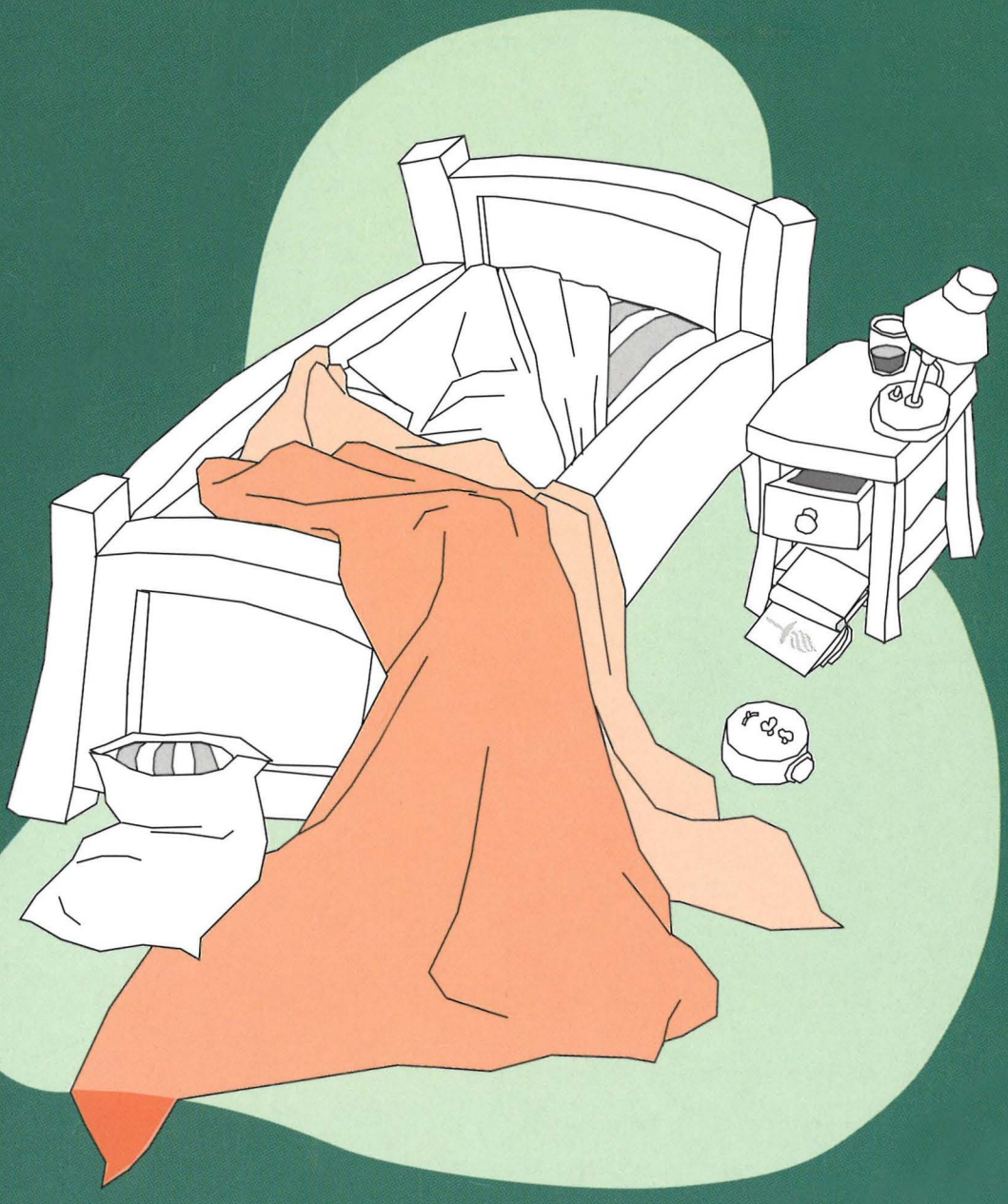
Jukka Kaartinen

# Nocturnal Body Movements and Sleep Quality



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Jukka Kaartinen

# Nocturnal Body Movements and Sleep Quality

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UNIVERSITY OF JYVÄSKYLÄ

JYVÄSKYLÄ 1997

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UNIVERSITY OF JYVÄSKYLÄ

JYVÄSKYLÄ 1997

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# ABSTRACT

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Diss.

Nocturnal body motility and autonomic nervous system (ANS) activity as manifested in respiratory movements and the pumping action of the heart (ballistocardiogram, BCG) registered by using the static charge sensitive bed (SCSB) method were investigated in five studies. The SCSB data were classified into quiet (QS), intermediate (IS) and active (AS) states according to the frequency of small body movements and the regularity of the ANS parameters. These states and body movements per se were assessed as measures of sleep quality. QS, IS, and AS were also studied in relation to dreaming. Both visual (Study I) and automatic (Study III) analyses revealed that the changes in different SCSB variables and in the activity states reflect the cyclic variation of the standard sleep stages. QS and IS were mainly related to NREM sleep, but while REM sleep was mostly scored as AS, the total nocturnal AS was a combination of wakefulness, stages 1 and 2, and REM sleep. The percentages of dream recall (Study II) after QS (20%) and IS (25%) confirmed their association with NREM sleep, whereas the recall rate in AS (80%) was comparable with the percentages usually found after REM awakenings. Study IV using behavioral responsiveness as a measure of sleep depth showed similar kinds of differences between the SCSB activity states as were found between the standard sleep stages, the amount of QS appearing to be a useful indicator of deep sleep. Study V revealed significant inter-subject differences in the SCSB parameters but also a noteworthy intra-subject variation across 14 consequtive nights was found. The subjective sleep evaluations during the individual extremes of SCSB activity significantly differed from each other, quiet SCSB recording indicating subjectively good sleep. Studies I-IV indicate that SCSB activity analysis provides a simple and inexpensive method for assessing sleep quality and for dream research. According to Study V the validity of single-night recordings as measures of sleep quality should be questioned, especially as regards experimental settings with small number of subjects. Nevertheless, the SCSB appears to be a suitable method when repeated recordings are needed, as in follow-up studies.

Keywords: sleep quality, body movements, sleep stages, static charge sensitive bed (SCSB), respiration, ballistocardiography, dreaming

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Jyväskylä, August 15, 1997

Jukka Kaartinen

# CONTENTS

# LIST OF ORIGINAL COMMUNICATIONS

I Kaartinen, J., Erkinjuntti, M. & Rauhala, E. (1996) Sleep stages and static charge sensitive bed (SCSB) analysis of autonomic and motor activity. *Journal of Psychophysiology, 10,* 1-16.

II Kaartinen, J., Fried, R., Lyytinen, H., Leppänen, A., Lähderinne, S. & Rantasuo, J. (1996) Sleep mentation related to autonomic and motor activity - A static charge sensitive bed study of dreaming. *Journal of Psychophysiology, 10,* 17-25.

III Kaartinen, J., Erkinjuntti, M. & Rauhala, E. (1996) Automatic SCSB analysis of motor and autonomic nervous functions compared with sleep stages. *NeuroReport, 7,* 1102-1106.
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IV Kaartinen, J., Polo, O., Sallinen, M. & Lyytinen, H. SCSB activity states and sleep depth: A behavioral and polygraphic assessment. Submitted manuscript.
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V Kaartinen, J., Kulhomäki, I. & Peura, P. Changes in motor activity in bed and subjective sleep quality. Submitted manuscript.
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# 1 INTRODUCTION

"Als Gregor Samsa eines Morgens aus unruhigen Träumen erwachte, fand er sich in seinem Bett zu einem ungeheuren Ungeziefer verwandelt. Er lag auf seinem panzerartig harten Rücken und sah, wenn er den Kopf ein venig hob, seinen gewölpten, braunen, von bogenförmigen Versteifungen geteilten Bauch, auf dessen Höhe sich die Bettdecke, zum gänzlichen Niedergleiten bereit, kaum noch erhalten konnte. Seinen vielen, im Vergleich zu seinem sonstigen Umfang kläglich dünnen Beine flimmerten ihm hilflos vor den Augen."
- Franz Kafka: Die Verwandlung (Kafka, 1984) -

"When Gregor Samsa awoke one morning from troubled dreams he found himself transformed in his bed into a monstrous insect. He was lying on his hard shell-like back and by lifting his head a little he could see his curved brown belly, divided by stiff arching ribs, on top of which the bed-quilt was precariously poised and seemed about to slide off completely. His numerous legs, which were pathetically thin compared to the rest of his bulk, danced helplessly before his eyes."
- The Transformation, translated by Malcolm Pasley (Kafka, 1992) -

The purpose of this predominantly methodologically oriented thesis is to describe five studies which were conducted in order to clarify whether one particular method, the static charge sensitive bed (SCSB), could serve as a tool for psychophysiological research on sleep. Sleep as a concept is often considered as an altered state of being, or as a state of alteration as evident in the citation above. However, modern sleep research has converted sleep from its traditional behavioral and subjective aspects to brain waves, and it is indeed obvious for anyone familiar with neuroscience that sleep is a process of the brain. Nevertheless, it is just as evident, also scientifically, that sleep can be *manifested* in different ways according to differing purposes and points of view. Kafka above, for instance, indirectly pointed out the restlessness of Samsa's sleep during the metamorphosis. In general, restless sleep most evidently refers

to motor activity, and it is movements, major and minor, which are the topic of the present thesis.

Traditionally sleep has been defined by using behavioral criteria. Whether or not someone is asleep has been inferred by direct observation according to various parameters including the person's position, closure of the eyes, relative immobility and reduced responsiveness to external stimuli. Furthermore, motility and responsiveness have also been used in assessing restfulness and depth of sleep, respectively, although subjective evaluations have ordinarily been the basic source of information concerning sleep quality. As nowadays, however, wakefulness and the different stages of sleep are defined by combinations of patterns recorded electrophysiologically, the literature review will start from the origins of such concepts of sleep in the 1930's. This is followed by an introduction to the idea of the *standard sleep stages* and by a short description of the models concerning their neural regulation. The following sections will review the studies on the effects of the laboratory environment on sleep, the laboratory research on dreaming, the studies on the behavioral assessment of sleep depth, and finally, those on subjectively experienced sleep as compared with parameters suggested to be objective. Research on autonomic nervous system functions and body movements during sleep will also be described before the introduction to the SCSB analysis, which utilizes both autonomic and motor phenomena.

The rest of the thesis will concentrate on the applicability of the SCSB method for psychophysiological sleep research by summarizing and discussing the results of five studies during which both visually and automatically analyzed SCSB recordings were compared with the standard sleep stages (Studies I and III). The visual analysis was consequently applied in the dream research (Study II), whereas the automatic analysis was both behaviorally tested (Study IV) and assessed as a method for the long-term monitoring of sleep quality (Study V). In the last study both inter- and intra-individual differences were investigated.

