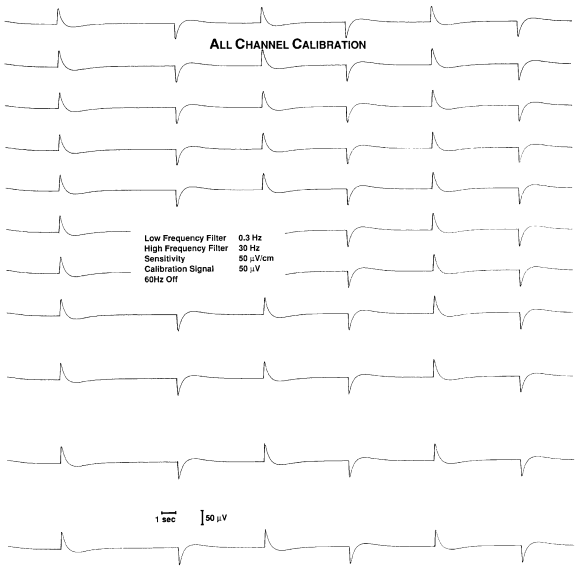


Fig. 3.1A. All channel calibration is shown. All amplifiers have the same sensitivity and high- and low-frequency filter settings.

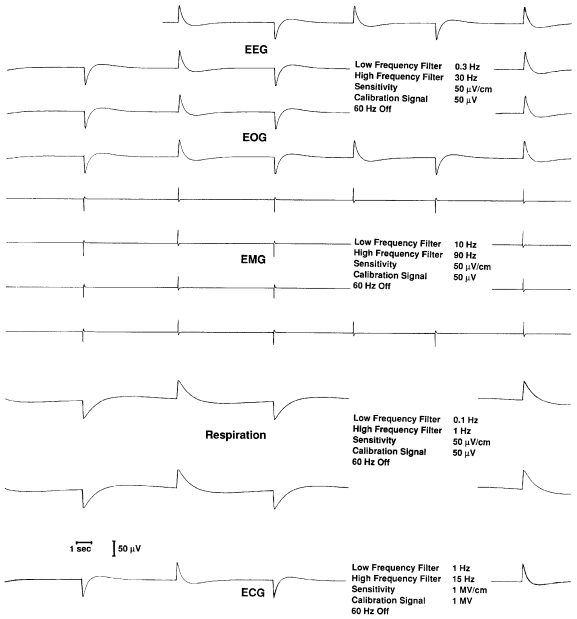


Fig. 3.1B. The montage calibration show changes in high- and low-frequency filter settings from the all-channel calibration to display a variety of physiologic signals for the polysomnograph. (EOG = electro-oculogram; EMG = electromyogram; ECG = electrocardiogram).

ity, high-frequency filter and low-frequency filter settings and a known signal is sent through all amplifiers simultaneously. The proper functioning of all amplifiers is thus demonstrated, ensuring that all are functioning in an identical fashion (see Figure 3.1A).

A second calibration is performed for the specific study protocol. During this calibration amplifiers are set with the high-frequency filter, low-frequency filter and sensitivity settings appropriate for each channel; the settings are dictated by the requirements of the specific physiologic parameter recorded on each channel (see Table 3.1, Figure 3.1B). The protocol calibration ensures that all amplifiers are set to ideal conditions for recording the parameter of interest. Filter and sensitivity settings should be clearly documented for each channel.

3.9. Data display and analysis

The process of sleep stage scoring and analysis of abnormalities is accomplished by an epoch-by-epoch review of the data.

Historically, a common paper speed for analog polysomnography was $10\,\mathrm{mm\,s^{-1}}$, providing a 30-s epoch (another widely accepted paper speed was $15\,\mathrm{mm\,s^{-1}}$, which gave a 20-s epoch length). An expanded time base may be necessary to visualize EEG data, specifically the spike activity associated with epileptic discharges. Compressed displays of greater than 30-s screen for EEG should be avoided because they compromise an adequate display of EEG data. Data such as oxygen saturation, respiratory signals, or changes in penile circumference, however, can be more easily visualized when display time is compressed to 2–5 minutes per screen. A major advantage of the digital systems lies in the ability to manipulate the display after data collection. A brief discussion of digital systems appears later in this chapter.

3.10. The study: electrode/monitor application process

The quality of the tracing generated depends on the quality of the electrode application (Tyner et al., 1983; IOSET, 1999). Before any electrode or monitor is applied the patient should be instructed about the procedure and given an opportunity to ask questions. The first step in the electrode application process involves measurement of the patient's head. The International Ten–Twenty System (Jasper, 1958) of electrode placement is used to localize specific electrode sites (Figure 3.2). The following sections address the application process for EEG, EOG, EMG and ECG electrodes.

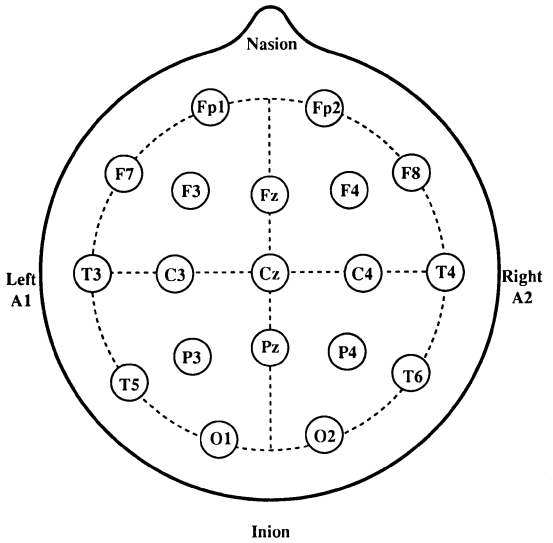


Fig. 3.2. The complete 10–20 system of electrode placement.

3.11. Electroencephalography

The EEG probably reflects local potential changes that occur on pyramidal cell soma and large apical dendrites of pyramidal cell neurons. The EEG is not likely the reflection of action potentials of the neurons (Walczak and Chokroverty, 1999).

