47. Polygraphy

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Polygraphy denotes the simultaneous recording of several physiological and/or behavioral variables. The main reasons for the simultaneous recording of several variables are to obtain information on behavioral aspects and to differentiate artifacts in the electroencephalographic (EEG) data. These objectives usually do not require precise representation; in many instances, the relevant information concerns only the occurrence of a certain phenomenon or is easily obtained from clearly discernible characteristics of a variable. Therefore, most polygraphic data of interest in EEG studies can be obtained using simple recording methods that allow appreciable distortion of the original data. If, however, the polygraphic variables are of primary concern, then sophisticated and precise recording methods are necessary. In view of the techniques used and the interpretation of the recorded data, these methods go far beyond the simple polygraphic methodology commonly applied to EEG studies. This chapter discusses these simple methods and presents a number of examples of variables that are of interest in certain EEG studies. A classic survey of variables of interest in polygraphic studies and of corresponding recording methods can be found in *Manual of Psychophysiological Methods,* edited by Venables and Martin (1967a).

In practice, polygraphic recordings are made with an EEG apparatus; this may be of primary interest for determining the temporal relations between the EEG and the other signals, which reflect different physiological functions and/or behavioral states. Unfortunately, the frequency characteristics and the magnitude ranges of many signals of interest for polygraphic studies fall outside those provided by a conventional EEG recording system; moreover, they might not be recordable due to the electrical characteristics of the input circuit of the EEG recorder. Such signals, therefore, require special provisions, such as the use of specialized preamplifiers or input couplers to obtain an adaptation or a conversion; in this way, the recording of such signals can be carried out with the EEG apparatus. Many variables of interest in polygraphic studies, such as blood pressure, respiratory parameters, temperature, and electrodermal signals, vary slowly as a function of time; therefore, their recording requires highly sensitive universal DC amplifiers that are equipped with means of sensitivity control and adjustable high- and low-pass filters for selection of the appropriate frequency response. Modern EEG recorders have low sensitivity auxiliary input terminals that also permit direct current (DC) recording; these inputs can be used to record other signals of sufficiently large amplitude (for example, in Fig. 47.8, the traces indicated by EDG, STIM, BUTTON PRESS, and TIME CODE). When the EEG is used to record different physiological and/or behavioral variables simultaneously, employing separate recording systems, the time relations between the various types of signals must be preserved by using a form of time indexing or time marking on both recording media.

Cardiovascular Variables

Electrocardiogram and Heart Rate

There are several reasons for recording the electrocardiogram (ECG) simultaneously with the EEG. It may be desirable in specific cardio- or cerebrovascular studies. In most cases, however, the ECG recording is not intended to carry out a vascular study but only serves as an indicator of ECG artifacts in EEG records or as a general parameter of vegetative functions; in these latter circumstances, one is mainly interested in the heart rate. An ECG can be recorded perfectly using an EEG system because the electrical characteristics of its input circuit and the provisions commonly available for adjustment of frequency response and gain are adequate. The bandwidth required for appropriate ECG recording goes from 0.8 to 60 Hz; the recording sensitivity required is approximately 1 mV/cm using conventional ECG electrode placements. When the ECG electrodes are placed on the chest wall, a higher sensitivity may be necessary. The subject's behavioral activities might lead to artifacts in the ECG record, owing to muscular activity or electrode motion. The latter can be reduced significantly by using an appropriate type of electrode, such as cup electrodes with a jelly bridge between skin and electrode surface. Interference caused by electromyographic potentials can be minimized by choosing electrode positions carefully and lowering the high-frequency response of the recording system (20 Hz; −3 dB) in order to attenuate the high-frequency electromyogram (EMG) potentials. High-frequency filtering can be obtained by means of the EEG apparatus's adjustable high-frequency filters.

Heart rate recording is best carried out by using a series of pulses generated at the top of clearly distinguishable R waves of the ECG. If, however, owing to less favorable electrode positions, the R wave cannot be easily distinguished, extra signal processing must be applied. This processing may consist of high-pass filtering and/or the introduction of a refractory period, during which the instrument is insensitive. Commercially available heart frequency meters or heart rate counters usually have such provisions. Heart rate measurements may be given in terms of the number of beats over a certain period of time (heart rate, HR) or in terms of heart period (HP), the average interval between a number of successive heartbeats $\left(\overline{T} = \frac{1}{N}\sum_{n=1}^{n} T_{int}(n)\right)$. Because HR and

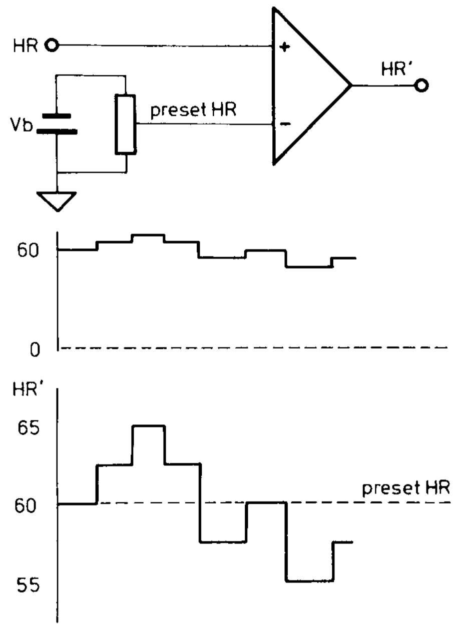

Figure 47.1. Method for recording instantaneous heart rate (HR); the momentary heart period (HP) value, transformed into HR, is plotted in relation to an adjustable preset mean HR value.