# 2 REVIEW OF THE LITERATURE

## 2.1 The beginning of electroencephalographic sleep research

Hans Berger (1930) almost seventy years ago first described some differences in the waveforms and frequencies of the human electroencephalogram (EEG) between wakefulness and sleep. A little later, Loomis, Harvey and Hobard (1937) analyzed longer periods of EEG activity during sleep and reported to "have been able to establish very definitive states of sleep which change suddenly from time to time" (Loomis et al., 1937, p. 128). The EEG patterns were classified into five categories with alphabetical codes from A to E. States A and B referred to lighter and C, D, and E to deeper forms of sleep. State A was characterized by EEG alpha together with slow rolling eye movements and state B by a low voltage EEG sometimes with rolling eye movements but without alpha activity. A low voltage EEG with 14 Hz spindles was typical for state C. High voltage slow potentials were found in both D and E, but more profoundly and without spindles during the latter.

The five states presented by Loomis et al. (1937) became the basis for the mainstream of later development in sleep stage classification, even though some rival systems were also proposed. Gibbs and Gibbs (1950), for example, presented a sevenfold classification: arousal, drowsiness, very light sleep, light sleep, moderately deep sleep, deep sleep, and *early morning sleep*. According to them early morning sleep was difficult to distinguish from a normal waking EEG, and it, as well as the *null phase* described earlier by Blake, Gerard and Kleitman (1939), referred to a low voltage EEG pattern which was common during the last hours of sleep. It is unclear whether these stages could be regarded as early equivalents of what is nowadays known as rapid eye movement (REM) sleep.

A new understanding concerning the nature of sleep architecture arose due to the findings of Aserinsky and Kleitman (1953, 1955) who reported the existence of regularly occurring periods of eye motility during sleep. This activity, recorded using two bipolar electro-oculogram (EOG) channels of an EEG machine, was different from the slow eye movements which were common during relaxation at the onset of sleep. Binocularly synchronous, rapid and jerky eye movements were found concomitantly with low amplitude activity in the frontal and occipital EEG channels, but not during sleep with spindles and/or delta activity. It was also found that dreaming was closely related to these periods.

Dement and Kleitman (1957a) introduced a new categorization system, which was a slightly modified version of the sleep states of Loomis et al. (1937) and with the EOG added to the recording procedure. According to the new classification Stage 1 was a low voltage, relatively fast pattern, absolutely without spindle activity. This stage corresponded approximately to state B of Loomis' system. Stage 2 was characterized by spindles or K-complexes with low voltage background activity. Stage 3 was an intermediate stage with high voltage slow waves and some spindling, whereas in Stage 4 the record was dominated by large amplitude slow activity. Dement and Kleitman (1957a) also confirmed the existence of rapid eye movement periods during sleep and their connection to a fast and low amplitude EEG as in Stage 1. In their study on the relationship between sleep stages and dreaming (Dement & Kleitman, 1957b) they introduced the abbreviations REM (rapid eye movements) and NREM (no rapid eye movements) to sleep research.

An important new finding of Dement and Kleitman (1957a) was the discovery of the regular cyclic variation of the EEG stages (NREM and REM sleep) throughout the night in approximately 90-100 min intervals starting from the onset of sleep and lasting to the end of the the first REM period, and thereafter from the end of each REM period to the end of the next one. Stages 3 and 4 were most common during the first cycle and occurred rarely after the second cycle. The NREM sleep of the later cycles, on the other hand, mainly consisted of Stage 2. Although there were some irregularities in the sequence of stages the cyclicity was found in all subjects. The cycle lengths varied between subjects but individual sleep patterns across several nights showed striking regularity.

The occurrence of REM periods in the cat was reported by Dement (1958), and a year later Jouvet and Michel (1959) published their finding concerning muscular activity during sleep also in cats. Electromyography (EMG) showed that while muscle tone was only slightly decreased during the other stages of EEG sleep, it was totally suppressed during REM periods (Jouvet & Michel, 1959). This phenomenon which was recorded from the cats' dorsal neck muscles was later also confirmed in the head and throat muscles during human REM periods (Berger, 1961; Jacobson, Kales, Lehmann & Hoedemaker, 1964). Muscle atonia indicated by a submental EMG recording became therefore one essential criterion of REM sleep.

However, in spite of the above mentioned physiological characteristics REM sleep is not a unitary state. According to different sources (e.g. Dement & Mitler, 1974; Grosser & Siegal, 1971; Molinari & Foulkes, 1969) it was Moruzzi (1963) who differentiated for the first time between the tonic and phasic components of REM sleep. The former includes the low amplitude waking-like EEG and the suppressed EMG signal which persist continuously throughout the REM stage. On the other hand, the phasic components, like bursts of rapid eye movements, are short term phenomena which appear intermittently during REM sleep. The other phasic components of REM sleep include irregularities in autonomic nervous system (ANS) functions, twitching body movements, and the so called ponto-geniculo-occipital (PGO) activity of the brain. All of these will be further described below.

## 2.2 The standardized criteria for sleep stages

After a decade's use of Dement-Kleitman's scoring system, it became obvious in order to avoid problems concerning the reliability of scoring (Monroe, 1968, 1969a) and to make the results from different laboratories more comparable, that the defining criteria had to be critically evaluated and revised. The resulting "Manual of Standardized Terminology, Techniques and Scoring System for Sleep Stages of Human Subjects" (Rechtschaffen & Kales, 1968) was designed by a group of leading sleep investigators of that time. As a reaffirmation and elaboration of the previous criteria (Dement & Kleitman, 1957a) it was designed to provide researchers with universal recommendations or, as Dement and Mitler (1974, p. 279) put it, "to set forth absolutely precise definitions of the sleep states and stages so that anyone, at least in theory, should get identical results" in scoring. The general features of the criteria, commonly known as the Rechtschaffen-Kales criteria according to the editors of the manual, will be briefly described below. A similar kind of manual has also been published for scoring the sleep states of newborn infants (Anders, Emde & Parmelee, 1971).

A minimum of four channels are recommended for sleep recording. The EEG should be recorded from derivations C4/A1 or C3/A2 of the international electrode placement system (Jasper, 1958). Two EOG electrodes (one from the outer canthus of each eye) with a common reference in one ear or mastoid are also needed for eye movement detection. The EMG is recorded bipolarly from beneath the chin. The slowest acceptable time scale for display is 10 mm/sec and the record is divided into 20 or 30 mm sections and scored epoch-by-epoch so that each of them is given a single stage score. The seven stages are: Stage W (wakefulness), Movement time (MT), NREM (non-REM) Stages 1-4, and Stage REM. The stages will be abbreviated below as W, MT, S1, S2, S3, S4, and REM sleep, respectively.

If the subject is resting with eyes closed W is seen as alpha-activity and/or low voltage, mixed frequency EEG. Tonic EMG is relatively high and eye

movements are common on the EOG. An epoch is scored as MT when more than a half of its duration is obscured by muscle tension artifact on the EEG and EOG channels. S1 refers to the transition to sleep (drowsiness) and it is characterized by low voltage EEG and a decrease in alpha activity to less than one half of an epoch, the increase of theta activity and the possible appearance of high amplitude vertex sharp waves. The EMG level may decrease as compared with stage W. Especially the early parts of S1 are characterized by slow (rolling) eye movements (SEMs). The total duration of S1 during a normal night's sleep is usually only a few minutes.

The NREM stages S2-S4 are defined according to EEG criteria. The most prominent features of S2 sleep are the 12-14 Hz sleep spindles and the polyphasic high amplitude K-complexes with the background EEG containing less than 20 % delta activity. S3 and S4 are often combined and called *slow wave sleep* (SWS). This is because of the presence of high amplitude (> 75 μV) delta (0.5-2 Hz) waves on the EEG. An epoch is scored as S3 when 20-50 % of its duration is occupied by delta activity, and as S4 if delta waves represent more than one half of the epoch .

The low voltage, mixed frequency EEG during REM sleep is similar to the pattern in S1 with some exceptions concerning the prominence of *vertex sharp waves* in S1 and the frequent appearance of *sawtooth waves* during stage REM. Spindles and K-complexes are not present in REM sleep. According to its name this stage is characterized by the occurrence of binocularly synchronous rapid eye movements which are detected as out-of-phase deflections on the two EOG channels. The other important sign of REM sleep is the decrease of tonic submental EMG activity to its minimum. Typical examples of the standard polygraphy from active and passive wakefulness through the NREM stages to REM sleep are presented in Figure 1.

The cyclic variation of the sleep stages described by Dement and Kleitman (1957a) can be verified in any laboratory. A normal nocturnal sleep starts with a few minutes period of S1 followed by a descending trend through S2, S3 and S4 as the sleep gets deeper. After a lengthy period of SWS, a gradual lightening of sleep, the ascending S2, can be observed before the first REM phase, which is usually quite short in duration. Sometimes the first REM period is not reached at all, but the second cycle starts as a new deepening trend of NREM sleep. The length of SWS during the second cycle is usually shorter than during the first and its portion decreases even more during later cycles. NREM sleep of morning hours is almost totally composed of S2. On the other hand, the duration of REM periods increases remarkably during subsequent cycles and can last for more than half an hour in the morning. The percentual amount of each sleep stage as a fraction of total sleep time (TST) varies with age (Roffwarg, Muzio & Dement, 1966). In young adults the nocturnal percentages of S1, S2, SWS and REM sleep are approximately 5%, 50%, 20%, and 25% respectively (e.g. Williams, Karacan & Hursch, 1974).