To record EEG, the standard electrode derivations for monitoring EEG activity during sleep are C3/A2 or C4/A1, and O1/A2 or O2/A1, but in many situations there may be a need for additional electrodes. For example, to rule out the possibility of epileptic seizures during sleep, or the presence of any other sleep-related EEG abnormality, it may be necessary to apply the full complement of EEG electrodes according to the International 10–20 System (Appendix 3).

For recording EEG, a gold cup electrode with a hole in the center is commonly used. Silver–silver chloride electrodes are also useful to record EEG, though they may have limitations such as increased maintenance (evidenced by the need for repeated chloriding) and the inability to attach these electrodes to the scalp.

The placement of C3, C4, O1 and O2 are determined by the International 10–20 System of Electrode Placement. Reference electrodes are placed on the bony surface of the mastoid process. A description of the measurement procedure appears in Appendix 4.

There are a variety of methods used to attach electrodes. The collodion technique (Tyner et al., 1983; Cross, 1992) has long been an accepted and preferred method of application for EEG scalp and reference electrodes. This technique ensures a long-term placement and allows for correction of high (over 5000 ohms) impedances, after application. Other methods using electrode paste and conductive medium are acceptable and sometimes necessary in certain conditions.

3.12. Electro-oculography

The EOG is a reflection of the movement of the corneo–retinal potential difference within the eye. The retina is negative with respect to the cornea. Thus, the eye exists as the potential field within the head, which serves as the volume conductor for that field. It is important to recognize that EOG as described here is not measuring eye muscle potentials changes (Walczak and Chokroverty, 1999).

An electrode is typically applied at the outer canthus of the right eye (ROC) and is offset 1 cm above the horizontal. Another electrode is applied to the outer canthus of the left eye (LOC) and is offset by 1 cm below the horizontal. The previously mentioned A1 and A2 reference electrodes are used as follows: ROC/A1 and LOC/A2. Additional electrodes can be applied infraorbitally and supraorbitally for either the right or left eye. The infraorbital and supraorbital electrodes enhance the ability to detect eye movements that occur in the vertical plane and can be particularly useful in the MSLT (Raynal, 1976; Keenan, 1999; Mitler et al., 2000) (Figure 3.3).

EOG electrodes are typically applied to the surface of the skin with an adhesive collar.

3.13. Electromyography

The EMG recording represents the summation of activity taking place on many individual motor end plates (Walczak and Chokroverty, 1999).

A gold cup or a silver–silver chloride electrode attached with an adhesive collar is used to record EMG activity from the mentalis and submentalis muscles. At least three EMG electrodes are applied to allow for an alternative electrode, in the event that artifact develops in one of the others. The additional electrode can be placed over the masseter muscle to allow for detection of bursts of EMG activity associated with bruxism (Figure 3.4).

Additional bipolar EMG electrodes are placed on the surface of the anterior tibialis muscles to record periodic limb movements in sleep (Coleman et al.,

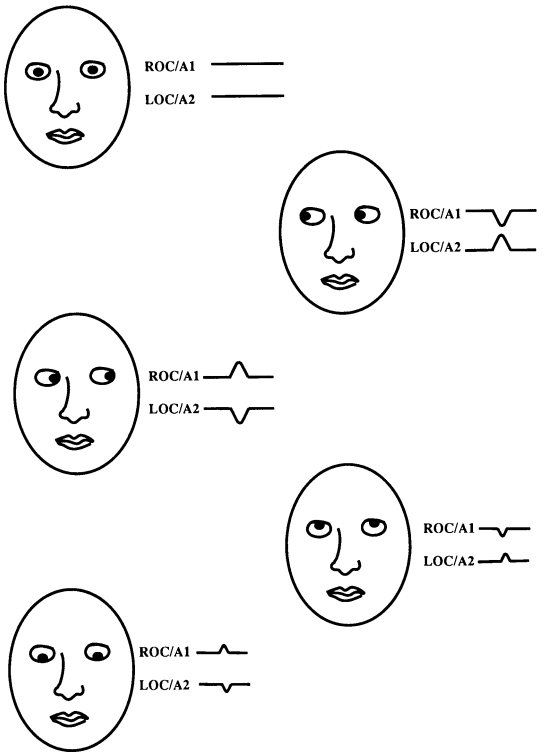


Fig. 3.3. The recording montage for a two-channel EOG demonstrates out-of-phase signal deflection in association with conjugate eye movements. Schematic diagram shows placement of the electromhyography (EMG) electrodes to record activity from the mental, submental, and masseter muscles. (ROC, LOC = outer canthus of the right and left eye, respectively; GND = ground (earth).)

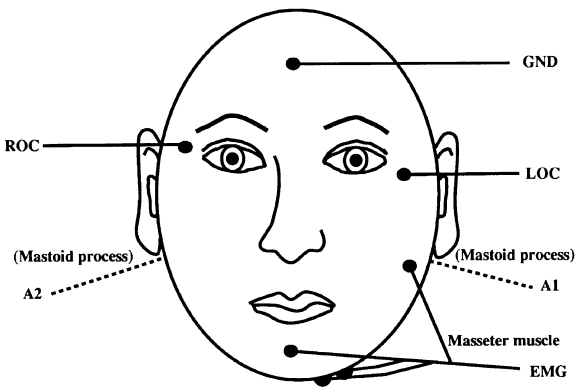


Fig. 3.4. Schematic diagram shows placement of the electromyography (EMG) electrodes to record activity from the mental, submental and masseter muscles. (ROC, LOC = outer canthus of the right and left eye, respectively; GND = ground (earth).)

1980) and on the surface of the extensor digitorum muscles if REM sleep behavior disorder (Schenk et al., 1986) is suspected.

3.14. Electrocardiography

There are a variety of approaches for recording the ECG during PSG. The simplest approach involves use of standard gold cup electrodes. However, disposable electrodes are also available.

ECG electrodes are applied with an adhesive collar to the surface of the skin just beneath the right clavicle and on the left side at the level of the seventh rib. A stress loop is incorporated into the lead wire to ensure long-term placement.

3.15. Monitoring breathing during sleep

It is necessary to record airflow and effort to breathe, and it is with these two measures that breathing irregularities can be detected. There are many sophisticated technical advances on the horizon, but the following describes common clinical practice.