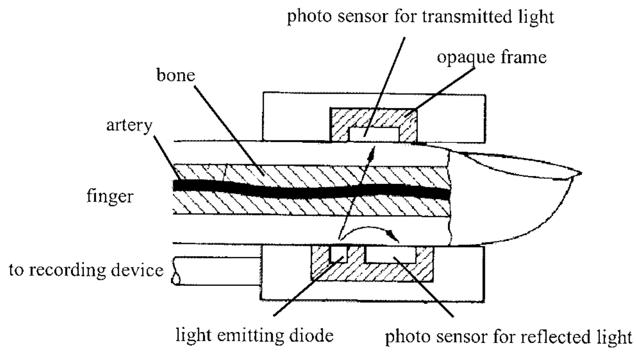

Figure 47.2. Principle of finger photoplethysmography for transmission and reflexion of light.

HP are reciprocal, the instrument, although calibrated in terms of heart rate, may have a meter deflection or another output signal proportional to T_{int} the interval between successive heartbeats. In the available instruments, heart rate is more commonly presented than heart period. In some applications of polygraphy, the main interest is not in the nominal HR, but rather in heart rate changes and the relation to other physiological, psychological, or behavioral variables. So that relatively small HR changes can be distinguished, the recording is best carried out with a preadjusted preset HR value. The model given in Fig. 47.1 demonstrates a simple method for subtracting a preset value from the HR meter's electrical output.

Plethysmography

Plethysmography is the measurement of the variations in organ or limb volume due to changes in the quantity of blood it contains. Because such volume changes are related to increased or decreased blood flow, plethysmographic methods can be used to obtain estimates of the mean blood flow rate and of pulsatile and transient flow changes. Plethysmography may be of interest in psychophysiological studies because mental processes and behavioral responses are often accompanied by changes in such cardiovascular parameters as blood flow, accompanied by measurable changes in limb volume. Continuous measurement of the latter is known as pulse volume plethysmography; under certain restricted conditions, an index of the blood flow rate can also be obtained in this way (Melrose et al., 1954). In most psychophysiological studies, however, the variable of interest relates to changes in blood volume and in blood volume pulses. The most common methods for measuring limb volume changes are pneumatic and photoelectric. Pneumatic methods are the more complicated and are not suited to psychophysiological studies. Therefore, although providing more precise information, they are much less frequently used in polygraphy. Figure 47.2 shows the principle of finger photoplethysmography. Two photo sensors measure the transmission and reflection of the light emitted from a light emitting diode. The fraction of transmitted light through the tissue and the fraction of reflected light from the tissue depend on the amount of blood in the tissue. Extensive discussions of the measuring principles, amplifier recorder requirements, and recorded waveforms have been provided by Lader (1967) (pneumatic plethysmography) and Weiman (1967) (photoplethysmography).

Impedance plethysmography of the thorax for impedance cardiography is the basis for noninvasive beat-to-beat monitoring of the stroke volume (Gratze et al., 1998). An electric current is introduced into the thorax and the corresponding voltage is measured. The ratio of voltage to current yields the impedance (Z) that varies (in a very simplified model) with the amount and distribution of blood in the thorax. Based on the ECG, the phonocardiogram (PCG) and impedance cardiogram (ICG), the stroke volume can be determined noninvasively (Fig. 47.3).

Blood Pressure

The catheter-manometer system is, at present, the fundamental method for continuous accurate measurement of the full arterial pressure waveform. It is, however, an invasive procedure and should be avoided unless the introduction of a catheter into an artery is absolutely necessary. The Riva-Rocci-Korotkoff method (using an upper arm cuff and a stethoscope) is noninvasive and commonly used, but it does not provide continuous blood pressure information. However, most automatic methods developed for determining blood pressure have been based primarily on the Riva-Rocci-Korotkoff method. For instance, Roy and Weiss (1962) described a technique for providing intermittent determinations of the systolic and diastolic blood pressure obtained over several heartbeats. Such systems have also become commercially available. The method indicated above, however, is sensitive to motion artifacts and not continuous.

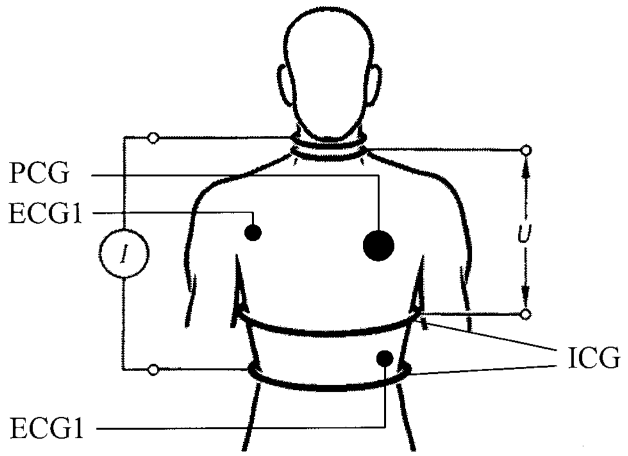

Figure 47.3. Principle of impedance cardiography. (Adapted from Gratze, G., Fortin, J., Holler, A., et al. 1998. A software package for non-invasive, real-time beat-to-beat monitoring of stroke volume, blood pressure, total peripheral resistance and for assessment of autonomic function. Comp. Biol. Med. 28:121–142.)