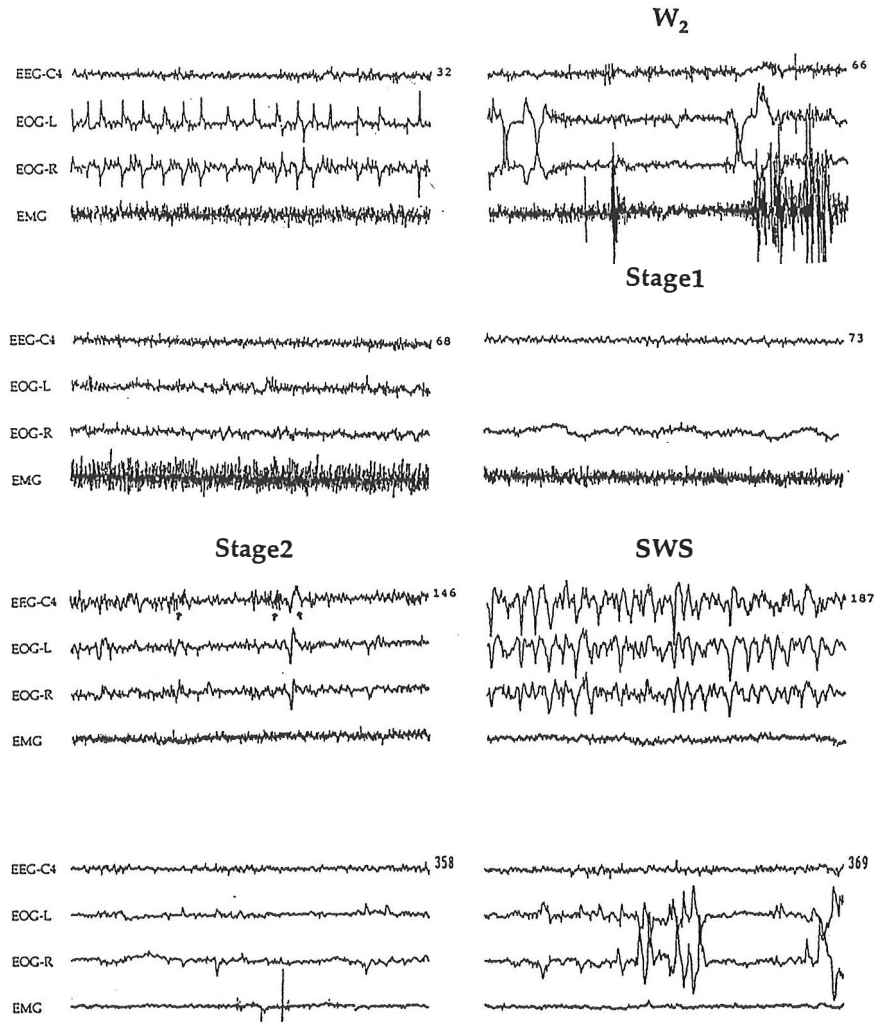


FIGURE 1 Examples of the standard polygraphy from active wakefulness through the deepening NREM stages to REM sleep. The W tracings were recorded while the subject was reading ($W_1$), when she asked to turn the lights off ($W_2$), and while she was lying quietly ($W_3$). The slow eye movements are typical for S1. Two spindles and a K-complex are indicated by arrows in the S2 sample. SWS is characterized by high amplitude delta activity. An increase in rapid eye movements can be seen from $REM_1$ to $REM_2$. The tonic EMG shows a gradual decrease from W to REM sleep. (Unpublished samples adopted from the experiment of Ruusuvirta, Lyytinen, Kaartinen and Sallinen (1991).)

## 2.3 Neural control of the NREM/REM oscillation

The early transection and stimulation studies revealed sleep enhancing structures in the brainstem and forebrain as well as brainstem regions which facilitate waking (e.g. Bremer, 1974; Moruzzi & Magoun, 1949; Sterman & Clemente, 1962). However, the search for discrete "centers" in the brain which could promote and control the different stages of sleep has been unsuccessful. Wakefulness, synchronization of the EEG indicating deactivation of the brain together with phasic spindles and K-complexes during NREM sleep and, finally, tonic CNS arousal, motor inhibition and the phasic activities during REM sleep are generated and regulated by an integrated system including several brain mechanisms which are only partly known (for review, see e.g. Drucker-Colin & Prospero-Garcia, 1990; McGinty & Siegel, 1983).

Jouvet (1967) proposed a monoaminergic theory of sleep which suggested that NREM sleep was induced mainly by the serotonergic raphe system, whereas REM sleep was triggered and regulated by noradrenergic cells in the pontine tegmentum. The more recent theoretical models of NREM/REM oscillation and EEG synchronization and desynchronization (Hobson, Lydic & Baghdoyan, 1986; McCarley & Hobson, 1975; McCarley & Massaquoi, 1986, 1992) suggest a reciprocal interaction between two neuronal populations: REM-on neurons which promote REM sleep and REM-off neurons which suppress it, as described in more detail below.

The REM-on system restrains the muscle tone and generates EEG desychronization and rapid eye movements as well as ponto-geniculo-occipital (PGO) activity. PGO waves refer to the monophasic spikes which herald the transition from NREM to REM sleep and the course of REM state in cats, and which were originally found in the pontine reticular formation (Jouvet, Michel & Corjoun, 1959) and later in the lateral geniculate nucleus (Bizzi & Brooks, 1963a, 1963b; Brooks & Bizzi, 1963) and occipital cortex of the animal (Brooks, 1967a, 1967b; Mouret, Jeannerod & Jouvet, 1963). Although PGO activity has been widely documented in cats but not in humans, periorbital integrated potentials and middle ear muscle activity have been suggested as the human analog or parallel phenomena (Benson & Zarcone, 1979; Pessah & Roffwarg, 1972; Rechtschaffen, Molinari, Watson & Wincor, 1970).

The original reciprocal interaction model (McCarley & Hobson, 1975) postulated the cells of the gigantocellular tegmental field (FTG) and those of the locus coeruleus as the REM-on and REM-off neurons respectively but such a specification was later abandoned (Hobson et al., 1986). According to the revised "limit cycle reciprocal interaction model" (LCRI) (McCarley & Massaquoi, 1992) the onset of REM sleep is generated by cholinergic projections from certain nuclei in the pons (mesopontine laterodorsal and pedunculopontine tegmental) to the effector cells of the reticular formation (REM-on).

The LCRI-model states that the REM-on neurons form an excitatory feedback interaction to maintain the REM state, and that they also begin to

slowly activate the REM-off system located in the serotonergic dorsal raphe nuclei and the noradrenergic locus coeruleus, which subsequently terminate the REM period by inhibiting the REM-on system. The REM-off activity decreases from its maximum after the REM offset due to an inhibitory self regulation and is lowest before the onset of the next REM period. The REM-on/REM-off model by itself, however, cannot be used to explain the generator mechanism of synchronized EEG activity during NREM sleep. Nevertheless, it has been found (Steriade, Curro Dossi & Nunez, 1991) that thalamocortical neurons show a progressive hyperpolarization during the deepening of NREM sleep, and during cortical SWS the membrane potentials of these neurons fluctuate synchronously in the EEG delta range. During transition from SWS to REM sleep the slow thalamic oscillation is suppressed by the cholinergic input from the brainstem nuclei.

## 2.4 Adaptation to sleep recording

Most polygraphic sleep studies presuppose a laboratory setting. Due to the unfamiliar situation and at least partly because of the discomfort caused by the electrodes sleep during the first night in the laboratory is disturbed. This phenomenon referring to the adaptation to altered sleeping conditions is known as the "first night effect" (FNE) (Agnew, Webb & Williams, 1966; Rechtschaffen & Verdone, 1964). It is usually manifested in a significantly longer sleep latency and greater amount of stages W and S1, in stage shifts, and in less REM sleep during the first night in the sleep laboratory as compared with the succeeding nights. Agnew et al. (1966) interpreted the effect to be due to the aroused state of the subjects as they were testing the new environment and suggested that the sleep recording data of the first night should be disregarded.

Later studies have both affirmed (Schmidt & Kaelbling, 1971; Webb & Campbell, 1979) and questioned (Browman & Cartwright, 1980; Clausen, Sersen & Lidsky, 1974; Coble, McPartland, Silva & Kupfer, 1974; Kader & Griffin, 1983) the presence of the FNE in laboratory recordings. It is, however, obvious that adaptation to a change in sleeping conditions depends on both environmental and subjective factors. While the results of Webb and Campbell (1979), for example, confirmed the general aspects of the FNE they also found that the effect does not appear similarly for all individuals and that it is greater among older subjects. The latter was more recently proposed also by Buysse et al. (1991). Kupfer, Weiss, Detre and Foster (1971) studied patients with different psychiatric diagnoses for four consecutive nights. The recordings did not show any FNE, but the virtually constant sleep patterns across the four nights were interpreted to represent a lack of adaptation. Kader and Griffin (1983) who did not find a significant difference between two consecutive nights in their patient group also doubted whether adaptation becomes evident until after several successive nights. Some results in healthy subjects also suggest that adaptation

may require several nights in the new environment, and that the effect may appear differently across different sleep parameters (Balestra et al., 1983; Hartmann, 1968; Rosadini et al., 1983; Schmidt & Kaelbling, 1971). Scharf, Kales and Bixler (1975) reported that readaptation effects similar to the FNE occur when subjects who have previously adapted to the laboratory return there after spending a week at home. Moreover, subjects who are accustomed to sleeping with a partner show an increase in S4 and a decrease in REM sleep when sleeping alone in the laboratory (Monroe, 1969b). Personality differences have also been found between those subjects who show a FNE and those who do not (Edinger, Marsh, McCall, Erwin & Lininger, 1991; Violani & Colavita, 1988), and the study of Hauri and Olmstead (1989) revealed that some insomniacs show a reversed FNE by sleeping better than usual during their first laboratory night. Finally, it has been proposed that the FNE can be reduced or eliminated by making the laboratory setting more natural by arranging it to resemble a normal home or hotel environment as much as possible (Browman & Cartwright, 1980; Coble et al., 1974), nevertheless, it is still usual in most laboratories to have one adaptation night before the experiment proper.

The FNE has not been documented to occur when subjects are recorded at home (Coates, George, et al., 1981; Coates, Rosekind, Strossen, Thoresen & Kirmil-Gray, 1979; 1981; Sharpley, Solomon & Cowen, 1988; Thoman, Acebo & Lamm, 1993) which implies that the disturbing effects of the polygraphic recording as such are not sufficient to elicit the phenomenon. The subjective estimations of normal sleepers, for instance, refer to the better quality of sleep at home than in the laboratory (Baekeland & Hoy, 1971; Frankel, Coursey, Buchbinder & Snyder, 1976), but objective measurements have not revealed significant differences between these two locations (Coates et al., 1979; Sewitch & Kupfer, 1985a, 1985b). The results of Sewitch and Kupfer (1985a, 1985b), however, showed differences between two ambulatory registering methods suggesting that the equipment can have an effect on sleep architecture also during home recordings. Coates et al. (1979) also found significantly less between-subjects and within-subject variability, for example, in total sleep time and sleep latency at home whereas some other sleep parameters, such as minutes awake after sleep onset and the number of arousals, were found to be more stable in the laboratory. Interestingly in this respect, Youmbi-Balderer and Borbely (1988) reported lower nocturnal motor activity percentages in the laboratory than at home. Moreover, although body movements can be thought to reflect the restlessness of sleep, no FNE has been found in nocturnal motor activity either in the laboratory (Browman & Cartwright, 1980; Coble et al., 1974; Kader & Griffin, 1983; Kronholm, Alanen & Hyyppä, 1987) or at home (van Hilten et al. 1993). However, more than 70% of those subjects of Hoelscher et al. (1987) who were studied by using both an ambulatory sleep polygraphy at their homes and a standard polysomnogram in the laboratory subjectively preferred the former procedure. Also, in addition to the increased subjective comfort and privacy, home recordings have been recommended on the basis of savings in labour and costs (e.g. Ancoli-Israel, Kripke, Mason & Messin, 1981).

## 2.5 Laboratory research on dreaming and sleep stages

Aserinsky and Kleitman (1953) found that when subjects were awakened during rapid eye movement periods they reported dreaming in most cases (74%) while awakenings during ocular inactivity yielded only rare detailed dream reports and in 83 % of cases a complete failure to recall any dreaming. This finding was affirmed by Dement and Kleitman (1957b) who found 80% and 7% recall rates for REM and NREM reports, respectively. Even though there have been differences in their definitions of dreaming, later laboratory studies also have revealed high dream recall rates after REM awakenings. The usual range for REM recall has been between 72-90% (Cavallero, Cicogna, Natale, Occhionero & Zito, 1992; Firth & Oswald, 1975; Foulkes, 1962; Foulkes & Rechtschaffen, 1964; Foulkes & Schmidt, 1983; Goodenough, Lewis, Shapiro, Jaret & Sleser, 1965; Goodenough, Witkin, Koulack & Cohen, 1975; Goodenough, Shapiro, Holden & Steinschriber, 1959; Wolpert & Trosman, 1958).

