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Monitoring sleep of hospital patients by measurement of electrical resistance of skin

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JOHNS, M. W., B. A. CORNELL, AND J. P. MASTERTON. *Monitoring sleep of hospital patients by measurement of electrical resistance of skin.* J. Appl. Physiol. 27(6): 898–910. 1969.—A relatively simple and accurate method for monitoring the sleep of hospital patients is described. This involves the continuous recording of basal skin resistance and galvanic skin responses on separate channels of a chart recorder with a chart speed of 6 inches/hr. The time of sleep onset, of any disturbances during the night, and of final waking can be determined with a resolution of 1–2 min. A rough estimate of the amount of slow-wave sleep and a semiquantitative measure of the patient's arousal in the waking state can be made.

basal skin resistance; galvanic skin response

SLEEP AND DREAMS have always been a source of speculation and wonderment, but it is only in recent years that they have become the subject of widespread scientific investigations. Much of this work has involved monitoring the electroencephalogram (EEG) and electrooculogram (EOG) following the classical work of Dement and Kleitman (2).

Variation with age in the total amount of sleep and the proportion of rapid-eye-movement (REM) or dreaming sleep, and of each of the four stages of non-REM sleep have been described (4). The effects of intentional deprivation of the different stages of sleep have been studied (1). Abnormal patterns of sleep are well known in certain psychiatric patients, such as those suffering from depression (7). However, there has been very little study of the sleep patterns of other hospital patients, in particular of the effects of major surgery and postoperative care in intensive-care wards. Postoperative psychosis has been described in several series of patients undergoing cardiac surgery, and one important causative factor may be sleep deprivation resulting from frequent disturbances in a strange, frightening, and often noisy environment (11). This hypothesis seems to be sustained by the fact that similar psychiatric disturbances have been described after voluntary sleep deprivation (18). The purpose of this paper is to describe a method of monitoring accurately the sleep and disturbances of surgical patients in order to relate sleep deprivation to any psychiatric disorder. This involves continuous measurement of the electrical resistance of skin and correlation of these changes with the EEG and EOG.

RATIONALE OF MEASURING ELECTRICAL RESISTANCE OF SKIN

It has been known since last century (5) that if a small electrical current is passed through electrodes on the skin surface the apparent resistance undergoes two types of variation with time. The first involves a sudden decrease in skin resistance lasting about 5 sec after which the resistance returns towards its previous level. This is called a galvanic skin response, or GSR, and occurs spontaneously (nonspecific GSR) or after any alerting stimulus (specific GSR). These GSRs are best seen when recording from the palms of the hands or soles of the feet. The second type of variation involves slower changes in what is often called basal skin resistance, or BSR. These changes take place over minutes or hours rather than seconds and are of a larger magnitude than the GSRs.

Both types of variation in skin resistance are brought about by changes in dermal sweat gland activity and probably other epidermal membrane changes, mediated by sympathetic cholinergic nerve fibers (9). Changes in sympathetic tone are in turn caused by activity in the hypothalamus with facilitatory influences from the rostral mesencephalic reticular system and inhibitory influences mainly from the forebrain, thalamus, and ventromedial reticular system (9). Sympathectomy (6) or local atropine application (12) block both the GSR and BSR changes at the periphery. The number of nonspecific GSRs increases as the subject becomes increasingly alert from being drowsy to a state of extreme anxiety (16). The BSR is generally low in the alert or agitated state but rises as the subject relaxes and becomes drowsy. This measure has been used in the past to determine changes in conscious state (14). Hawkins et al. (8) and Tart (17) found changes in the BSR during sleep and dreaming by frequent intermittent measurement. Johnson and Luben (10) have described changes in the number of nonspecific GSRs during waking and sleeping. We have found that a combination of continuous GSR and BSR measurements provide a simple and objective way of monitoring the sleep and wakefulness of patients in hospital.

METHODS

Skin resistance measurements. Information about both GSR and BSR is obtained from four silver cup electrodes 8 mm in diameter placed over the volar surface of the distal phalanges of two fingers previously washed with soap and water. This arrangement has proved of minimal disturbance to the patient or to his medical care.

The actual skin resistance is proportional to that area of skin in contact with the electrode paste (15). This area must, therefore, be kept constant by applying to each finger a piece of waterproof adhesive tape (Sleek, manufactured by T. J. Smith and Nephew Ltd., England) with two holes cut in it. The holes are circular with a diameter of 5 mm and a space of 5 mm between them. The skin exposed by these two holes and the outside surface of the tape between them is wet with Cambridge paste (manufactured by Cambridge Instrument Co. Ltd., England). The electrodes are held in place by another strip of tape. With this arrangement the electrodes become stable after 10–25 min and remain satisfactorily in place for periods from 12 to 24 hr. By this time the electrode paste has usually dried and the skin has undergone some depolarization so that the electrodes must be reattached at a different site on the same or the other hand.