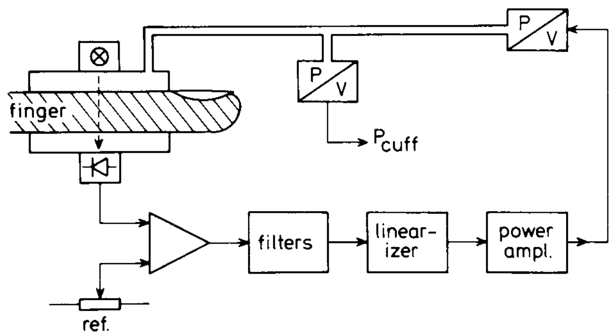

Figure 47.4. Block diagram of a system for noninvasive continuous recording of blood pressure based on the Penaz principle. (From Wesseling, K.H., van Bemmel, R.A., van Dieren, A., et al. 1978. Two methods for the assessment of hemodynamic parameters for epidemiology. Acta Cardiol. 33:84–87).

Penaz (1973) developed an important improvement in the noninvasive determination of blood pressure, using continuous measurement of the blood pressure in the finger. This method uses a finger cuff. By means of a servosystem the cuff pressure is maintained equal to the arterial pressure. This is achieved by minimizing arterial diameter changes using a photoelectric plethysmographic feedback method. The working principle is shown in the block diagram of Fig. 47.4. The further development and evaluation of methods based on this approach (Reeben and Epler, 1975; Wesseling et al., 1978) are of great interest to those interested in the continuous measurement and recording of beat-to-beat diastolic, systolic, and mean arterial pressure. This is indicated in Fig. 47.5 by the similarity between continuous blood pressure and curves recorded simultaneously by way of noninvasive and invasive methods.

The noninvasive blood pressure measurement was first applied during anesthesia (Wesseling et al., 1986) and was also used for long-term sleep monitoring in patients with systemic hypertension and sleep-related breathing disorders (Penzel et al., 1991a). The new system gives valuable results if the position of the finger cuff is carefully controlled. An example of blood pressure recordings combined with respiratory measurements is displayed in Fig. 47.6. A review of noninvasive continuous blood pressure measurements is found in Ruddel and Curio (1991) and more recently in Parati et al. (2003).

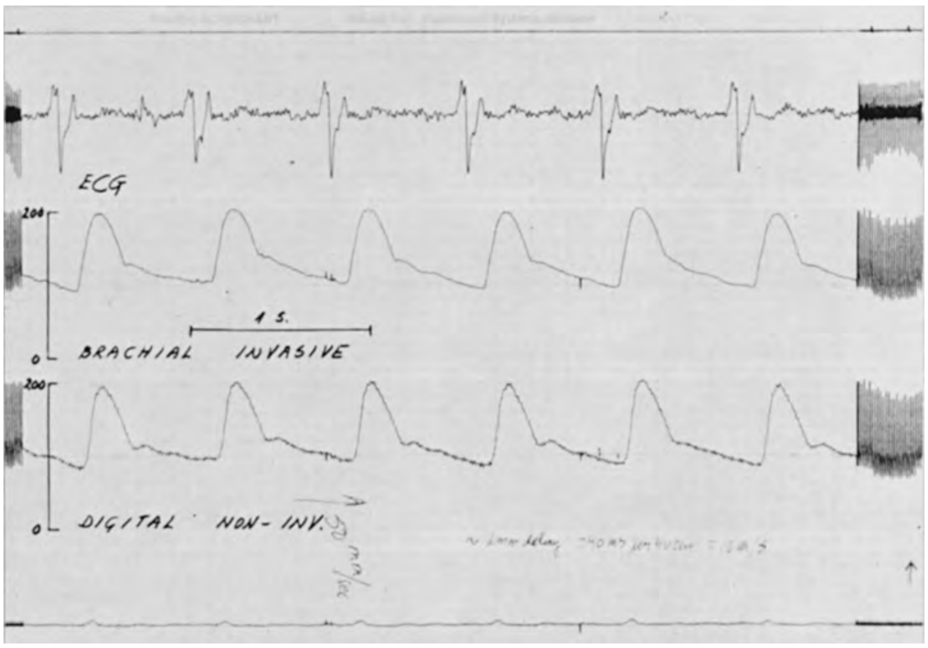

Figure 47.5. Example of a comparison of continuous recordings of blood pressure, simultaneously obtained by an invasive (intra-arterial) and a noninvasive method. The latter was performed according to the method introduced by Penaz.