The occurrence of dreaming is not restricted to REM sleep but awakenings during other phases of sleep can also be followed by a dream report. While most of the early studies (Aserinsky & Kleitman, 1953; Dement & Kleitman, 1957b; Wolpert & Trosman, 1958) indicated low dream recall during NREM awakenings, Goodenough et al. (1959), on the other hand, reported a 34% recall rate for NREM dreaming. Subsequently, Foulkes (1962) found a 54% recall of dreaming and an additional 20% of thinking reports during NREM awakenings and suggested that "reportable mental activity is always present" (p. 24) during sleep. Foulkes and Rechtshaffen (1964) also reported of a 89% and 62% dream recall for REM and NREM awakenings respectively but considerable individual differences were revealed in the recall and content of the NREM dreams. Zimmerman (1970) used an auditory arousal threshold as a measure of sleep depth and found that "light" sleepers recalled considerably more (71%) dreaming during NREM awakenings than "deep" sleepers (21%), but there was no difference between the groups in REM mentation. Regardless of the preceding stages, the method of awakening (abrupt vs. gradual) has been shown to have an effect on what is reported, thinking reports being more frequent when the subjects are awakened gradually (Goodenough et al., 1965; Shapiro, Goodenough & Gryler, 1963). The content of REM reports are generally regarded as more like dreaming proper; more affective, bizarre, visual and vivid, whereas NREM mentation is more like thinking and related to contemporary life and everyday things (e.g. Foulkes, 1962; Foulkes & Rechtschaffen, 1964; Rechtschaffen, Verdone & Wheaton, 1963). Nevertheless, it has been suggested that the qualitative differences between REM and NREM mentation, e.g. the greater bizarreness of REM dreams, are merely due to the greater length of REM reports (Antrobus, 1983).

Most of the literature on NREM dreaming has concerned reports obtained after S2. Cavallero et al. (1992) reported about 89%-93% sleep mentation recall rates for REM sleep and 64%-77% for SWS (S3+S4). Even though the REM

reports were significantly longer than the SWS reports and contained more characters, emotions and references to semantic memory sources, the researchers concluded, in agreement with Foulkes (1962), that mental activity is continuously going on during sleep, even in SWS. The results of Fried's group (e.g. Fried et al., 1987; Fried, 1990) also pointed at the continuous nature of sleep mentation.

Some studies have suggested that laboratory dreams have less impulse-related content (e.g. sexual and aggressive elements) than home reports (Domhoff & Kamiya, 1964; Weisz & Foulkes, 1970). Rechtschaffen and Verdone (1964) found less dreaming during the first laboratory night than on succeeding nights. However, more controlled experiments (Foulkes, 1979) do not indicate any significant laboratory effect on dream recall or content. Even though the first night effect on physiological sleep parameters can be reduced by using a comfortable laboratory setting, the phenomenon may still manifest itself as a high incorporation of laboratory and experimental elements in the first night's dreams (Browman & Cartwright, 1980).

## 2.6 Behavioral responsiveness as a measure of sleep depth

The principal methods which have been used in studies on sleep depth have been the analysis of auditory arousal thresholds and the probability and latency of behavioral responses occurring to stimuli presented during sleep. The deepening of NREM sleep from S1 through S2 to SWS has been demonstrated in numerous studies for different variables such as the probability of responding (Badia et al., 1984; Ogilvie & Wilkinson, 1984, 1988; Rechtschaffen, Hauri & Zeitlin, 1966; Williams, Hammack, Daly, Dement & Lubin, 1964; Williams, Morlock & Morlock, 1966), response latencies (Badia et al., 1984; Balkin, Badia, Harsh & Klempert, 1985; Magee, Harsh & Badia, 1987; Ogilvie & Wilkinson, 1984) and stimulus intensities (Bonnet, Johnson & Webb, 1978; Johnson, Church, Seales & Rossiter, 1979; Lammers, Badia, Hughes & Harsh, 1991; Williams et al., 1964). While the depth of NREM stages have been shown to be quite unambiguous, the results with regard to REM sleep have been more inconsistent. According to studies using various methods and different behavioral criteria, REM sleep can be considered either as deep sleep comparable to SWS (Ogilvie & Wilkinson, 1988; Pisano, Rosadini, Rossi & Zattoni, 1966; Williams et al., 1964), relatively light sleep comparable to S2 (Burton, Harsh & Badia, 1988; Lammers et al., 1991; Rechtschaffen et al., 1966; Watson & Rechtschaffen, 1969), or it can be placed somewhere between SWS and S2 (Badia, Harsh, Balkin, O'Rourke & Burton, 1985; Balkin et al., 1985; Bonnet et al., 1978; Johnson et al., 1979) on a hyphothetical depth continuum. Occasionally REM sleep has been considered even lighter than S2 (Langford, Meddis & Pearson, 1974).

In addition to the sleep stage differences, it has been found that responsiveness, especially during S2 and REM sleep, depends on the

meaningfulness of the stimuli (Langford et al., 1974; Oswald, Taylor & Treisman, 1960; Williams et al., 1966), that is, the response latencies decrease and the probability to respond increases when personally significant or otherwise more meaningful stimuli are used as compared with neutral ones. Similarly, the ongoing cognitive activity has an effect on responsiveness, since dreaming tends to decrease it, especially if the stimuli are incorporated into ongoing dreaming (e.g. Bradley & Meddis, 1974; Burton et al., 1988). Moreover, a decrease in the rate of responsiveness or an increase in response latencies as a function of the time of night have also often been reported (Harsh et al., 1987; Lammers & Badia, 1991; Lammers et al., 1991; Williams et al., 1964). In addition to this circadian tendency an ultradian oscillation in responsiveness temporally close to the sleep stage cyclicity has also been described (Harsh, Stone, Leiker & Badia, 1990). Responsiveness appears quite stable across non-consecutive nights (Bonnet & Johnson, 1978) but has been found to decrease across consecutive ones (Badia et al., 1984; Badia et al., 1985; Badia, Harsh & Balkin, 1986; Harsh et al., 1987). The type of response can also have a great effect on the probability of responding. While the percentages of responses have been relatively low in S2, REM sleep, and SWS, in studies using a microswitch closure as a behavioral response (Ogilvie & Wilkinson, 1984, 1988; Williams et al., 1964; Williams et al., 1966), those using a deep breath as an instructed response have reported considerably higher response rates (Badia et al., 1984; Badia et al., 1985; Harsh et al., 1987; Magee et al., 1987).

## 2.7 Subjective estimations of sleep

Monroe (1967) found that subjectively poor sleepers also objectively sleep worse than subjectively good sleepers, but not as badly as would be expected on the basis of their subjective reports. Physiological functioning during sleep among the poor sleepers was closer to waking functions than among the good sleepers. Coates et al. (1982) reported that while good sleepers' estimations concerning the latency to S1 and the time spent awake after sleep onset do not significantly differ from those physiologically recorded, insomniacs report longer S1 latencies and more minutes awake than objectively observed. If questioned during S1 insomniacs tend to report being "awake" whereas good sleepers usually refer to being "drowsy" or "asleep" (Coates et al., 1983). Subjective insomniacs also report less sleep experiences when awakened 3 minutes after the onset of initial S2 (Borkovec, Lane & Van Oot, 1981). It has been suggested that the observed differences in poor sleepers' subjective and objective sleep may be due to a misperception of time (Coates et al., 1982), or the roughness of the physiological measures, as the polygraphic recordings are analysed in 20 or 30 min epochs, and thus some short episodes of arousal are unobserved (Borkovec et al., 1981; Coates et al., 1983). Furthermore, the insomniacs' prolonged subjective sleep latency could be a result of a disability to recognize awakenings and short episodes of sleep i.e. short-lasting

awakenings are interpreted as a continuous wakefulness, as compared to good sleepers who do not perceive these awakenings at all (Knab & Engel, 1988). With the use of some specific markers, insomniacs can be instructed to more accurately differentiate sleep from wakefulness (Downey & Bonnet, 1992).

The experience of sleep onset is not restricted to S1 in normal sleepers either. Bonnet & Moore (1982) found that according to auditory arousal thresholds sleep spindles herald objective sleep onset but that subjective onset appears to be a more uncertain and relatively lengthy period; for instance, 50% of their subjects reported being asleep 2-4 min after the first spindle, 90% felt being asleep after 16 min, and 100% at the latency of 25 min. This uncertainty of subjects in perceiving their state also occurs after consolidated sleep. Sewitch (1984b) noticed that when the subjects were awakened after initial EEG sleep onset the ability to differentiate between sleep and wakefulness was worse in S2 awakenings than during REM sleep. Moreover, during NREM sleep disruptions the sense of having been asleep increases as a function of the length of continuous NREM sleep prior to arousal (Sewitch, 1984a).

The findings concerning the accuracy of night-to-night variations in subjective sleep estimations as compared with objective polygraphic sleep parameters are somewhat ambiguous. Overestimated sleep latencies and underestimated total sleep time have been found among both good sleepers (Bonnet & Moore, 1982; Lewis, 1969) and insomniacs (Carskadon et al., 1976; Kryger, Steljes, Pouliot, Neufeld & Odynski, 1991). Frankel, Coursey, Buchbinder and Snyder (1976) reported similar results for insomniacs but discrepancies in the opposite direction for normal controls. The normal subjects of Lewis (1969) overestimated the number of awakenings, but the insomniacs studied by Carskadon et al. (1976) underestimated their frequency which is in concordance with more recent observations (Knab & Engel, 1988). According to Frankel et al. (1976) insomniacs report more night-to-night variations than are observed in sleep polygraphy. Baekeland and Hoy (1971) found in normal sleepers that the subjective evaluations of sleep are mainly related to the episodes of wakefulness rather than to the stages of sleep. Saletu (1975) reported that subjectively, increased sleep latency, the number of awakenings, as well as decreased sleep comfort, depth, and restlessness, together with increased drowsiness in the morning, were associated with increased polygraphically defined wakefulness and movement time. Johns (1975) carried out a factor analytic study using standard sleep polygraphy and subjective estimations. Two of the four sleep quality factors, i.e. fragmentation of sleep and sleep latency, revealed high loadings on both subjective and objective variables. Bonnet and Johnson (1978) did not find a significant relation between nocturnal auditory arousal thresholds and subjective sleep depth but the latter was reversibly related to the amount of polygraphically defined W and S1. Visser et al. (1979) reported parallel inter-night changes on subjective and objective sleep parameters as well as on performance and vigilance tests when subjects were predisposed to disturbing external pre-sleep stimuli.