It is well recognized that the pneumotachograph is the gold standard for measuring airflow. However, it is customary for many clinical studies to rely on qualitative methods to index airflow during sleep. Historically, thermistors or thermocouples were used, while presently a more accepted practice is to record change in pressure to indicate airflow (AASM, 1999).

Respiratory inductive plethysmography (RIP) is often thought of as a reliable, non-invasive measure of work of breathing. If calibrated, it can give a measure of changes in tidal volume. There have been reports of difficulty maintaining calibration for the duration of the study. Piezo crystals embedded into adjustable belts worn around the chest and abdomen reflect changes in association with effort to breathe, and are commonly used. There are numerous ways to index work of breathing, including but not limited to: intercostal and/or diaphragmatic EMG and impedance pneumography.

A quantitative measure of work of breathing is endoesophageal manometry (German and Vaughn, 1996). For greater reliability and validity, multiple methods of monitoring airflow and effort of breathing should be used.

Commercially available devices also allow for non-invasive blood gas monitoring during sleep. These measures are essential in assessment of the severity of the sleep-related breathing disorder.

3.16. Gastroesophageal reflux studies

It is common for PSG to include monitoring of endoesophageal pH when patients complain of reflux or waking with a choking sensation (Orr et al., 1982). Commercially available devices allow for the recording of changes in pH at the level of the distal esophagus during sleep. Events of reflux and the 'clearing time' or time necessary to return to normal acid levels can be demonstrated and correlated with other physiologic events or EEG arousals.

3.17. Quality control

Before recording, electrodes should be visually inspected to check the security of their placement and an impedance check should be obtained and documented. Adjustment should be made to any EEG, EOG, ECG or chin EMG electrode with an impedance greater than 5000 ohms. Impedances of 20 000 ohms are acceptable for limb EMG recordings (Bonnet et al., 1993).

3.18. Physiologic calibrations

Physiologic calibrations are performed after the electrode and monitor application is complete. This calibration allows for documentation of proper functioning of the electrodes and other monitoring devices, and provides baseline data for review and comparison when scoring the PSG. The specific instructions given to the patient for this calibration include:

- Eyes open, look straight ahead for 30 seconds.
- Eyes closed, look straight ahead for 30 seconds.
- Hold head still, look to left and right, up and down. Repeat.
- Hold head still, blink eyes slowly, five times.
- Grit teeth, clench jaw, or smile.
- Inhale and exhale.
- Hold breath for 10 seconds.
- Flex right foot, flex left foot.
- Flex right hand, flex left hand.

As these instructions are given to the patient, the technologist examines the tracing and documents the patient's responses. When the patient stares straight ahead for 30 seconds with eyes open, the background EEG activity is examined. As the patient looks right and left the tracing is examined for out-of-phase deflections of the signals associated with recording the EOG. Out-of-phase deflection occurs if the inputs to consecutive channels of the polygraph are ROC/A1 for the first EOG channel and LOC/A2 for the second. It is also important, when the patient closes the eyes, to observe the reactivity of the alpha rhythm seen most prominently in the occipital EEG (O1/A2 or O2/A1); usually alpha is best visualized when the patient's eyes are closed. The patient is also asked to blink five times.

The mentalis/submentalis EMG signal is checked by asking the patient to grit the teeth, clench jaws or yawn. The technologist documents proper functioning of the electrodes and amplifiers used to monitor anterior tibialis EMG activity by asking the patient to flex the right foot and the left foot in turn. If REM sleep behavior disorder is suspected, additional electrodes should be applied to the surface of the skin above the extensor digitorum muscles of each arm. Patients are asked to flex their wrists while the technologist examines the recording for the corresponding increase in amplitude of the EMG channel amplitude.

Inhalation and exhalation allow for examination of channels monitoring airflow and effort of breathing. A suggested convention is that inhalation causes an upward deflection of the signal and exhalation a downward deflection. It is most important that the signals on all the channels monitoring breathing are in phase with each other to avoid confusion with paradoxical breathing. The technologist should observe a flattening of the trace for the duration of a voluntary apnea.

If the 60- or 50-Hz notch filter is in use, a brief examination (2–4 seconds) of portions of the tracing with the filter in the 'off' position is essential. This allows for identification of any 60- or 50-Hz interference that may be masked by the filter. Care should be taken to eliminate any source of interference and to ensure that the 60- or 50-Hz notch filter is used only as a last resort. This is most important when recording patients suspected of having seizure activity, because the notch filter attenuates the amplitude of the spike activity seen in association with epileptogenic activity. If other monitors are used, the technologist should incorporate the necessary calibrations.

The physiologic calibrations enable the technologist to determine the quality of data before the PSG begins. If artifact is noted during the physiologic calibrations, it is imperative that every effort be made to correct the problem; the condition is likely to get worse through the remaining portions of the recording. The functioning of alternative (spare) electrodes should also be examined during this calibration.

When a satisfactory calibration procedure is completed and all other aspects of patient and equipment preparation are completed, data collection can begin. This is referred to as 'lights-out' and time should be clearly noted.

3.19. Monitoring recording: documentation

Complete documentation for the PSG is essential. This includes patient identification (patient's full name and medical record number), date of recording and a full description of the study. The names of the technologist performing the recording should be noted and any technologists involved in preparation of patient and equipment. The specific instrument used to generate the recording should be identified. This is particularly useful in the event that artifact is noted during the analysis portion (scoring) of the sleep study.

Specific parameters recorded on each channel should be clearly noted, as should a full description of sensitivity, filter and calibration settings for each channel. The time of the beginning and end of the recording must be noted, as well as specific events that occur during the night. Usually a predetermined montage is available as a simple software selection. Any changes made to filter and for sensitivity settings should be clearly noted.

The technologist is also responsible for providing a clinical description of unusual events. For example, if a patient experiences an epileptic seizure during the study, the clinical manifestations of the seizure must be detailed: deviation of eyes or head to one side or the other, movement of extremities, presence of vomiting or incontinence, duration of the seizure and postictal status. Similar information should be reported on any clinical event observed in the laboratory, such as somnambulism or clinical features of REM sleep behavior disorder. Physical complaints reported by the patient are also noted.