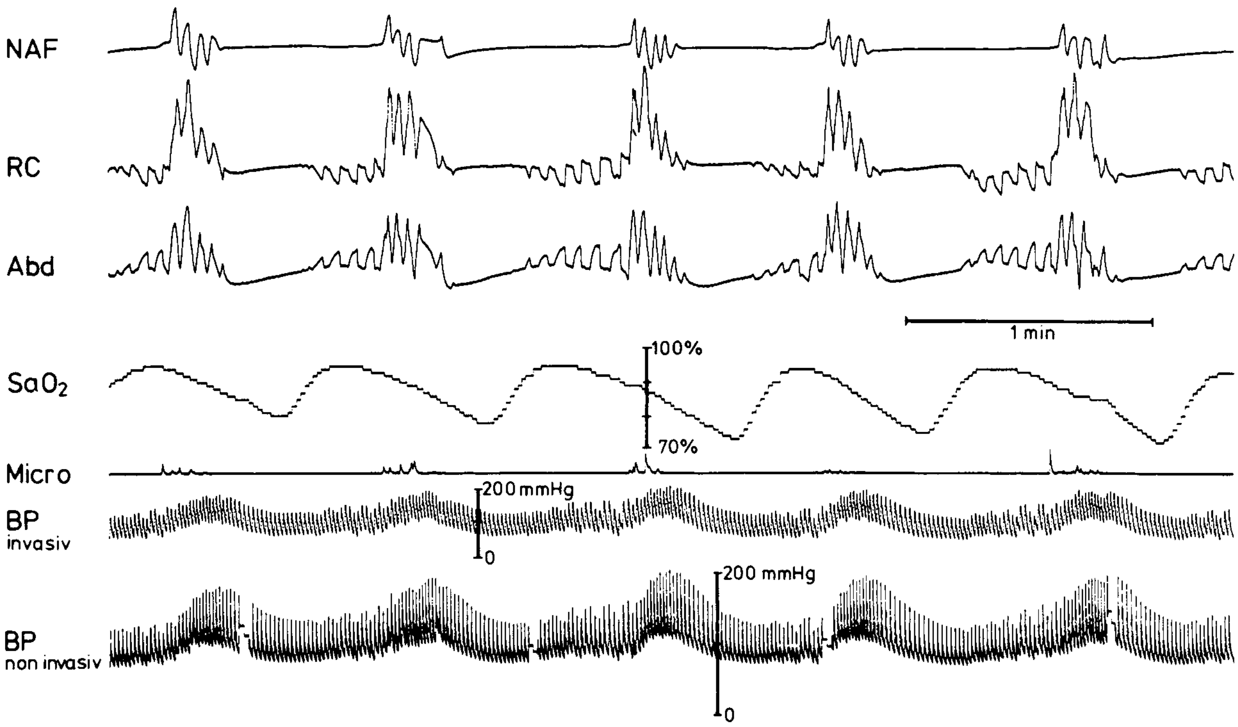

Figure 47.6. Recording of a patient with obstructive apneas and systemic hypertension. The trace of nasal airflow (NAF) shows complete cessation of respiratory flow, whereas rib cage (RC) and abdominal (Abd) movement show obstructive efforts. Noninvasive (FINA-PRES) and invasive BP were recorded in parallel. SaO_2, oxygen saturation; Micro, snoring noise. (From Penzel, T., Ducke, E., Peter, J.J., et al. 1991a. Non-invasive monitoring of blood pressure in a sleep laboratory. In *Non-invasive Continuous Blood Pressure Measurement,* Eds. H. Ruddel and I. Curio. Frankfurt am Maim: Peter Lang.)

The capacity for measuring acute and immediate changes in autonomic, EEG, and hemodynamic physiological variables during different sleep stages on a continuous basis has played an important role in enabling us to understand the interplay between changes in EEG and changes in circulatory variables and in autonomic neural functions. In this way the possibility of recording simultaneously with the EEG, heart rate (HR) variability, and blood pressure (BP), among other cardiovascular physiological variables, has advanced our understanding of mechanisms linking sleep and cardiovascular physiology (Murali et al., 2003).

Respiration

The polygraphic recording of respiration patterns is usually carried out to obtain information on frequency or changes in inhalation depth. Changes in thoracic volume due to respiratory movements are usually estimated in terms of changes in the perimeter of the chest; this can be measured easily using transducers working on the principle of a strain gauge. This type of respiration transducer, which is commercially available, consists of a tube with an inner diameter of a few millimeters; the tube is elastic and is filled with an electrically conductive liquid substance with measurable electrical resistance. The tube forms part of a belt strapped around the chest; changes in resistance resulting from changes in chest perimeter are measured by means of the Wheatstone bridge circuit. The rather smooth slow respiration rhythm can be recorded with most EEGs without further measures; in case of insufficient frequency response of the apparatus, an alternating current (AC) voltage can be applied to the measuring bridge instead of a DC voltage. If respiration must be recorded from moving subjects, chest size changes not related to respiration can easily occur; in these cases other methods should be chosen.

A simple and easily implemented solution is to use a thermistor or equivalent temperature-sensitive device placed in the mouth and/or nostrils. Such a device works as a respiration transducer by signaling the characteristic differences in temperature of the inspired and expired air. With such methods, information is obtained on frequency and on depth of chest movements. Other methods should be used to obtain exact information concerning respiratory volume.

For information concerning respiratory volume and thoracic and abdominal diameter, variations can be measured by using elastic strips provided with strain gauges that encircle the thorax and abdomen at the level of the nipple and umbilicus, respectively. Using both measurements, the respiratory volume can be calculated. This method of spirometry determines the contributions of the chest and abdomen separately, then adds them together to mimic the total spirometric volume. As the chest and abdominal volumes change during breathing, changes in electrical impedance of the bands are related to changes in the spirometric volume contributions using a calibration and gain adjustment procedure. A combination of techniques is commonly used, namely the measurement of oral and nasal airflow and, in parallel, of abdominal and thoracic movements (Fig. 47.4). The best method to analyze the respiratory effort is the use of an esophageal pressure probe (Roberts and Davies, 1989).