Different studies have revealed both quite strong (Kryger et al., 1981; Saletu, 1975; Violani & Cagnoli, 1985) and weak (Webb & Schneider-Helmert,

1984; Weiss, McPartland & Kupfer, 1973) relationships between subjective and objective sleep parameters. Even though statistically significant, the correlations between subjective estimations and polygraphic characteristics may appear to be relatively low (Spiegel, 1981; Webb & Schneider-Helmert, 1984). They may also be high at the group level but can show great individual differences (Kryger et al., 1981). Young subjects for example show higher correlations between habitual subjective sleep and laboratory recordings than elderly people (Buysse et al., 1991). Females have also been reported to show higher correlations between subjective and objective measures (Hoch et al., 1987; Kaartinen & Lyytinen, 1990; Spiegel, 1981) referring to their better ability to accurately estimate their physiological state. As would be expexted, there are individual differences also among women, since Shaver, Giblin & Paulsen (1991) described four subtypes showing both low and high correlations concerning subjective vs. objective sleep.

Factor analytic studies of different sleep questionnaire data have revealed the characteristics which are most typically used when people describe their sleeping patterns. In spite of the differences in the naming of the factors these include evaluations of latency, depth, and length of sleep (which refer to the ability to initiate and maintain sleep), and the recall and quality of dreaming (Domino, Blair & Bridges, 1984; Evans, 1977; Webb, Bonnet & Blume, 1976). According to Poelstra (1984) the correlation coefficients between reported and recorded sleep are affected by the variety of the subjective criteria which are applied by individuals when they evaluate their sleep quality, e.g. whether or not objective characteristics, like duration of sleep, are perceived or thought of as important, and by individual ideas about what is normal and what is not. Some groups of psychiatric patients, for instance, do not seem to use the amount of sleep in their subjective assessments (Weiss et al., 1973).

Even though the reports concerning the accuracy of subjective sleep estimations are ambiguous, the results do not challenge the significance of individual experience. Johns (1975), for example, stated that most hypnotic drug prescriptions are written based upon subjective reports, without any objective investigation, and the situation has hardly changed during the last two decades. Also, according to Evans (1977), the usefulness of subjective sleep parameters does not depend on their correlations with EEG sleep, and that experienced sleep difficulties should therefore be taken seriously regardless of the objective findings. Furthermore, Trinder (1988) proposed that the lack of objective evidence regarding the disturbed sleep of so called subjective insomniacs may be due to too few registering nights for the problem to be manifested.

## 2.8 Autonomic nervous system activities in sleep

In addition to brain activity, eye movements, and muscle tonus, several somatic activities controlled by the autonomic nervous system (ANS) reflect the cyclic

variation between NREM and REM sleep. The autonomic concomitants of NREM/REM oscillation were already noticed by Aserinsky and Kleitman (1953) who reported that the cyclicly occurring periods of rapid eye movements were accompanied by an increased respiratory and heart rate as well as by peaks in body motility. Snyder, Hobson, Morrison and Goldfrank (1964) described a decrease in respiratory rate, heart rate, and systolic blood pressure in NREM sleep as compared with wakefulness, but a slight increase in them (7 %, 6 %, and 4 %, respectively) during REM sleep. Since then the decrease in pulse and breathing frequency from the presleep level to the NREM stages S1-S4 and their subsequent increment during REM sleep has been repeatedly reported (Aldredge & Welch, 1973; Johnson, 1970; Khatri & Freis, 1967; Zemaityte, Varoneckas & Sokolov, 1984). The studies of Khatri and Freis (1967) and Coccagna, Mantovani, Brignani, Manzini and Lugaresi (1971) have also shown a decline in blood pressure from wakefulness to NREM sleep and a slight increase in REM sleep. The decreasing trend in autonomic functions from wakefulness to NREM sleep appears constant for different mammalian species, but the animal data concerning REM sleep are not as unambiguous. Cardiovascular variables (heart rate, blood pressure) generally show a further decrease from NREM to REM sleep (Baust & Bohnert, 1969; Fewell, Williams & Hill, 1985; Gassel, Ghelardicci, Marchifava & Pompeiano, 1964) while respiratory frequency increases as in humans (Orem, Netick & Dement, 1977; Phillipson, Murphy & Kozar, 1976).

Both human and animal data indicate that the variability of autonomic variables more clearly differentiates between NREM and REM sleep than the rates or levels of these parameters per se. In mammals, NREM sleep is characterized by regular autonomic activity, while an augmented irregularity in breathing, cardiac activity, and blood pressure, resembling that during active wakefulness, is characteristic of REM sleep. For example, although Snyder et al. (1964) found a slight average increase in ANS variables from S2 to REM sleep they also reported an increase of more than 50 % in their short-term variability. The changes during REM sleep were often associated with eye movement bursts. Autonomic parameters oscillated quite regularly during NREM sleep when abrupt rises associated with gross body movements or transient arousals were excluded. The variability indices during S2 were slightly but insignificantly higher than those during SWS. Subsequently, the differences in variability of autonomic activity between the human NREM sleep stages have been both questioned (Cajochen, Pischke, Aeschbach & Borbely, 1994; Lisenby, Richardson & Welch, 1976; Snyder, 1967) and confirmed (Aldredge & Welch, 1973; Shore, Millman, Silage, Chung & Pack, 1985; Zemaityte et al., 1984). Interestingly, as regards the differences in ANS activity between the standard stages of sleep and wakefulness, similar heart rate power spectra have been reported for awake, stage 1 and REM sleep, and for S2-S4 respectively (Lisenby et al., 1976; Zemaityte et al., 1984). In addition to these stage related changes, considerable phasic changes in autonomic variables can also be found during all sleep stages in relation to body movements with or without cortical signs of

arousal (Alihanka, 1982; Altshuler & Brebbia, 1967; Baust & Bohnert, 1969; Brooks et al., 1956; Townsend, Johnson, Naitoh & Muzet, 1975).

The increased variability of autonomic nervous system activities in REM sleep has been confirmed for irregular breathing patterns (Bülow, 1963; Johnson, 1970; Hathorn, 1974; Phillipson et al., 1976; Remmers, Bartlett & Putnam, 1976; Tabachnik, Muller, Bryan & Levison, 1981) and for heart rate variability (Aldredge & Welch, 1973; Johnson, 1970; Zemaityte et al., 1984). Phasic changes in both heart rate (Baust & Bohnert, 1969; Gassel, Ghelarducci et al., 1964) and respiration (Aserinsky, 1965; Goodenough et al., 1975; Spreng, Johnson & Lubin, 1968) have been found to coincide with REM bursts. Shapiro, Goodenough, Biederman and Sleser (1964) also reported of more irregular respiratory rates during those REM sleep awakenings which were followed by dreaming reports than during those which led to reports with no dream recall. Increased rate of respiration has also been found to be related to the emotional content and vividness of both REM and NREM dream reports (Hobson, Goldfrank & Snyder, 1965).

The primary animal experiments on the autonomic control of cardiac activity during sleep were performed by Baust and his co-workers (Baust, Böhmke & Blossfeld, 1971a, 1971b; Baust & Bohnert, 1969; Baust, Weidinger & Kirchner, 1968). The studies with cats indicated a manifold course of changes in ANS activity during transitions from wakefulness to the different stages of sleep. There was a general increase in parasympathetic vagal tone in NREM sleep and further a tonically decreased sympathetic discharge in REM sleep (Baust et al., 1968; Baust & Bohnert, 1969). Evoked sympathetic responses were reduced to the lowest level during REM sleep, but the evoked parasympathetic responses during REM sleep approximated those during wakefulness (Baust et al., 1971a, 1971b). Phasic heart rate accelerations during REM sleep were due to inhibition of parasympathetic vagal activity, while the following decelerations were caused by a combination of the phasic inhibition of sympathetic activity and an increase in parasympathetic discharge (Baust & Bohnert, 1969). The heart rate accelerations after arousal were caused by a phasic inhibition of parasympathetic activity (Baust & Bohnert, 1969). According to Mancia and Zanchetti (1980) the same tonic and phasic cardiovascular phenomena apparently occur both in cats and humans, with the less evident tonic inhibition during human REM sleep being presumably due to the greater extent of phasic phenomena as compared with cats. Studies on autonomic functions during sleep in human subjects systematically confirm augmented parasympathetic dominance during NREM sleep (e.g. Baharav et al., 1995; Zemaityte et al., 1984). On the other hand, while Zemaityte et al. (1984) found a reduction in parasympathetic control during REM sleep and a constant sympathetic activity throughout stages 2-4 and REM sleep, several reports have suggested an increase in sympathetic activity during REM sleep (e.g. Hersch, Antrobus, Arkin & Singer, 1970; Baharav et al., 1995; Okada, Iwase, Mano, Sugiyama and Watanabe, 1995; Shimizu et al., 1992).

Regular respiration in NREM sleep is influenced by parasympathetic vagal activity and other peripheral afferent functions whereas the irregular

breathing pattern in REM sleep is relatively independent from these (Phillipson et al., 1976; Sullivan, Kozar, Murphy & Phillipson, 1978). According to modern theories of respiratory regulation there are two distinct control systems responsible for the different kinds of breathing patterns in NREM and REM sleep. Respiration in NREM sleep is controlled by an automatic metabolic system while during REM sleep a voluntary, behavioral system has influence on breathing, resembling respiratory control during active wakefulness (Orem, 1990; Phillipson & Sullivan, 1978; Sullivan 1980).

## 2.9 Body movements during sleep

Sleep is characterized by a relative immobility and, in turn, increased motor activity in bed can be regarded as a sign of disturbed sleep. In the standard sleep stage scoring (Rechtschaffen & Kales, 1968) an epoch is scored as *movement time* (MT) when more than 50% of the EEG and EOG tracings during it are obscured by elevated EMG activity (or amplifier blocking). There are separate definitions for discrete *body movements* and *movement arousals*, which should be distinguished from the MT epochs, but it is also stated that researchers do not need to report them because MT "will usually satisfy the criteria for body movements and movement arousals" (Rechtschaffen & Kales, 1968, p. 5). This has actually been the case for the majority of sleep studies since then. Even MT is often omitted in descriptions of sleep architecture, and only the percentages for different sleep stages and wakefulness are presented. Indeed, during the early years of sleep psychophysiology body movements were commonly regarded as bare artifacts, hardly worth of attention (Altshuler & Brebbia, 1967).