3.20. Trouble shooting/artifact recognition

In general, when difficulties arise during recording, the troubleshooting inquiry begins at the patient and follows the path of the signal to the recording device. More often than not, the problem can be identified as a difficulty with an electrode or other monitoring device. It is less likely that artifact is the result of a problem with an amplifier. If the artifact is generalized (i.e., on most channels) then the integrity of the ground electrode and the instrument cable should be checked. If the artifact is localized, i.e., on a limited

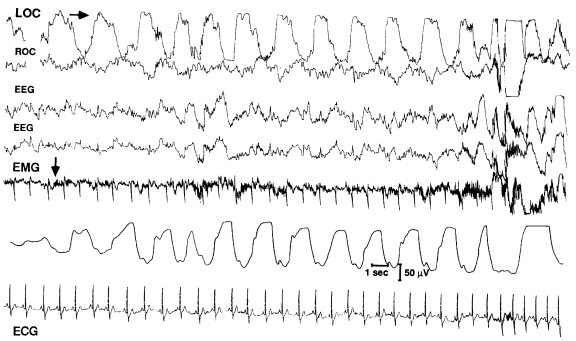


Fig. 3.5. Artifact in LOC channel (LOC/A1) can be localized to the left outer canthus electrode. The EEG channels in the trace are C3/A2 and O2/A1. Since the artifact does not appear in the O2/A1 channel the artifact is localized to the LOC electrode. The electrode placement may be insecure or the patient may be lying on the electrode and producing movement of the LOC electrode in association with breathing. Additional artifact is noted in the EMG channel. This signal is contaminated with ECG artifact and the intermittent slower activity as well as the wandering baseline are most likely due to a loose lead. The ECG channel also shows a pattern consistent with a loose electrode wire.

number of channels, then the question should be, which channels have this artifact in common and what is common to the channels involved? The artifact is probably the result of a problem located in an electrode or monitoring device that is common to both channels. If the artifact is isolated to a single channel, the source of artifact is limited to the inputs to the specific amplifier, the amplifier itself, or to the ink-writing system for the channel.

Figures 3.5–3.13 depict some frequently encountered artifacts seen during PSG.

3.21. Ending the study

Clinical circumstances and laboratory protocol dictate whether the patient is awakened at a specific time or allowed to awaken spontaneously. After awakening, to end the study the patient should be asked to perform the physiologic calibrations to ensure that the electrodes and other monitoring devices are still functioning properly. The equipment should be calibrated at the settings used for the study, and finally, the amplifiers should be set to identical settings for high- and low-frequency filters and sensitivity and an all-channel calibration should be performed. This is essentially the reverse of the calibration procedures mentioned for the beginning of the study.

A subjective evaluation is made by the patient. The patient is asked to estimate how long it took to fall

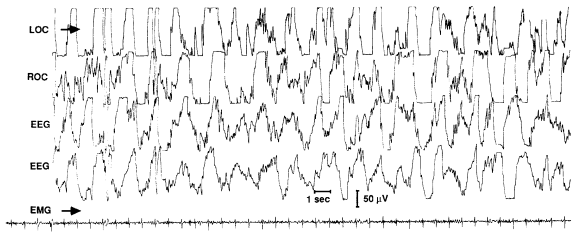


Fig. 3.6. This figure illustrates the blocking artifact seen with inappropriate sensitivity settings. This can be alleviated by decreasing sensitivity. If adjustments to sensitivity are made they should be clearly noted and should be made on all channels displaying EEG data. It is common procedure to calibrate the equipment with decreased sensitivities (i.e., $100\,\mu v\,cm^{-1}$) for children's studies or increasing sensitivity (i.e., $30\,\mu v\,cm^{-1}$) for older patients. Typically, sensitivity settings are not changed frequently during the recording (as they may be in routine EEG). As a result it is not uncommon to see this artifact when the patient enters slow-wave sleep. This is not a common problem with digital systems because of the user's ability to manipulate sensitivity after collection.

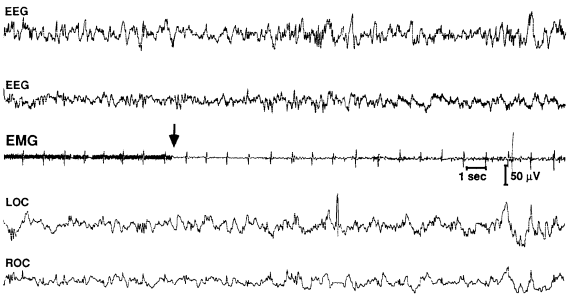


Fig. 3.7. A 60-Hz artifact exists in the EMG channel in this tracing. At the arrow the 60-Hz filter is turned on. However, there is continued evidence of difficulty with electrodes on this channel, as evidenced by the ECG artifact and occasional spike-like activity. Turning on the 60-Hz filter is not the correct response to eliminate the artifact. If possible, the technologist should switch to an alternative electrode or fix the one involved.

asleep, the amount of time spent asleep, and if there were any disruptions during the sleep period. Patients should report on quality of sleep and the level of alertness upon arousal.

It is also worthwhile for the sleep laboratory staff to know how patients intend to leave the laboratory. A patient who has a severe sleep disorder should avoid driving. An arranged ride or public transportation should be used, particularly if the patient has withdrawn from stimulant medications for the purpose of the study.

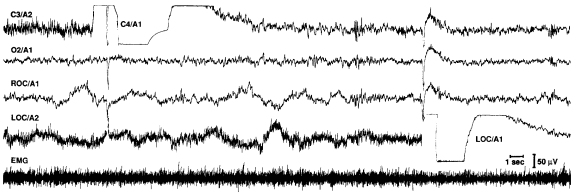


Fig. 3.8. The high-frequency (probably EMG) artifact noted in the C3/A2 and LOC/A2 channels can be localized to the A2 electrode. This problem can be solved by switching to the alternative reference (A1) electrode. A high-amplitude discharge is noted during the switch from C3/A2 to C4/A1 and LOC/A2 to LOC/A1. This can be avoided by placing the amplifier in standby mode while making the change.