Pulse oximetry is a noninvasive method to measure the arterial hemoglobin oxygen saturation (SaO_2). Continuous pulse and oxygen saturation measurements are obtained by ear, finger, or soft probes (Fig. 47.4 contains an example). The widely used pulse oximeter quantifies the SaO_2 as a percentage based on spectrophotometric and photoelectric plethysmography (West et al., 1987). The SaO_2 measurement yields information about the effectiveness of respiration and is recommended for all types of sleep monitoring (Penzel et al., 1991b).

Electrodermal Activities

The variations of skin electrical properties in relation to psychological variables, commonly known as the galvanic skin response (GSR) or psychogalvanic response (PGR), consist of changes of the electrical conductivity of the skin or of the electrical skin potential, which can be measured by means of electrodes placed on the palms or the soles in reference to an electrode placed elsewhere, such as on the back of the hand.

For such measurements, the skin should be intact; when placing the electrodes, the skin must not be abraded. The skin potential can be recorded easily, but it is unstable and of little use; therefore, skin electrical conductance is much more useful in this respect. It can be estimated by applying a constant voltage across two electrodes and by measuring the resulting electrical current. This is, of course, equivalent to estimating the skin electrical resistance by applying a constant current through the electrodes and measuring the voltage across the electrodes. Skin resistance can vary considerably among subjects, assuming values from kilo- to megaohms. Transient skin resistance responses related to sudden changes in psychological state are on the order of 100 ohms. In practice, it is preferable to measure skin electrical conductance by applying a constant voltage, instead of measuring resistance by applying a constant electrical current. The circuit of Fig. 47.7A illustrates a constant voltage measuring procedure. An example of electrodermal responses recorded during the performance of a contingent negative variation (CNV) paradigm from a normal subject is shown in Fig. 47.8. Classic extensive basic and practical information about electrodermal response recording can be found in the publications by Venables and Martin (1967b) and Montagu (1964) on skin resistance potential. Interesting applications of the GSR in psychophysiological studies have been published by Deschaumes-Molinaro et al. (1992) and Vernet-Maury et al. (1999).

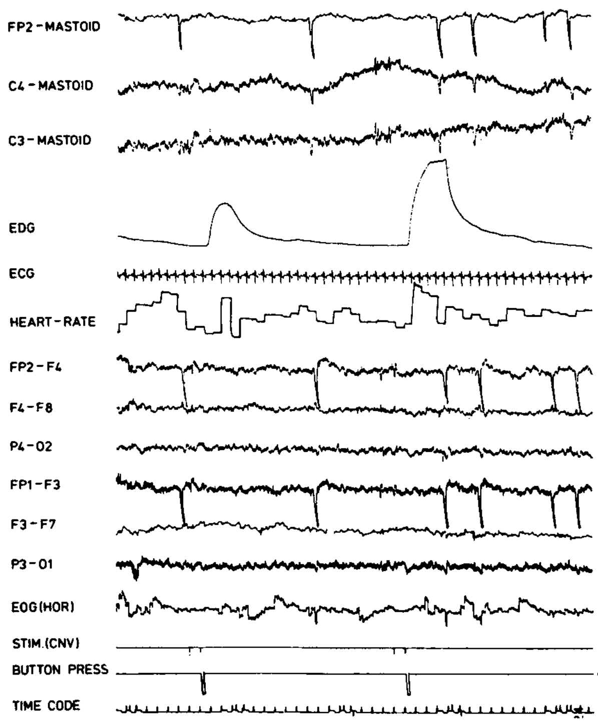

Figure 47.8. Polygraphic recording obtained during a contingent negative variation (CNV) investigation carried out in a normal subject. EEG activities were recorded from three direct coupled CNV derivations (FP_2, C_4, and C_3 against linked mastoids) and six anteroposterior symmetrical derivations. Other variables recorded were electrodermogram (EDG), electrocardiogram (ECG), instantaneous heart rate, electro-oculogram horizontal eye movements [EOG(HOR)], CNV stimulus presentation [STIM.(CNV)], the button press, and a time code (1-second intervals).

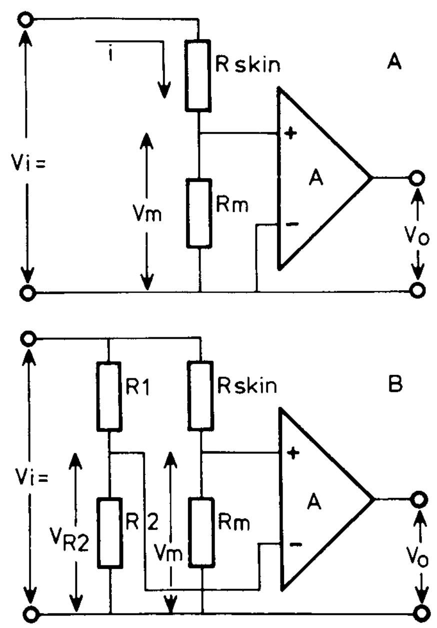

Figure 47.7. **A:** Schematic diagram of a basic electronic circuit for the recording of electrodermal conductance using a constant voltage source. **B:** Bridge circuit for the recording of relatively small changes in electrodermal conductance.