In those studies where nocturnal body movements have been explicitly investigated, the number of movements observed per night varies due to the accuracy of different kinds of measuring methods. For example Moses, Lubin, Naitoh and Johnson (1972), who used the *EEG-artifact* method described above, reported an average of about 14 movements/night, whereas Alihanka and Vaahtoranta (1979) found 80-200 movements during one night using the static charge sensitive bed (SCSB). The EEG-artifact procedure has been the most commonly used, but a variety of other methods also have been applied for detecting body movements during sleep. They include "sensitive bed methods" measuring the displacement of the bed (Muzet, Becht, Jacquot & Koenig, 1972; Stonehill & Crisp, 1971), the SCSB method (Alihanka & Vaahtoranta, 1979), and the polyvinylidenefluoride (PVDF) mattress (Siivola, 1989) which are all capable of registering movements from all parts of the body, although they are generally incompetent in providing information about the part of the body where the movement occurred. On the other hand, the EMG and different kinds of transducers, such as semiconductor strain gauges (Baldridge, Whitman & Kramer, 1965) and piezo-electric actigraphs (Kripke, Mullaney, Messin & Wyborney, 1978) can be used to register the motility of different limbs and

other specific parts of the body. When these methods are used multiple channels and transducers are needed for an overall view of motility. Direct observations and continuous or time-lapse photography and video recording (Aaronson, Rashed, Biber & Hobson, 1982; De Koninck, Gagnon & Lallier, 1983; Fuller, Wenner & Blackburn, 1978; Hobson, Spagna & Malenka, 1978) have also been applied in studies on sleep motility. Because of this diversity of methods and their sensitivity, the literature on nocturnal motor activity should be interpreted with caution, especially as regards the absolute numeric values.

As compared with wakefulness, the rate of body motility is clearly lower in sleep but movements still occur during all sleep stages, even though there are differences in their number, duration and type between the stages. Brief and sudden bodily jerks, for instance, are common during the transition phase when falling asleep (Oswald, 1959). In NREM sleep motor activity decreases as sleep deepens and movements are most infrequent in SWS (Alihanka, 1982; Dement & Kleitman, 1957; Gastault & Broughton, 1965; Middelkoop, van Hilten, Kramer & Kamphuisen, 1993; Monroe, 1967; Sassin & Johnson, 1968; Wilde-Frenz & Schulz, 1983). The longest immobility periods in a sleep cycle are usually found during descending NREM sleep (Aaronson et al., 1982; De Koninck et al., 1983; Hobson et al., 1978; Middelkoop et al., 1993).

In spite of the general loss of the muscle tone during REM sleep, an elevation of motility in REM sleep has been reported (Alihanka, 1982; Gastault & Broughton, 1965; Hasan & Alihanka, 1981; Sassin & Johnson, 1968; Wilde-Frenz & Schulz, 1983). The increase is mainly a result of small and short lasting (twitching) movements. Dement and Kleitman (1957) reported that while the number of gross movements sharply decreased during REM sleep, there was an increase in the frequency of small distal limb and digital movements, which could be seen by direct observation but not as EEG artifacts or by the motility recording system attached to the bed spring. These small twitching movements occur often but not always concomitantly with REM bursts (Baldridge et al., 1965; Gassel, Marchiafava & Pompeiano, 1964). Furthermore, using direct observation, EMG, and video recording, Gardner, Grossman, Roffwarg and Weiner (1975) found that reported dreamed actions are significantly related to such actual small movements during REM sleep with respect to amount and girdle location. Indeed, the appearance of short and small movements during REM sleep is a well known phenomenon but because the duration of the movements is rarely reported, only occasional references concerning small movements during normal sleep can be found in recent sleep literature (Aaronson et al., 1982; Alihanka, 1982; Erkinjuntti, 1988; Hasan & Alihanka, 1981).

Some early studies suggested that a certain number of gross body movements are needed to avoid discomfort and to maintain sleep (e.g. Johnson & Swan, 1930). The explanatory value of this assumption was questioned by Muzet, Naitoh, Townsend and Johnson (1972) who found that gross movements are related to stage changes both within NREM and between NREM and REM sleep, especially during transitions from SWS to S2 and from S2 to REM sleep. Nocturnal body movements can be evoked by external stimuli

(Goebel & Jovanivic, 1977; Harsh et al., 1987; Muzet, Naitoh, Johnson & Townsend, 1974; Townsend, Johnson & Muzet, 1973), but presumably due to adaptation, long lasting exposure to nocturnal noise does not have a significant effect on sleep motility (Horne, Pankhurst, Reyner, Hume & Diamond, 1994; Muzet et al, 1974). During the first night after total sleep loss the rate of motility decreases in all sleep stages as compared with the pre-experimental level but returns to the baseline during the second recovery night (Naitoh, Muzet, Johnson & Moses, 1973).

The nocturnal motor activity of poor sleepers is significantly higher than that of good sleepers (Hobson et al., 1978; Kronholm et al., 1987; Monroe, 1967). In their study on the reliability of different sleep measures Moses et al. (1972) found in normal sleepers that the number of body movements is intra-individually one of the most stable sleep parameters. It is apparent that those movements were linked to the changes in body position, because similar nocturnal ranges have been more recently reported for the major postural shifts (Aaronson et al., 1982; Alihanka, 1982). Data collected by using more sensitive movement detectors also suggest the night-to-night consistency of gross movements in good sleepers (Kronholm et al., 1987). On the other hand, the intra-individual variability in the frequency of small movements can be even greater than the variation between individuals (Merica & Gaillard, 1985; Kronholm et al., 1987). In patients with sleep complaints great intra-individual variance has been found in both small and gross movements (Kronholm et al., 1987).

While the values of some sleep parameters during the first night in the laboratory are significantly different from those registered during subsequent nights (Agnew et al., 1966), no FNE has been found in motor activity (Coble et al., 1974; van Hilten et al. 1993; Kader & Griffin, 1983; Kronholm et al., 1987) and due to the absence of this phenomenon Kronholm et al. (1987) and van Hilten et al. (1993) suggested that single-night recordings ought to be sufficient, even though both of these studies also revealed great differences in the number of movements between individuals and nights. Kaartinen and Lyytinen (1990), on the other hand, reported a pendulum-like trend in motility across four consecutive nights, and other studies with several consecutive nights have furthermore indicated associations between changes in various parameters of motility and subjective sleep quality (Horne et al. 1994; Kecklund, Åkerstedt & Sigurdson, 1991; Kaartinen & Lyytinen, 1990). Therefore, even though body movements are normal phenomena during sleep they can also reflect a heightened nocturnal psychophysiological arousal (Kronholm et al., 1993; Monroe, 1967) and thus be signals of restless sleep and some sleep disturbance.

The appearance of new sensitive movement detectors, such as actigraphs and the SCSB, has greatly increased the interest in nocturnal motility during the last two decades. As compared with traditional procedures the new methods can easily be used in naturalistic settings, because they do not presuppose complicated registering equipment or a laboratory environment. Actigraphs (Kripke et al., 1978) are small piezo-electric acceleration sensors and, generally, the movement records are based on the activity of one limb, usually that of the

nondominant hand (for review, see Sadeh, Hauri, Kripke & Lavie, 1995). The method has been used for obtaining estimations of sleep time by making sleep/wakefulness distinctions on the basis motor activity (Cole, Kripke, Gruen, Mullaney & Gillin, 1992; Kripke et al., 1978; Mullaney, Kripke & Messin, 1980; Sadeh, Alster, Urbach & Lavie, 1989; Webster, Kripke, Messin, Mullaney & Wyborney, 1982). The actigraphic motility recordings have been applied in sleep studies for evaluating, for instance, the effects of behavioral interventions (Sadeh, 1994), drugs (Borbely, 1986), and aircraft noise (Horne et al., 1994).

The SCSB is an unobtrusive sensor which has been developed for the recording of body motility and autonomic nervous system functions which manifest themselves as movements (Alihanka & Vaahtoranta, 1979; Alihanka, Vaahtoranta & Saarikivi, 1981). The method will be described in more detail below.

## 2.10 Static charge sensitive bed (SCSB) analysis

The static charge sensitive bed (SCSB) is a transducer which was developed to register a wide range of movements from all parts of the body (Alihanka & Vaahtoranta, 1979). In addition to ordinary body movements like postural shifts, other organized movements and twitches of the limbs, respiratory movements and those caused by the recoil power of the pumping action of the heart (ballistocardiography, BCG) can also be registered (Alihanka, 1982; Alihanka et al., 1981). No electrodes or other attachments to subjects are needed. The device is an approximately 2 cm thick plate which is placed on an ordinary bed under a normal foam plastic mattress. Movements from the whole area of the bed generate a static charge distribution in the active layers of the sensor and these charges induce potential differences between two large metal plates which are isolated from each other. The static charge layers and the metal plates are enclosed in a grounded metal folio. The potential differences between the metal plates are amplified. Respiratory movements and the BCG are filtered from the original movement signal by using appropriate band-pass settings. The preamplifier providing three signals (the unfiltered, moderately amplified movement signal and the filtered and further amplified respiratory and BCG signals) can be coupled with a polygraph, a tape-recorder or computer's A/D-converter. For visual analysis the curves are drawn by using a relatively slow speed of 1 mm/sec (Alihanka, 1987). The three SCSB signals are illustrated in Figure 2.

The SCSB has been used in studies investigating sleep movements in healthy adults (eg. Alihanka, 1982; Hasan, 1983; Kaartinen & Lyytinen, 1990) and in studies comparing nocturnal motor activity in different patient groups and non-patient controls. The former have included poor sleepers with non-specific somatic complaints (Hyyppä & Kronholm, 1987; Kronholm et al., 1987; 1993), teethgrinders (Sjöholm, Polo & Alihanka, 1992), and patients with Parkinson's disease (Laihinen, Alihanka, Raitasuo & Rinne, 1987) and

fibromyalgia (Hyyppä & Kronholm, 1995). Erkinjuntti (1988) also investigated sleep movements in healthy and neurologically damaged infants by using the SCSB. The method has also been applied as a movement detector in animal studies with cats (Valleala, Vaahtoranta & Alihanka, 1981), rats (Hilakivi & Hilakivi, 1986; Hilakivi, Taira & Hilakivi, 1988), and mice (Päivärinta & Korpi, 1989).

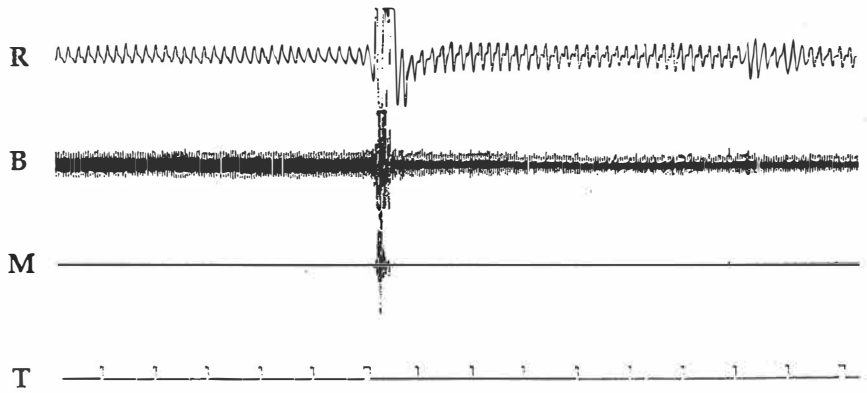


FIGURE 2 Five minutes of SCSB registering (R = respiration, B = BCG, M = movement channel, T = timer pulse). A body movement can be seen near the middle and some irregularity of respiration is apparent at the end of the sample. The broader timer pulses indicate a 3 min epoch and the narrower refer to each 20 sec interval. (An unpublished sample adopted from the experiment of Kaartinen and Lyytinen (1990).)