Figure 1 shows the circuitry required to measure both the BSR and GSR activity. A mercury cell impresses a constant current of 7 μa through the application electrodes on each finger via a transistor. The current is maintained for resistance between 0 and 2.25 megohm, a much greater range than that actually found in patients' skin.

The effective potential difference across the skin is sensed from

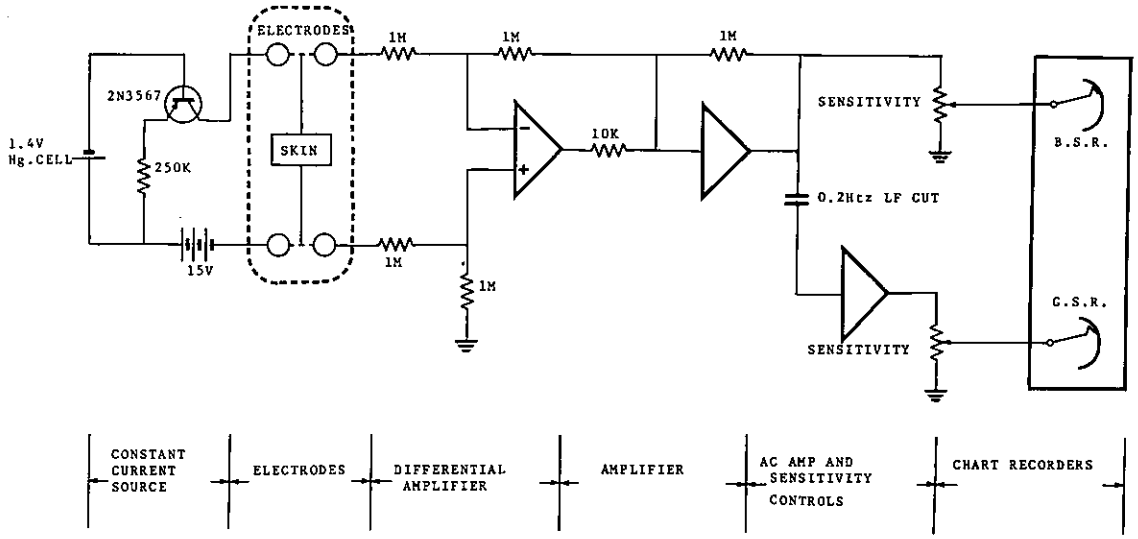

FIG. 1. Schematic diagram of circuitry for measuring BSR and GSR.

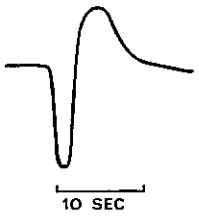

FIG. 2. GSR recorded at a chart speed of 6 inches/min. (15.2 cm/min). Vertical scale: 400 ohm/cm.

separate electrodes by an isolated differential input amplifier with a high input resistance. The differential amplifier and driving amplifier consist of 709 integrated circuit blocks with the appropriate input and feedback resistors. The driving amplifier has a gain of 100. The signal which is proportional to the BSR is fed via a scaling potentiometer onto one channel of a twin-channel chart recorder. In addition, the unscaled signal is fed separately via a capacitive coupling into a second amplifier with a gain of approximately 300, and via another scaling potentiometer onto the second channel of the chart recorder. The a-c amplifier has a frequency characteristic such that the gain is 3 db down at 0.2 Hz with 6 db/octave attenuation below this frequency. This second channel distinguishes GSR activity by measuring only rapid changes about a base line while overcoming the effects of slower base-line shifts. Figure 2 shows an example of a GSR recorded at a fast chart speed of 6 inches/min (15.2 cm/min). The GSR as recorded by this method is presented as a biphasic curve, the distance between the positive and negative peaks of the curve being proportional to the actual change in skin resistance, in this case a change in resistance of approximately 1,000 ohms from a level of around 30,000 ohms. During sleep monitoring the chart recorder is run at a speed of 6 inches/hr (15.2 cm/hr). Thus an entire night's sleep and wakefulness is represented on a chart less than 6 ft long.

EEG and EOG. Preliminary skin resistance measurements have been carried out on 12 volunteers (mostly medical students; 9 male and 3 female, ages 22–37 years) and 19 convalescent surgical patients (7 males and 12 females, ages 16–76 years). In many of these the EEG and EOG were also monitored so that variations in skin resistance with the different stages of non-REM and REM sleep could be established.