Eye Movements

In various behavioral studies, particularly in sleep research for the recognition of sleep stages, eye movement recording (i.e., by means of the electro-oculogram, EOG) is necessary. Eye movement recording is also useful in EEG recording, for identifying eye movement artifacts and studying lambda waves. An example of the former is the recording of eye movement in relation to that of the CNV; in this case, it is possible either to reject the EEG epochs, where the amount of eye movement exceeds a certain predetermined threshold in order to carry out selective averaging (Papakostopoulos et al., 1973), or to average the EOG along with the CNV to obtain an indication of the reliability of the latter (see also Chapter 48, "Polysomnography"). Preferably, the method chosen for identifying eye movement artifacts will make use of the electrical field generated by the eyes. The EOG is, in general, easy to measure. The usual principle of EOG measurement is demonstrated by the model in Fig. 47.9. As a result of the corneoretinal standing potential (the cornea is positive relative to the fundus), a DC potential difference can be measured either between the pair of electrodes (EH) placed in a horizontal plane near the canthi of the eyes or between the two electrodes (EV) placed in a vertical plane, depending on the position of the eyeballs. Any change in eyeball position results in a corresponding change of these two potential differences. DC recording is necessary to measure exact eye positions, whereas AC recording suffices for determining changes in eye position.

To carry out a DC recording of the EOG, nonpolarizable electrodes must be used, and the drift of the electrodes' offset potential should be taken into account. To obtain sufficiently high recording sensitivity, the electrodes must be placed as close to the eye as possible. To record horizontal movements, the electrodes should be placed near the external canthus of each eye; for vertical movements, the electrodes should be placed closely above and below one or both eyes. The EOG measured in this way has an amplitude of about 20 μV per degree of eyeball rotation. A frequency response up to about 30 Hz is adequate to record the most rapid eye movements, and thus an EEG recording channel can be used without further provision [see, for example, trace EOG (HOR) in Fig. 47.8]. Other principles for monitoring eye movement in clinical EEG are the measurement of changes in impedance related to eye movements (Sullivan and Weltman, 1963) and use of a pressure transducer system (Winter and Kellenyi, 1971). In the latter system, a thin membrane covering one end of a tube held in a spectacle frame is adjusted to touch the closed eyelid lightly. A pressure transducer connected at the other end of the tube detects pressure changes from eye movements. Robinson (1963) describes eye movement recording systems that also provide information on exact eye position; eye position is determined from the voltage generated by an alternating magnetic field in a coil embedded in a scleral contact lens worn by the subject. A similar photoelectric device (Gauthier and Voile, 1975) consists of four small infrared detecting cells mounted on a light spectacle frame together with a miniature infrared (9,000 Å) emitting diode. This system, which preserves maximum vision field size, has a resolution less than 1 min of arc, a band width of 1,000 Hz, and 5% linearity of the maximum range. Currently, systems are available for recording and analysis of a wide range of eye movements, both saccadic and smooth pursuit movements, where these are measured using a scleral reflection technique (IRIS instrument) (Muir et al., 2003). Saccades are rapid eye movements that move the line of sight between successive points of fixation; they are among the best understood of movements, possessing dynamic properties that are easily measured (Leigh and Kennard, 2003). Saccades have become a popular means to study motor control and cognitive functions, particularly in conjunction with other techniques such as EEG, evoked potentials, functional imaging, and transcranial magnetic stimulation.

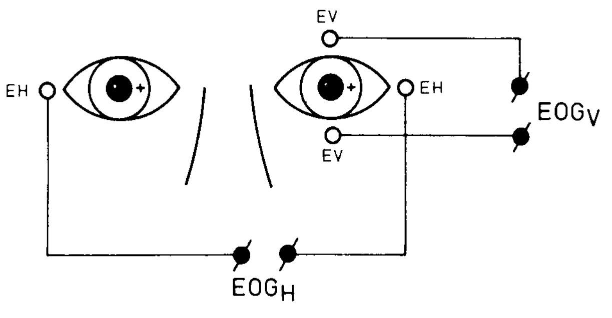

Figure 47.9. Positions of EOG electrodes for recording horizontal and vertical eye movements.

Muscle Activity and Body Movements

EMG Activity

Part of the electrical activity of muscles (EMG) can be recorded easily, by means of either surface electrodes placed on the surrounding skin or needle electrodes inserted into muscle. The frequency range of EMG potentials, particularly those recorded by means of intramuscular needles, goes far beyond the frequency response of most EEG recording systems. Even an EEG apparatus having an ink-jet writing system with a frequency response up to 1,000 Hz does not provide a faithful representation of EMG potentials. However, using a filter giving the highest possible EEG frequency response (usually 70–100 Hz), the recording of EMG activity in most instances adequately indicates the presence of muscular activity and may even provide a rough quantitative measure of the amount of such activity. In certain applications, the latter can be better obtained by passing the EMG potentials through a two-way rectifier, the output of which is integrated with a specified time window. In this way, a rectified smoothed EMG record is obtained. It is important to recognize that the recording of EMG along with EEG signals may be necessary for the interpretation of some specific features of the latter, particularly in those applications such as EEG-based brain-computer interfaces that rely on automated measurements of EEG features (Goncharova et al., 2003).

In behavioral studies, EMG activity is often used to monitor the onset of certain motor activities such as limb movements. Another way of determining limb movements and tremor (Oppel and Umbach, 1977) makes use of displacement transducers or accelerometers. A special form of tremor is the microtremor (microvibration), which is a phenomenon of the sensorimotor system that is modulated by central mechanisms (Burne et al., 1984). This microtremor is in the frequency range of 8 to 12 Hz (amplitudes of 1–10 μm) and can be recorded by an accelerometer fixed, e.g., at the wrist. The measurement range of such an accelerometer should be between ±5 g, such that the microtremor in the range of 10 mV/g can be recorded. Using accelerometry and EMG recordings of the forearm, the characteristics of physiological tremor have been studied (Elble, 2003). In addition to the microtremor, also ballistic movements can be measured with this technique.