The term ballistocardiogram (BCG) was introduced to the literature by Starr, Rawson, Schroeder and Joseph (1939) for the recording of body movements caused by the heartbeat. According to Alihanka et al. (1981) the SCSB provides BCG signals comparable with the ultra low frequency (ULF) BCG (eg. Smith, 1974) and respiratory signals corresponding to those obtained by using the conventional impedance method. Since the discovery of the SCSB the utilization of the BCG channel has been quite uncommon (eg. Alihanka, 1982) and not until recently has there been interest in evaluating it in particular (Jansen, Larson & Shankar, 1991; Kirjavainen, Polo, McNamara, Vaahtoranta & Sullivan, 1996; Polo, Tafti, Hämäläinen, Vaahtoranta & Alihanka, 1992). On the other hand, the respiratory channel has been widely applied and the most significant utilization of the SCSB has been in the screening of sleep related respiratory problems in adults (eg. Partinen, Alihanka & Hasan, 1983; Polo, 1992; Polo, Brissaud, Sales, Besset & Billiard, 1988; Polo et al. 1991; Salmi, Partinen, Hyyppä & Kronholm, 1986; Svanborg, Larsson, Carlsson-Nordlander & Pirskanen, 1990). The method has also been applied in recording respiration in infants and young children (Erkinjuntti, Vaahtoranta, Alihanka & Kero, 1984; Kirjavainen, Cooper, Polo & Sullivan, 1996b).

Different combinations of the three SCSB signals and scoring procedures have been suggested in order to represent activity states which, more or less, would reflect the general cyclic variations in EEG sleep. It has also been suggested that some kind of sleep staging might be possible using the SCSB. Hasan and Alihanka (1981), for example, found a 75% agreement in REM/NREM classifications between EEG-EOG recordings and stages defined by the occurrence of short (< 5 sec) SCSB movements. Alihanka, Toivonen, Hasan and Vaahtoranta (1983) also reported that the classified index sums of respiratory and cardiac activity and body motility, that is the "autonomic sleep stages" of active (AS), intermediate (IS), and quiet sleep (QS), were related to the standard sleep stage classifications. AS showed "good temporal correlation" with REM sleep and partial overlapping with S2 especially before REM periods. QS correlated with S3 and S4, overlapping with the adjoining S2. Nevertheless, no exact numeric values for the correlations were presented.

Alihanka (1987) presented criteria for the visual analysis of SCSB recording in adults. The SCSB activity states are defined according to the stability and irregularity of respiration and the BCG, and the frequency of small body movements. The signals are analyzed in 3 min epochs and variability scores are given to each parameter according to special rules. Because the absolute amplitude values depend on the subjects position, only the relative changes during epochs are taken into consideration in scoring. The sum of scores from the three channels is classified into three activity categories: QS, IS, and AS. In newborn infants and young children quite successful sleep state scoring as compared with the EEG-based polygraphy has been achieved by using visual analysis of the SCSB data (Erkinjuntti, Kero, Halonen, Mikola & Sainio, 1990; Kirjavainen, Cooper, Polo & Sullivan, 1996a). The SCSB has also been used to distinguish between the principal sleep states in animals (Hilakivi et al., 1988; Valleala et al., 1981).

Salmi and Leinonen (1986) used the automatic analysis of body movements for classifying SCSB data into wakefulness, active sleep, and quiet sleep. Comparisons with a simultaneous polysomnography showed a 81% agreement with NREM-REM variation. Jansen and Shankar (1993) aimed at an automatic sleep staging by using body movements and the BCG. They concluded that changes in motility and BCG activity are not consistent enough to perform reliable sleep staging. A classification system distinguishing between awake, REM and NREM sleep yielded a better result, and agreement rates from 86% to 98% were achieved in discriminating between sleep and wakefulness. Recently, Pulli, Härmä, Hasan, Värri and Loula (1994) compared the three automatically analyzed SCSB signals with the amount of EEG delta activity. The autonomic activity index (AAI) was defined as a sum score of several variability parameters provided by the BR01 software. No linear correlation was found between the AAI and the amount of delta during NREM sleep in the first sleep cycle after night shift work. However, the data automatically classified as QS, IS, and AS quite well differentiated the average distributions of "high" and "low"" amplitude delta activity (29 μV as a criterion).

# 3 AIMS OF THE STUDIES

In addition to the movement based methods reviewed above (section 2.9) numerous other alternative types of sleep recording procedures using different physiological parameters (e.g. Helfand, Lavie & Hobson, 1986; Mamelak & Hobson, 1989; Okuma, Fukuma & Hata, 1971; Welch & Richardson, 1973) have been introduced since the standard criteria for registering, scoring, and defining the stages of sleep (Rechtschaffen & Kales, 1968) were published. The main reason for them has been that the standard sleep polygraphy has been considered too complicated and expensive for different kinds of applications. Moreover, polygraphic studies in the laboratory can also have effects on sleep architecture (e.g. Agnew et al., 1966), in some cases even paradoxial ones (Hauri & Olmstead, 1989). The sleep polygraphy is also too laborious to be widely applied in long-term follow up studies with an extended number of subjects, and whereas subjective reports of sleep quality are important and useful, they are often imperfect and even unreliable. Therefore there is a need for objective methods which are uncomplicated and low-cost as compared with the standard sleep polygraphy, and which can be easily used in natural sleeping environments.

The general aim of the present studies was to investigate the validity and reliability of the SCSB based measures in order to evaluate, whether and to what extent the method can be applied to psychological/psychophysiological studies on sleep. According to the literature nocturnal body movements and autonomic nervous functions have concomitant features with the cyclic variations of the sleep stages. Previous studies have already suggested a relation between SCSB recordings and the stages of sleep. The following experiments were carried out in order to systematically and critically assess the SCSB as a method for psychological studies on sleep quality and dreaming.

Alihanka (1987) presented rules for the visual analysis and scoring of the SCSB signals and for defining the "autonomic sleep stages". Even though there have been some references in the literature to these kinds of "stages" their validity has not been tested. The aim of Study I was to critically evaluate the visual analysis of the SCSB signals by comparing the SCSB data with the standard sleep polygraphy.

The purpose of Study II was to investigate whether the SCSB could be applied in dream research. In the light of the literature it was hypothesized that there would be differences in dream recall if the subjects were awakened during different kinds of SCSB activity.

The software (BR01) used in the automatic analysis of SCSB data was recently presented and compared with EEG delta activity (Pulli et al., 1994). As a validated automatic analysis would increase the usefulness of the SCSB, the various parameters provided by the BR01 program were assessed in Study III. The automatically analyzed whole night SCSB data were compared with the standard stages of sleep.

Study IV was performed in order to behaviorally assess whether the SCSB activity states could be used as rough indicators of the depth of sleep. The behavioral responsiveness to instructed auditory stimuli during quiet (QS), intermediate (IS), and active (AS) states as defined in Study III was compared to the standard polygraphic criteria.

Single-night recordings have been suggested as an objective measure of sleep quality, because no systematic FNE has been found in nocturnal body movements. Study V focused therefore on the between-subjects differences in body movements and the SCSB activity states, on the intra-subject stability of these measures, and on their relationship with different aspects of subjective sleep quality.

# 4 SUMMARY OF THE STUDIES

## 4.1 Study I

The aim of the study was to investigate the relationship between standard EEG, EMG, and EOG based sleep stages and activity states defined using the visual analysis of SCSB recordings. For the SCSB analysis a slight modification of the scoring system suggested by Alihanka (1987) was applied.

### 4.1.1 Methods

The nine healthy subjects (mean age of 25.0) of the study were adapted to sleep in the laboratory. EEG, EMG, and EOG were registered from the standard sites (Rechtschaffen & Kales, 1968) and displayed on-line through a Beckman Type R411 Dynograph (paper speed 10 mm/sec). The sleep stages were defined in 20 sec epochs independently by two clinical neurophysiologists. Stages 3 and 4 were combined as SWS. Only the epochs with consensus between the two raters were used in the comparison with the SCSB data.

The original SCSB movement signal was filtered by a BR-CPA8 preamplifier. The band-pass settings for respiration and BCG were 0.3-1 Hz and 5-30 Hz respectively. The resulting three signals were recorded with a Hewlett-Packard 3960 Instrumentation Recorder and run off-line into the Beckman polygraph with paper speed corresponding to 1.25 mm/sec real time. The SCSB activity states were based on the activity index (AI) which is the sum of scores indicating the stability and irregularity of respiration and BCG, and the frequency of small body movements during 3 min epochs. Figure 3 shows nine SCSB epochs illustrating the SCSB states. In general, QS is characterized by immobility together with regular breathing and cardiac activity. In AS, considerable variations in the amplitudes and frequencies of the autonomic curves and the occurrence of small body movements are typical, whereas in IS the sum of activity scores falls between those of the other two. Alihanka (1987)

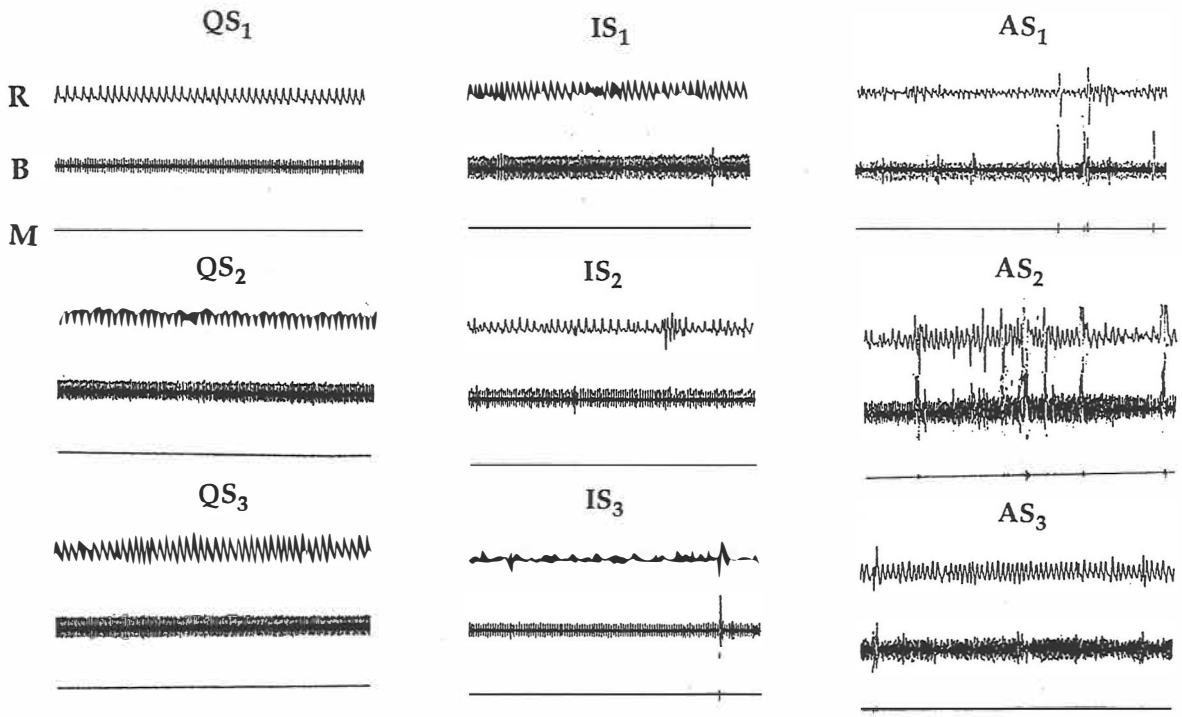


FIGURE 3 Nine 3 min epochs illustrating the SCSB activity states (R = respiration, B = BCG, M = movement channel). The motionless QS tracings with regular BCG show increasing irregularity of the respiratory signal from $QS_1$ to $QS_3$. Each of the IS examples indicate some variability on the autonomic channels and one short body movement is present in $IS_3$. Several twitching movements and the consirable irregularity of the autonomic parameters can be seen in $AS_1$ and $AS_2$. $AS_3$ shows an example of the "slow BCG amplitude variation".

has suggested that an epoch should be scored as motor active wakefulness (MAW) if the total duration of motility during an epoch exceeds 40 sec.