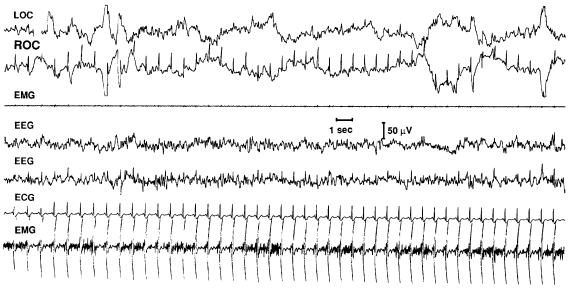


Fig. 3.9. The ROC channel (ROC/A1) and the second EEG (O2/A1) channels are contaminated with ECG artifact. The artifact can be identified by aligning the spike-like activity noted in channels with the R wave on the ECG channel. It is localized to the A1 electrode because it is seen in both ROC/A1 and O2/A1 channels and A1 is common to both channels. It should be noted that the high-amplitude ECG artifact, seen in the EMG channel below the ECG channel, is unavoidable. This artifact is due to the proximity of EMG electrodes to the heart, which creates a robust signal superimposed on the intercostal EMG signal.

3.22. The final report

The interpretation of the PSG is a process involving review of clinical presentation, history, as well as parametric analysis of the polysomnogram. The variables listed in Table 3.2 are ones most commonly used to inform the interpretation and create the final report.

3.23. Digital systems

Within the past two decades digital systems have made it possible to manipulate data after recording and to permit extraction of otherwise inaccessible information. Digital systems provide flexibility in the manipulation of filter settings, sensitivities, and change in the display of montages after collection. The first digital EEG systems

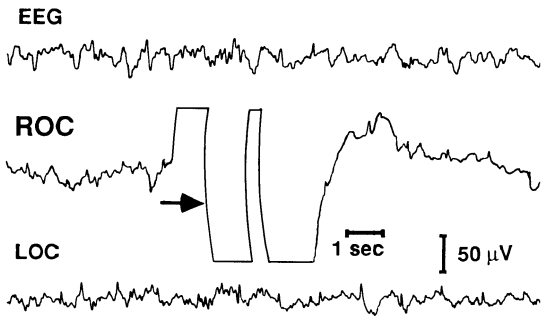


Fig. 3.10. The high-amplitude deflection in the ROC (ROC/A1) channel is associated with an electrode artifact commonly referred to as an 'electrode pop'. This can be the result of a compromised electrode placement or insufficient electroconductive gel under the electrode. When this artifact is observed the electrode involved should not be trusted to give reliable data.

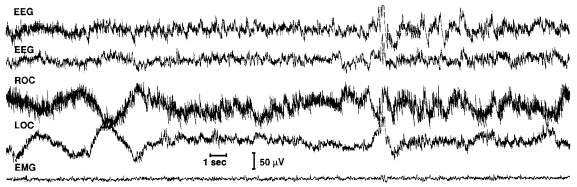


Fig. 3.11. There is a generalized, high-frequency activity superimposed upon the EEG and EOG channels. This is most likely secondary to muscle activity. The EMG channel shows only artifact.

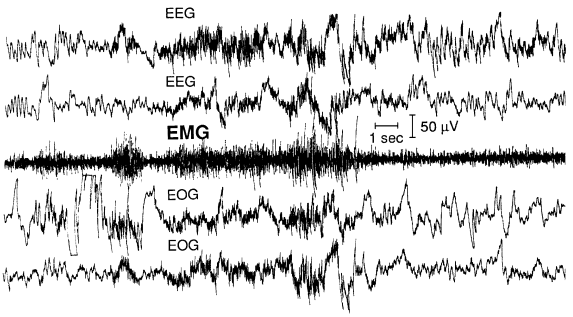


Fig. 3.12. This burst of high-frequency artifact, superimposed on the EEG and EOG channels, is due to a brief movement on the part of the subject. As in Figure 3.10, this is a superimposition of EMG activity on the EEG and EOG channels. It should also be noted that in the first EOG channel there is an electrode pop. The EMG channel in this tracing is of good quality and should be compared to Figure 3.10.

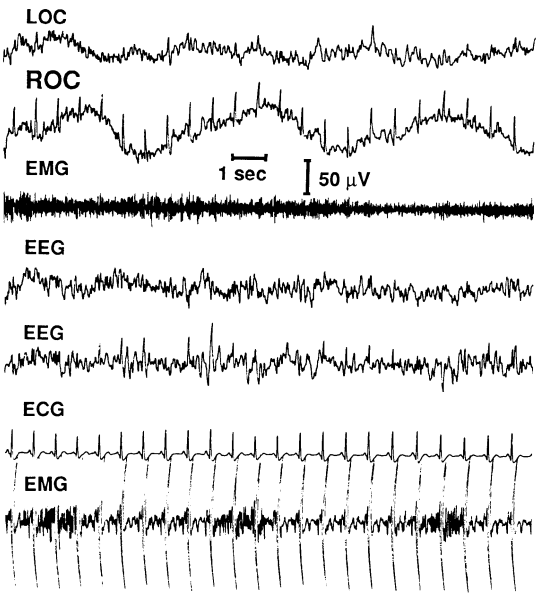


Fig. 3.13. A high-amplitude, slow artifact is noted in the ROC (ROC/A1) channel. This is most likely associated with the patient's breathing and is secondary to a loose electrode or the patient lying on the right side and disturbing the electrode in synchrony with breathing. A relatively high-amplitude ECG artifact is also seen. The artifact can be localized to the ROC electrode. The EMG tracing noted at the bottom of this example is an intercostal EMG. The high-amplitude ECG spike in this channel is impossible to eliminate, however, the brief bursts of EMG activity can be noted in association with the artifact seen in the ROC/A1 channel. This lends further evidence that the artifact noted in the ROC electrode is probably associated with breathing inasmuch as the bursts of intercostal EMG activity are seen in association with the effort of breathing.

became available in the late 1980s and caused a revolution in electroencephalography and polysomnography (Wong, 1996; IOSET, 1999; Penzel and Conradt, 2000). This revolution has been primarily in making the static format of analog system data more flexible.

Significant advantages of digital systems include: auto-correction of amplifier gains, self-diagnostic tests of amplifier functions, and the software controlled in-line impedance testing. The use of the computer has facilitated storage of data, manipulation of data after collection, and the presentation of different views of the data. Both analog and digital systems require electrodes and other sensors be applied with the greatest of care. Ideally, calibration procedures should be performed to document and ensure the collection of high-quality data

Table 3.2

Definitions of PSG variables.