Body Movements

The detection of limb or whole-body movements can be of interest in sleep studies. With a simple wrist actigraph, a discrimination between sleep and wakefulness is possible (Sadeh et al., 1989). Actigraphy has been found to be reliable for evaluating sleep patterns in patients with insomnia, for studying the effect of treatments designed to improve sleep, in the diagnosis of circadian rhythm disorders, including shift work (Ancoli-Israel et al., 2003). Such a wrist actigraph can be used, not only in the sleep laboratory, but also with outpatients to obtain a picture of the degree of sleep disturbances within, e.g., a 24-hour period (Penzel et al., 1991b). The recording of movements along with the EEG can also be important in differentiating authentic EEG activity from movement artifacts (Buchtal et al., 1973), which, on the basis of their waveforms and amplitude, cannot easily be identified as noncerebral. When monitoring movements of epileptic patients to determine the occurrence of seizures during the night, transducers indicating global body movements may be used. With this objective, conventional pressure or displacement transducers or other special methods developed for the detection of whole-body (van Nimwegen et al., 1975) or limb movements (Kripke et al., 1978) have been used.

Another method used for recording body movements is the static charge-sensitive bed, which consists of a mattress with two electrically active layers (Alihanka et al., 1981) with the use of filters, the ballistocardiogram, respiratory signals, and movement signals can be differentiated.

For movement quantification in epileptic seizures advanced video analysis methods can be applied (Li et al., 2002). Markers at landmark points are attached to the patient. Then EEG is acquired and the movement of the body parts is monitored using special cameras. Quantified motion trajectories of body parts can be extracted based on the fiducial markers. The trajectories reflect the motion pattern of patients during seizures yielding additional movement information that cannot be obtained from standard video EEG analysis.

Temperature

Temperature can be measured with sensors placed on the skin or with a rectal probe. Temperature measurements are especially important in sleep studies. Detailed studies of rectal temperature recordings over 24 hours are reported by Stephan and Dorow (1985). Experiments with long-term isolation of subjects have revealed a relationship between the body temperature and the duration and stage of sleep (Zulley et al., 1981). To assess core temperature, for instance during monitoring under anesthesia, the recording of tympanic temperature may be carried out.

References

Alihanka, J., Vaahtoranta, K., and Saarikivi, J. 1981. A new method of long-term monitoring of the ballistocardiogram, heart rate, and respiration. Am. J. Physiol. 240:348–392.

Ancoli-Israel, S., Cole, R., Alessi, C., et al. 2003. The role of actigraphy in the study of sleep and circadian rhythms. Sleep 26(3):342–392.

Buchthal, F., Dahl, E., and Projaborg, W. 1973. Simultaneous recording of acceleration and brain waves. Electroencephalogr. Clin. Neurophysiol. 34:550–552.

Burne, J.A., Lippold, O.C., and Pryor, M. 1984. Proprioceptors and normal tremor. J. Physiol. 348:559–572.

Deschaumes-Molinaro, C., Dittmar, A., and Vernet-Maury, E. 1992. Autonomic nervous system response patterns correlate with mental imagery. Physiol. Behav. 51(5):1021–1027.

Elble, R.J. 2003. Characteristics of physiologic tremor in young and elderly adults. Clin. Neurophysiol. 114(4):624–635.

Gauthier, G.M., and Volle, M. 1975. Two-dimensional eye movement monitor for clinical and laboratory recordings. Electroencephalogr. Clin. Neurophysiol. 39:285–291.

Goncharova, I.I., McFarland, D.J., Vaughan, T.M., et al. 2003. EMG contamination of EEG: spectral and topographical characteristics. Clin. Neurophysiol. 114(9):1580–1593.

Gratze, G., Fortin, J., Holler, A., et al. 1998. A software package for non-invasive, real-time beat-to-beat monitoring of stroke volume, blood pressure, total peripheral resistance and for assessment of autonomic function. Comp. Biol. Med. 28:121–142.

Kripke, D.R., Mullaney, D.J., Messin, S., et al. 1978. Wrist actigraphic measures of sleep and rhythms. Electroencephalogr. Clin. Neurophysiol. 44:674–676.

Lader, M.H. 1967. Pneumatic plethysmography. In *A Manual of Psychophysiological Methods,* Eds. P.H. Venables and I. Martin, pp. 159–183. Amsterdam: North Holland.

Leigh, R.J., and Kennard, C. 2003. Using saccades as a research tool in the clinical neurosciences. Brain 127(3):460–477.

Li, Z., da Silva A.M., and Cunha, J.P.S. 2002. Movement quantification in epileptic seizures: a new approach to video-EEG analysis. IEEE Trans. Biomed. Eng. 49:565–573.

Melrose, D.G., Lynn, R.B., Rainbow, R.L.G., et al. 1954. A sensitive digital plethysmograph. Lancet 1:810–812.

Montagu, J.D. 1964. The psycho-galvanic reflex: a comparison of d.c. and a.c. methods of measurement. J. Psychosom. Res. 8:49–65.