The EEG was derived from a single pair of midline parietooccipital electrodes and observed directly on a cathode-ray oscilloscope. The EEG was scored for the different stages of sleep according to the system of Dement and Kleitman (2). The EOG derived from an electrode at the outer canthus of each eye gave an indication of REM sleep.

In a few cases closed-circuit television from the subject's bedside to another monitoring room enabled the effects of body movements to be ascertained. Later it was found sufficient to have a microphone under the subject's bedclothes to monitor even minor movements during the night.

The necessary electrodes were attached to the subjects early in the evening so that the waking patterns could be observed. The subjects were then allowed to sleep, usually without purposeful interruptions. Some were given their usual night sedation, whereas others were given no drugs at all.

RESULTS

A common waking pattern of BSR is shown in Fig. 3. It is characterized by an irregular series of gradual increases in resistance over a few minutes interrupted by more rapid falls. Some of the sharp falls in skin resistance were seen to follow identifiable alerting stimuli such as the start of a conversation or the approach of a nurse with a syringe and needle. Movement of the fingers with the attached electrodes had no such effect.

The actual skin resistance measured varied between about 10,000 and 150,000 ohms in different individuals when awake. The more relaxed or sedated a patient, the higher his skin resistance. Conversely lower resistances were associated with apprehension and alertness. Under the latter circumstances the BSR underwent smaller fluctuations. In the waking state the number and size of GSRs, both specific and nonspecific, depended on the individual patient and his degree of arousal. There tended to be more GSRs when the BSR was low, that is, with greater degrees of arousal. Alert young patients may have 6 or 8 GSRs/min. However, more relaxed patients may show only 1 or 2 GSRs/min with a relatively high BSR.

Basal skin resistance changes during sleep. On going to sleep the BSR increased fairly rapidly in a smooth curve over a few minutes (Fig. 4). It may continue to increase up to a maximum resistance which may be found during the first 2 or 3 hr of sleep, or in the last 2 or 3 hr of the night's sleep. In some cases, especially when the BSR is initially high, it remains at about the same elevated level after the 1st hr or so of sleep.

During the night there may be several sharp decreases in BSR

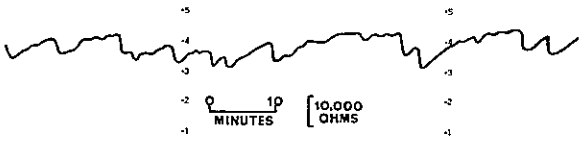

FIG. 3. Pattern of BSR while awake, recorded at 6 inches/hr. (15.2 cm/hr). Resistance varied between 31,000 and 45,000 ohms during this period.

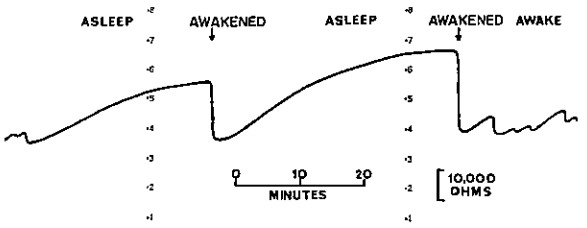

FIG. 4. Pattern of BSR during short periods of sleep with disturbances, recorded at 6 inches/hr. (15.2 cm/hr). Resistance varied between 35,000 and 66,000 ohms during this period.

which coincide with brief awakening of the patient (intentional or otherwise). Each rapid decrease in BSR which appears also as a large GSR on the other channel of the chart recorder is usually followed by a gradual increase again as the subject goes back to sleep (Fig. 4).

The maximum BSR reached during sleep varies from about 30,000 to about 300,000 ohms in different subjects, depending on their waking BSR level. In general the absolute level of the BSR during sleep did not correlate with the depth of sleep measured by EEG stages. In a few cases the BSR decreased during periods of stage 3 or 4 sleep, but often there was no indication from the BSR alone of changes in sleep stage. When the subject woke up in the morning the BSR decreased dramatically over a period of a few seconds by as much as 50,000–100,000 ohms in those cases with a high sleeping BSR.

The general level of the BSR after waking up in the morning is usually similar to that just before going to sleep. The pattern of BSR may immediately revert to the typically waking pattern in the morning or there may be a few periods of a few minutes duration when the subject doses off to sleep again before finally waking up.

To demonstrate that the changes in BSR which were measured were not due to electrode polarization potentials, the BSR was monitored on several occasions using a 50-Hz alternating current of 10 μa with two silver electrodes in the usual position on two fingers. The general levels of BSR and the shape of the curve during wakefulness and sleep were the same as those obtained with direct current and four electrodes.