Lights out	Time	Clock time when the technologist turns the lights out for the patient to go to sleep
Lights on	Time	Clock time when the technologist turns the lights on to end the study
SO	Time and/or epoch #	Sleep onset. Operational definitions vary, but commonly used definition for sleep onset is first of 3 consecutive epochs of stage 1 or the first epoch of any other stage of sleep
Latency to SO	Min	Time from lights out to the first of 3 continuous epochs of stage 1 or any other stage of sleep in minutes
Latency to S1	Min	Time from lights out to the first epoch of Stage 1 sleep in minutes
Latency to S2	Min	Time from lights out to the first epoch of Stage 2 sleep in minutes
Latency to SWS	Min	Time from lights out to the first epoch of Stage Slow Wave Sleep in minutes (Stages 3 or 4)
Latency to REM	Min	Time from sleep onset to the first epoch of Stage REM sleep in minutes
Stage 1	%	The percentage of time spent in stage 1. Calculated by taking the entire total sleep time (TST) and dividing it into the time spent in Stage 1 sleep
Stage 2	%	The percentage of time spent in stage 2. Calculated by taking the entire total sleep time (TST) and dividing it into the time spent in Stage 2 sleep
Stage SWS	%	The percentage of time spent in SWS. Calculated by taking the entire total sleep time (TST) and dividing it into the time spent in SWS
Stage REM	%	The percentage of time spent in stage REM. Calculated by taking the entire total sleep time (TST) and dividing it into the time spent in REM sleep
Stage MT	%	The percentage of time spent in Movement Time. Calculated by taking the entire total sleep time (TST) and dividing it into the time spent in stage Movement Time
Average O2 sat	%	The average oxygen saturation for the entire night
Low O2 sat	%	The lowest oxygen saturation for the entire night
TS1	Min	Total number of minutes spent in stage 1
TS2	Min	Total number of minutes spent in stage 2
TREM	Min	Total number of minutes spent in stage REM
TMT	Min	Total number of minutes spent in stage Movement Time
TRT (TIB)	Min	Total Recording Time (Time in Bed). Calculated by determining the amount of time from lights out to lights on
TST mins:	Min	Total Sleep Time. The amount of time spent sleeping in minutes
TWT mins:	Min	Total Wake Time. The amount of time spent awake in minutes
SE	%	Sleep Efficiency. The amount of time spent sleeping divided by the total time in bed (TIB)
WASO	Min	Wake After Sleep Onset. The amount of time spent awake after sleep onset in minutes
OSA	#	The total number of obstructive sleep apnea events during the night
CSA	#	The total number of central sleep apnea events during the night
HYP	#	The total number of hypopneas during the night
AHI	#	Apnea Hypopnea Index. Calculated by adding the apneas and hypopneas during the night and dividing it by total sleep time (events per hour)
RDI	#	Respiratory Disturbance Index. Calculated by adding all respiratory events during the night and dividing it by total sleep time (events per hour)
AI	#	Apnea Index. Calculated by taking the number of apnea events during the night and dividing it by total sleep time (events per hour)

at the beginning and end of the recording. Knowledge of the specifics of the equipment and of the physiology of interest is important to ensure accurate signal processing.

In digital systems it is rare to encounter breakdown of any mechanical component – most frequently encountered problems have to do with the disk drives or cables. The most important things to avoid for trouble-free operation are mechanical shock, dust or static electricity.

An important factor for understanding digital PSG systems is the concept of sampling rate. Sampling rate can be understood as the frequency with which the signal is reviewed (sampled) for conversion to a digital signal. The minimum acceptable sampling rate for EEG, EOG and EMG in PSG is 100 Hz when using a 35-Hz filter. A 200-Hz sampling rate is required for a 70-Hz high filter setting (AEEGS, 1991).

Another issue unique to digital systems is the accuracy or precision of recordings. The resolution of the signal is a function of the number of binary bits used to represent the digital values. Readers will recall that a bit is a value of 1 or 0. Eight bits is 2 to the 8th power or 256. For example, if we assume an EEG voltage over 256 microvolts, from negative 128 microvolts to positive 128 microvolts this would result in a resolution using an 8-bit system of 1 microvolt difference being represented in 1 bit of change. The 8-bit system is a system which represents the least amount of precision. A 12-bit system is the accepted minimum for sleep recording (Hirshkowitz and Moore, 2000). This provides a range of values between −2048 and −2047. The 12-bit successive digital values represent a 0.0625 microvolt change. The 12-bit representation is far more precise and reflects a smaller change in the signal. (It is interesting to note that the equivalent precision of paper-tracings is approximately 6 bits. The decreased precision for analog systems is a function of the limitation in the amount of paper available for one channel and pen thickness.)

Also to be considered is the display resolution, which is determined by the resolution of the monitor. The screen used for reviewing the data must be at least 20 inches in size, and display a resolution of 1280 × 1024 pixels (flicker free, i.e., 75-Hz monitor scan rate) (Hirshkowitz and Moore, 2000).

3.24. Digital recording samples

The following figures (Figs. 3.14–3.17) are examples of digital data used with permission of the author and publisher (Butkov, 1996).

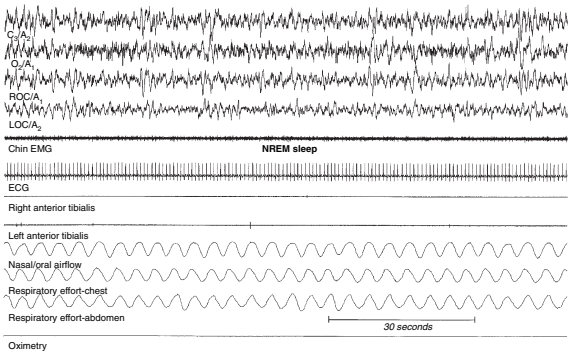


Fig. 3.14. Digital record sample. Digital record sample of NREM sleep using time-scale compression. Digital data can be further compressed to display several epochs on a screen simultaneously. The sample above, and the recordings shown in Figures 3.15–3.17 have been compressed to accommodate four epochs of data (2 min) to a page. This type of display offers the scorer or interpreter a general overview of the sleep recording, as well as a practical method of counting any prominent sleep-related events such as obstructive apneas, hypopneas or body movements. The resolution of the data is inadequate, however, for precise EEG evaluation or sleep-stage scoring. This sample shows a normal respiratory pattern during NREM sleep, without any apparent evidence of arousal, movement, or other form of sleep disturbance. (ROC, LOC = outer canthus of the right and left eye, respectively; EMG = electromyography; ECG = electrocardiography.) (Reproduced with permission from Butkov, 1996.)