Muir, S.R., MacAskill, M.R., Herron, D., et al. 2003. EMMA—an eye movement measurement and analysis system. Australas Phys. Eng. Sci. Med. 26(1):18–24.

Murali, N.S., Svatikova, A., and Somers, V.K. 2003. Cardiovascular physiology and sleep. Front Biosci. 8:s636–652.

Oppel, F., and Umbach, W.W. 1977. A quantitative measurement of tremor. Electroencephalogr. Clin. Neurophysiol. 43:885–888.

Papakostopoulos, D., Winter, A., and Newton, P. 1973. New techniques for the control of eye potential artifacts in multichannel CNV recordings. Electroencephalogr. Clin. Neurophysiol. 34:651–653.

Parati, G., Ongaro, G., Bilo, G., et al. 2003. Non-invasive beat-to-beat blood pressure monitoring: new developments. Blood Pressure Monitoring 8(1):31–36.

Penaz, J. 1973. Photoelectric measurement of blood pressure volume and flow in the finger. In Digest of the 10th International Conference on Medicine and Biological Engineering, Eds. R. Alben, W. Vogt, and W. Helbig, p. 104. Dresden.

Penzel, T., Ducke, E., Peter, J.J., et al. 1991a. Non-invasive monitoring of blood pressure in a sleep laboratory In *Non-invasive Continuous Blood Pressure Measurement,* Eds. H. Ruddel and I. Curio. Frankfurt am Main: Peter Lang.

Penzel, T., Stephan, K., Kubicki, S., et al. 1991b. Integrated sleep analysis, with emphasis on automatic methods. In *Epilepsy, Sleep and Sleep Deprivation,* 2nd ed. (Epilepsy Res. Suppl. 2), Eds. R. Degen and E.A. Roding, pp. 177–204. Amsterdam: Elsevier.

Reeben, V., and Epler, M. 1975. Detection and many-side use of signals from controlled counter pressure finger cuffs. Proc. Biocapt. Paris 1: 265–270.

Roberts, S., and Davies, W.L. 1989. Comparison of simple (slope based) and more complex (simple syntactic) algorithms for central apnoea detection. In *Sleep Research,* Eds. M.H. Chase, R. Lydic, and C. O'Connor, p. 398. Los Angeles: Brain Information Service/Brain Research Inst.

Robinson, D.A. 1963. A method of measuring eye movement using a scleral search coil in a magnetic field. IEEE Trans. Biomed. Eng. BME 10:137–145.

Roy, R., and Weiss, M. 1962. Automatic blood pressure indicator. IRE Trans. Biomed. Electron. 9:244–246.

Ruddel, H., and Curio, I. 1991. *Non-invasive Continuous Blood Pressure Measurement.* Frankfurt am Main: Peter Lang.

Sadeh, A.J., Alster, J., Urbach, D., et al. 1989. Actigraphically based automatic bedtime sleep-wake scoring: Validity and clinical applications. Ambulatory Monitoring 2:209–216.

Stephan, K., and Dorow, R. 1985. Circadian variations of core body temperature, performance and subjective ratings of fatigue in "morning" and "evening" types. In *Circadian Rhythms in the Central Nervous System,* Eds. P.A. Redfern et al., pp. 233–236. Weinheim: VCH.

Sullivan, G.H., and Weltman, G.1963. Impedance oculograph—a new technique. J. Appl. Physiol. 18:215.

van Nimwegen, C.. Boter, J., and van Eijnsbergen, B. 1975. A method of detecting epileptic seizures. Epilepsia 16:689–692.

Venables, P.H., and Martin, I. (Eds.). 1967a. *A Manual of Psychophysiological Methods.* Amsterdam: North Holland.

Venables, P.H., and Martin, I. 1967b. Skin resistance and skin potential. In *A Manual of Psychophysiological Methods,* Eds. P.H. Venables and I. Manin, pp. 53–102. Amsterdam: North Holland.

Vernet-Maury, E., Alaoui-Ismaili, O., Dittmar, A., et al. 1999. Basic emotions induced by odorants: a new approach based on autonomic pattern results. J. Auton. Nerv. Syst. 15; 75(2–3):176–183.

Weiman, J. 1967. Photoplethysmography. In *A Manual of Psychophysiological Methods,* Eds. P.H. Venables and I. Martin, pp. 185–217. Amsterdam: North Holland.

Wesseling, K.H., van Bemmel, R.A., van Dieren, A., et al. 1978. Two methods for the assessment of hemodynamic parameters for epidemiology. Acta Cardiol. 33:84–87.

Wesseling, K.H., Settels, J.J., and de Wit, B. 1986. The measurement of continuous finger arterial pressure noninvasively in stationary subjects. In *Biological and Psychological Factors in Cardiovascular Disease,* Eds. T.H. Schmidt, T.M. Dembroski, and G. Blumchen, pp. 355–375. Berlin: Springer-Verlag.

West, P., George, C.F., and Kryger, M.H. 1987. Dynamic in vivo response characteristics of three oximeters: Hewlett-Packard 47201A, Biox III, and Nellcor N-100. Sleep 10:263–271.

Winter, A.L., and Kellenyi, L. 1971. Eye movement monitoring. Proc. Electrophysiol. Technol. Assoc. 18:121.

Zulley, J., Wever, R.A., and Aschoff, J. 1981. The dependence of onset and duration of sleep on the circadian rhythm of rectum temperature. Pflugers Arch. 391:314–318.