GSRs during sleep. On going to sleep the number of GSRs initially decreased in all cases compared with the waking state. Along with the changes in the BSR this provided a ready means of detecting sleep onset within a few minutes. There were very few GSRs recorded during stage 1 or stage 2 sleep, but in stages 3 and 4 the number of GSRs increased markedly in most cases (Fig. 5). Stage 4 sleep was often accompanied by between 5 and 12 GSRs/min. The absolute number varied between individuals and at different times. The subjects showing most GSRs when awake also showed the most GSRs during stage 4 sleep. There were very few, if any, GSRs seen during REM sleep. The number of nonspecific GSRs could not be used alone as an accurate measure of the duration of different stages of sleep. The sleeping GSRs were only occasionally large enough to produce fluctuations visible clearly on the BSR recording which remained usually smooth. In many cases a change in sleep stage was indicated by

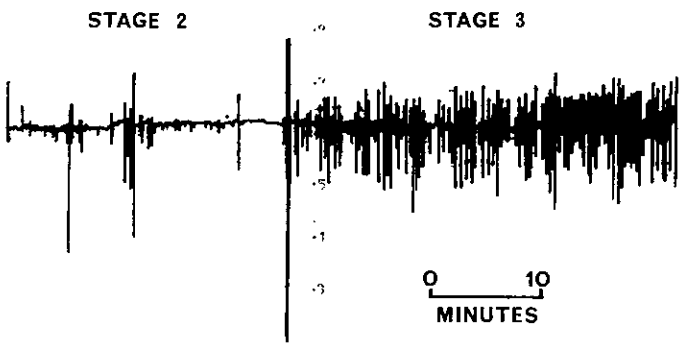

FIG. 5. Pattern of GSRs during sleep, recorded at 6 inches/hr (15.2 cm/hr). Each vertical line represents a biphasic GSR. Vertical scale: approximately 100 ohms/cm.

a larger than usual GSR (Fig. 5). This may represent the movement arousal which has been observed commonly at the beginning and end of sleep stages.

DISCUSSION

To measure the apparent electrical resistance of skin it is required to measure the potential developed across membranes in the skin as a result of the passage of a known current. However, there are several unwanted variables which arise in practice. One of these is due to the polarization potentials which develop at the electrode-paste contact as a result of the passage of current. Another problem arises because of damage to the skin which increases with both current density and time. In the present study an attempt has been made to minimize these effects by using a very low current density and two pairs of electrodes as a modification of the two element electrode system used by Lykken (15). Silver electrodes were chosen because when used with a sodium chloride electrolyte paste a thin coating of silver chloride provides an electrode system with relative stability and low bias (3).

The present electrode system employs two "active" skin sites on the fingers where resistance changes are virtually identical and hence additive in effect. The skin resistance as measured by this system is not an absolute value which can be compared with values obtained by other methods. However, when as many variables as possible are kept constant, the resistance values can be compared between different subjects at different times, semiquantitatively at least.

From the shape of the BSR curve and the number of GSRs the duration of sleep can be measured very readily from the chart record. The time of awakening in the morning or of any number of disturbances to sleep can be determined accurately with a resolution of about 1 min. The time of falling sleep may be obtained with a resolution of 2 or 3 min.

As was found also by Tart (17) the pattern of BSR throughout the night seemed to vary between different subjects but to be fairly constant in the same individual on different nights. There was no consistent relationship between REM periods and increased BSR as has been suggested by Hawkins et al. (8).

The number of nonspecific GSRs during wakefulness did seem to be proportional to the subjects level of arousal or anxiety and increased as the BSR fell, as has been reported by Silverman et al. (16). The increased GSR activity during stages 3 and 4 sleep has been observed by other workers and has been attributed to a possible release of cortical inhibition of brain-stem activity (10).

When such an increase in GSR activity occurred during wakefulness in the present study there was an associated fall in BSR. This was also seen in a few cases during sleep when GSR activity increased. However, in general there seemed to be dissociation between the BSR level and GSR activity of sleep.

Lester et al. (13) demonstrated that presleep stress increased the number of GSRs during any particular stage of sleep. However, the significance of the number of GSRs with respect to the quality or restfulness of sleep is not yet clear.

In conclusion, these experiments have shown that it is possible to monitor sleep objectively and fairly simply by recording GSRs and BSR continuously at a distance from the patient for prolonged periods. The patient suffers minimal disturbance and may still use his hand with the attached electrodes as required, for example, for eating. The time of going to sleep, of any disturbances to sleep during the night, and of waking up in the morning can be determined with a resolution of 2 or 3 min. The patient's state of daytime arousal can be determined, semiquantitatively at least, from waking recordings. The disadvantages of this system of monitoring are that only a rough indication of the various stages of sleep can be given and the electrodes must be replaced at least once every day. However, the convenience of the method and the accuracy of the sleep records as compared with subjects' subjective reports of their sleep justifies the further use of skin resistance monitoring in sleep investigations.

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