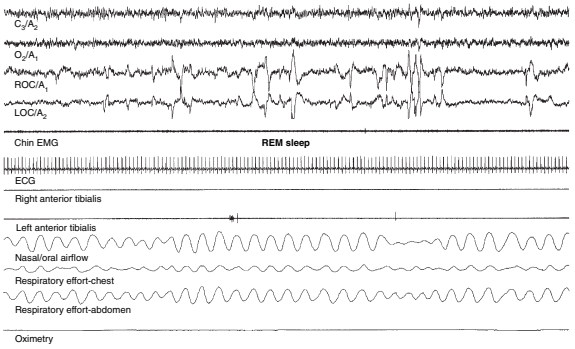


Fig. 3.15. Digital record sample of REM sleep. Although altered by time-scale compression, the sleep-stage pattern seen in the above sample can readily be identified as REM. Note the mild respiratory irregularity, which is a normal variant of REM sleep physiology. (ROC, LOC = outer canthus of the right and left eye, respectively; EMG = electromyography.) (Reproduced with permission from Butkov, 1996.)

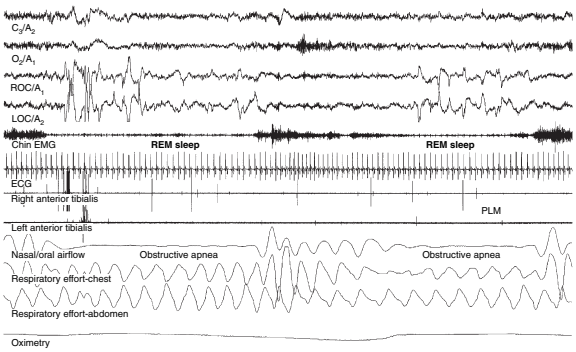


Fig. 3.16. Digital record sample of obstructive apneas. This sample shows a compressed display of repetitive obstructive apneas, occurring during REM sleep. As noted before, these represent the extreme end of the sleep-disordered breathing continuum. In the example above, all the features of classic obstructive sleep apnea are present, including distinct paradoxic (out-of-phase) respiratory effort, instances of complete cessation of airflow, subsequent EEG arousals and cyclic O_2 desaturations. (ROC, LOC = outer canthus of the right and left eye, respectively; EMG = electromyography; ECG = electrocardiography.) (Reproduced with permission from Butkov, 1996.)

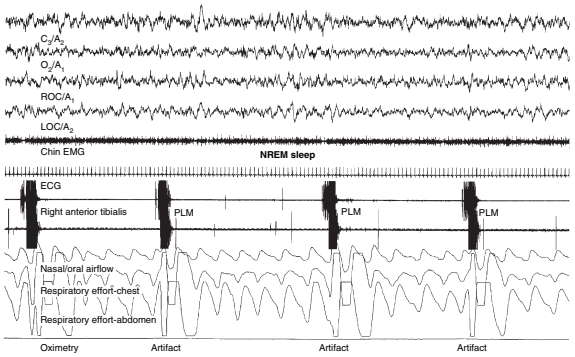


Fig. 3.17. Digital record sample of periodic limb movements. As described previously, periodic limb movements often generate artifacts in the respiratory channels that appear similar to cyclic hypopneas. This sample shows a compressed version of the characteristic pattern of periodic limb movement (PLM), recorded by the right and left anterior tibialis electromyography (EMG). Note that the respiratory channel artifact appears almost identical to the cyclic hypopneas seen in the preceding sample. (ROC, LOC = outer canthus of the right and left eye, respectively; EMG = electromyography; ECG = electrocardiography.) (Reproduced with permission from Butkov, 1996.)

3.25. Summary

Throughout its evolution PSG has proven a robust tool for enhancing understanding of sleep and its disorders. It is an essential diagnostic procedure.

PSG is complex and labor-intensive. It requires specialized technical skills and knowledge of normal sleep and sleep disorders. Technologists need to be experts with equipment, competent in dealing with medically ill patients, and capable of dealing with emergencies that may be encountered in the sleep laboratory. They must also be skilled enough to work in many circumstances outside of the traditional laboratory setting.

Our field faces many challenges. Evaluation of sleep disorders must be made readily available to millions of sleep-disorder patients lacking diagnosis and treatment (Phillipson, 1993; Young et al., 1993, 1997). Cost-effectiveness in sleep health care and maintenance of high-quality evaluation and treatment remain important challenges. Digital systems can facilitate data storage, manipulation and analysis provided the user is knowledgeable of both instrumentation and the physiology of interest.

Appendix 1
Template for 24-hour sleep/wake log

This log should be completed by the patient for a period of 2 weeks prior to the study.

	Date			Date			Date	
Time	Awake	Asleep	Time	Awake	Asleep	Time	Awake	Asleep
12:00			12:00			12:00		
13:00			13:00			13:00		
14:00			14:00			14:00		
15:00			15:00			15:00		
16:00			16:00			16:00		
17:00			17:00			17:00		
18:00			18:00			18:00		
19:00			19:00			19:00		
20:00			20:00			20:00		
21:00			21:00			21:00		
22:00			22:00			22:00		
23:00			23:00			23:00		
24:00			24:00			24:00		
01:00			01:00			01:00		
02:00			02:00			02:00		
03:00			03:00			03:00		
04:00			04:00			04:00		
05:00			05:00			05:00		
06:00			06:00			06:00		
07:00			07:00			07:00		
08:00			08:00			08:00		
09:00			09:00			09:00		
10:00			10:00			10:00		
11:00			11:00			11:00		
Exercise			Exercise			Exercise		
Treatment			Treatment			Treatment		
Sleep quality			Sleep quality			Sleep quality		
Medications			Medications			Medications		
Comments			Comments			Comments		

For each hour of the day:

- indicate sleep or wake time with an (X)
- indicate naps with an (N)
- indicate periods of extreme sleepiness with an (S)

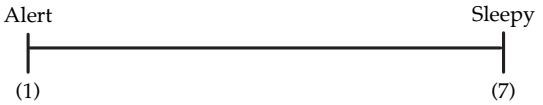
Appendix 2
Subjective evaluation of sleepiness

Stanford Sleepiness Scale (Hoddes et al., 1972, 1973)

(1) Feeling active and vital; alert; wide awake.
(2) Functioning at a high level, but not at peak; able to concentrate.
(3) Relaxed; awake; not at full alertness; responsive.
(4) A little foggy; not at peak; let down.
(5) Fogginess; beginning to lose interest in remaining awake; slowed down.
(6) Sleepiness; prefer to be lying down; fighting sleep; woozy.
(7) Almost in reverie; sleep onset soon; lost struggle to remain awake.

Linear Analog Scale

Ask patient to make a mark on the scale that corresponds to state prior to testing.



Appendix 3

Suggested montage for recording sleep-related seizure activity for a 12-channel study

(1) Fp1 – C3
(2) C3 – O1
(3) Fp1 – T3
(4) T3 – O1
(5) Fp2 – C4
(6) C4 – O2
(7) Fp2 – T4
(8) T4 – O2
(9) EMG – submentalis–mentalis
(10) Right outer canthus – left outer canthus
(11) Nasal/oral airflow
(12) ECG.

Suggested montage for recording sleep-related seizure activity for a 21-channel study

(1) Fp1 – F3
(2) F3 – C3
(3) C3 – P3
(4) P3 – O1
(5) Fp2 – F4
(6) F4 – C4
(7) C4 – P4
(8) P4 – O2
(9) Fp1 – F7
(10) F7 – T3
(11) T3 – T5
(12) T5 – O1
(13) Fp2 – F8
(14) F8 – T4
(15) T4 – T6
(16) T6 – O2
(17) EMG mentalis–submentalis
(18) Right outer canthus/A1
(19) Left outer canthus/A2
(20) Nasal/oral airflow
(21) ECG.

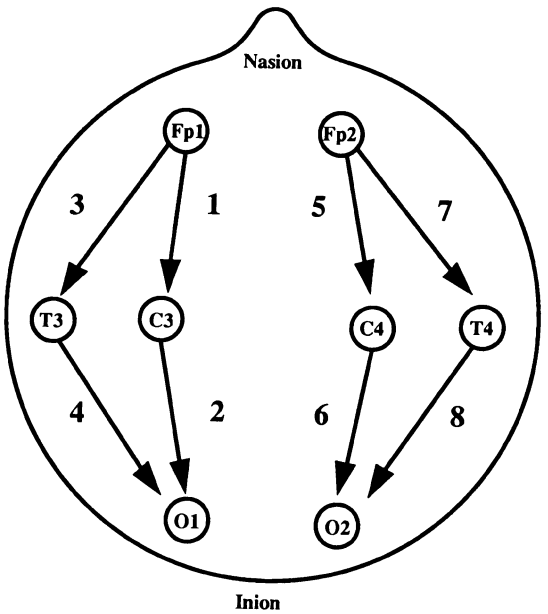


Fig. 3.A2. Suggested montage to be used to screen for possible seizure activity during sleep. Use of wide inter-electrode distance affords for a global view of EEG activity and conserves the channels. To more adequately localize epileptogenic activity a full complement of electrodes should be used. For a more comprehensive review of montages the reader is referred to *Standard EEG Montages* as proposed by American EEG Society Guidelines 1980 No. 7, Grass Instruments.

Appendix 4
Measuring the head for C3, C4, O1 and O2

Before measuring the head, it is helpful to make an initial mark at the inion, the nasion, and the two preauricular points.

(1) Measure the distance from the nasion to inion along the midline through the vertex. Make a preliminary mark at the midpoint (Cz). An electrode will not be placed on this spot, but it will be used as a landmark.
(2) Center this point in the transverse plane by marking the halfway point between the left and right preauricular points. The intersection of marks from steps 1 and 2 give the precise location of Cz.
(3) Reposition the measuring tape at the midline through Cz and mark the points 10% up from the inion (0z) and nasion (Fpz).
(4) Reposition the measuring tape in the transverse plane, through Cz, and mark 10% (T3) and 30% (C3) up from the left pre-auricular point and 10% (T4) and 30% (C4) up from the right preauricular point.
(5) Position the tape around the head through Fpz, T3, Oz, and T4. Ten percent of this circumference distance is the distance between Fp1 and Fp2 and between O1 and O2. Mark these four locations on either side of the midline.
(6) The second marks for O1 and O2 are made by continuing the horizontal mark for Oz. Do this by holding the tape at T3 and T4 through Oz, and extend the horizontal mark to intersect the previous O1 and O2 marks.
(7) To establish the final mark for C3, place the tape from O1 to Fp1 and make a mark at the midpoint of this line. When extended, this mark will intersect the previous C3 mark. Repeat on the right side for C4.

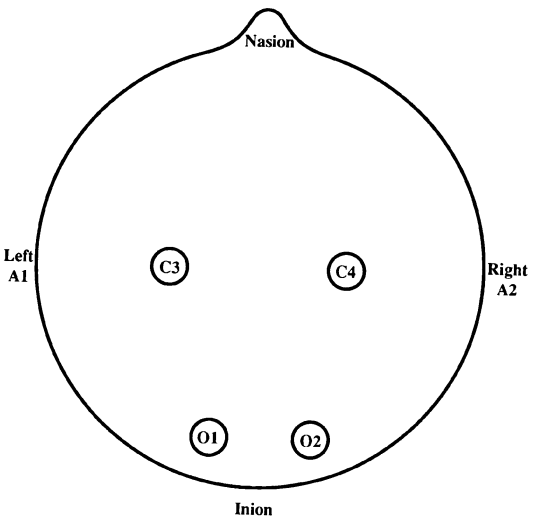


Fig. 3.A3. The international 10–20 EEG electrode placement for sleep recordings are shown.

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