### 4.1.2 Results

The overall inter-scorer agreement for the sleep stages was 76.0%. The disagreements were mainly found between S2 and SWS. If S1, S2, and SWS were combined as NREM sleep, agreement would have been 93.3%.

The SCSB epochs scored as MAW were mainly obtained from a single subject. The polygraphic data during MAW epochs included mostly W or MT (56.7%) but they represented only 8.9% of all W or MT. One subject who stayed awake for 2.5 hours in bed prior to sleep onset, had only one MAW episode. As a consequence, the MAW epochs were scored again according to the signals available when the motility was excluded.

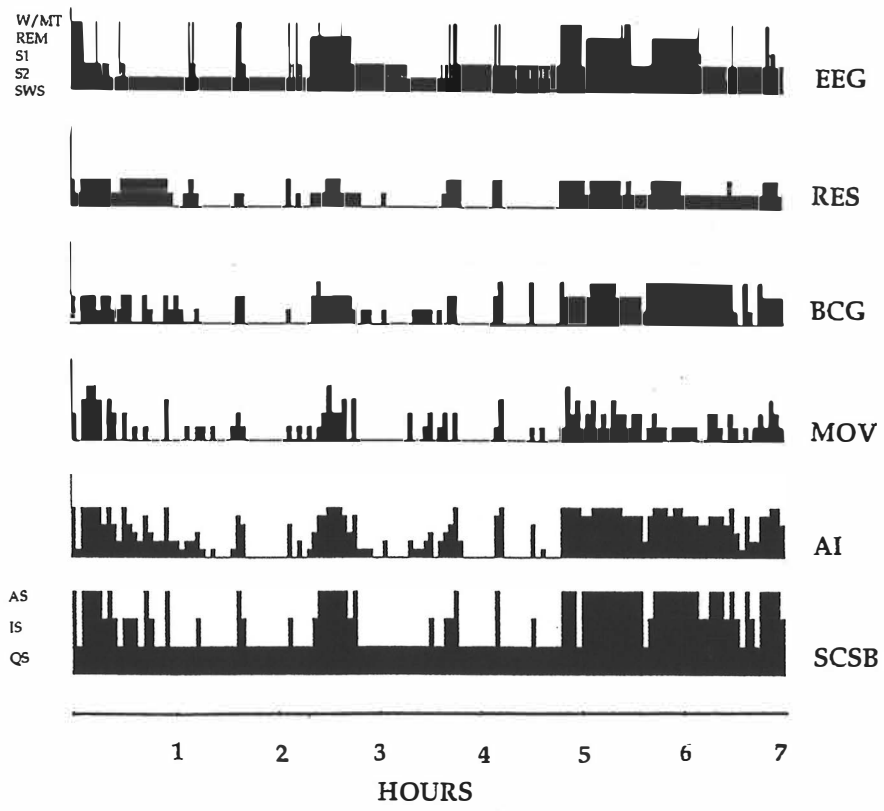


FIGURE 4 The sleep stages (EEG) as defined by one scorer, the calculation of the activity index (AI) as a sum of three parameters (RES = respiration, BCG = ballistocardiogram, MOV = small movements), and the final SCSB activity state categories (SCSB) of one subject.

The mean scores of all SCSB parameters during W, S1, REM and MT were clearly above those found in S2, and the lowest SCSB scores for all parameters were found during SWS. The mean AIs were highest during REM sleep but in the same range as those during W, S1, and MT. As compared with these, the AIs during S2 were significantly ($p<.001$) lower, and lower still in SWS. An example of the calculation of the AI according to the three signals, of the activity states following the categorization of the AI, and of the EEG based sleep stages is presented in Figure 4.

QS and IS occurred mainly during NREM sleep across the subjects (Figure 5); 94.3% of QS and 78.8% of IS took place during S2 or SWS. In turn 97.0% of the SCSB data during SWS and 81.1% in S2 consisted of QS or IS. The distribution of AS was more variable and most deviant in two subjects. The SCSB records during REM sleep were mostly scored as AS but the total nocturnal AS was a combination of both REM sleep and S2. Subject 4 (see Figure 5) accounted for the majority of AS during W/MT due to her long sleep latency, and subject 6 had a lot of AS due to small periodic movements during S2. Generally, if abrupt changes were not taken into account, practically all lasting variations after sleep onset in the SCSB activity states reflected the NREM-REM variation. The close temporal relationship between AS and REM periods in undisturbed sleep was evident, even though there was fluctuation in timing. The second scoring of four SCSB records yielded a 87.4 % agreement for the activity states.

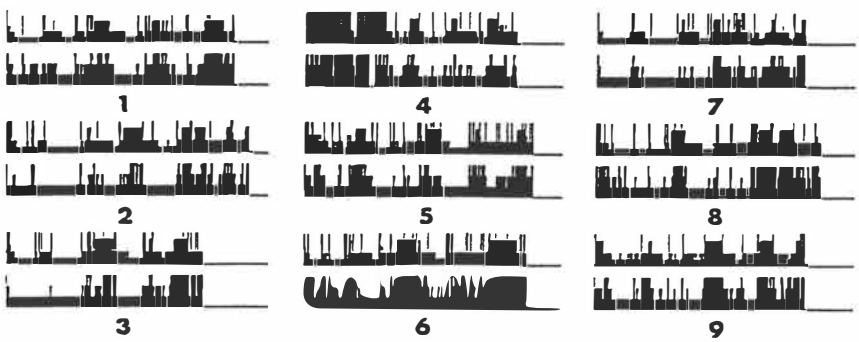


FIGURE 5 The sleep stages (upper parts) and SCSB activity states (lower parts) of the nine subjects. Despite the individual differences the cyclic trends are obvious across the subjects. Subject 4 had an extended sleep latency and subject 6 showed several episodes of small periodic movements during S2.

### 4.1.3 Discussion

The overall tendency shows that IS and especially QS become more common and AS more rare with the descending arousal and deepening of NREM sleep. QS and IS therefore seem to be useful indicators of the amount of NREM sleep. In undisturbed sleep AS is particularly related to REM sleep, overlapping with S2, especially during the morning hours. If only continuous

AS (two or more consecutive epochs) after the first hour was taken into account the role of nocturnal AS as a concomitant of REM sleep would be even clearer. On the other hand, a noticeable amount of AS during the first hours in bed obviously indicates disturbed sleep. The results suggest that the NREM-REM cyclicity of sleep can be roughly estimated by using SCSB registering. The second analysis of four SCSB records showed a reasonably high reliability for the visual scoring system.

## 4.2 Study II

Sleep mentation related to the SCSB activity states, QS, IS, and AS was investigated in this study. It was hypothesized that the SCSB could provide an alternative and uncomplicated method for detecting the dreaming phases in a relatively natural setting as compared with the standard EEG based sleep polygraphy.

### 4.2.1 Methods

Six subjects (mean age 23.8) were monitored for seven consecutive nights using the SCSB. The three SCSB signals were recorded using a Gilson M8PM polygraph (1 mm/sec), and QS, IS, and AS were visually defined on-line in 2.5 min epochs. After one adaptation night the subjects were awakened to report approximately four times a night. The scoring of the last four SCSB epochs before each awakening was checked off-line. The reports were rated into six categories (Table 1) by a person who was not aware of the SCSB data preceding each report. The report categories were partly adopted from those presented by Foulkes (1962) and Brown and Cartwright (1978). One SCSB record of each subject was scored off-line by two experimenters in order to study the reliability of the activity classification.

TABLE 1 Categories for classifying the nocturnal reports and imagined examples of each category.

| Category | Example |
|---|---|
| 1) No recall | "I cannot recall anything ..." |
| 2) Thinking claim | "I was thinking, but I don't recall the content". |
| 3) Dreaming claim | "I was dreaming, but I don't recall the content". |
| 4) Thinking report | "I was wondering whether red is the opposite of blue". |
| 5) Visual image | "There was a cow, just a cow grazing, I do not recall anything else". |
| 6) Dreaming report | "Yes, there was a reddish cow eating grass. Then, a blue bull suddenly entered and asked me whether I would have anything against it, if he asks the lady for a dance. Then they began to jive". |

### 4.2.2 Results

The percentages of proper dream reports (class 6) were 79.7% after AS awakenings, 25% after IS and 20% after QS. During 46.6% of QS awakenings and 36.1% of those during IS the subjects could not recall any mental activity (class 1), but less than 5% of the AS awakenings were followed by such reports. In turn, more than 90% of the reports of no recall were obtained from either QS or IS. Reports classified into categories 2-5 were incoherently distributed across the activity states. Reports with at least some detailed content (classes 4-6) were somewhat more common in IS (41.7%) than in QS (33.3%), but rare as compared with those which were given after AS (87.4%).

### 4.2.3 Discussion

Significantly dissimilar kinds of mental activities were reported by the subjects when awakened during different SCSB activity states. The percentage frequencies of dream reporting proper are in agreement with the "classical" studies of dreaming during REM and NREM sleep (e.g., Aserinsky & Kleitman, 1953; Dement & Kleitman, 1957b) indicating that the dreaming phases of young healthy adults are quite reliably distinguishable through the sole use of the SCSB. This result suggests that in studies where it is desired to detect the likely phases of sleep mentation and in which knowledge concerning the preceding brain state is not essential, the SCSB can be substituted for the EEG based procedure.

## 4.3 Study III

Pulli et al. (1994) reported that the SCSB based "autonomic sleep stages" provided by the BR01 software were significantly related to EEG delta activity. The results indicated the potential use of automatically analyzed SCSB recordings as rough measures of sleep quality. Nevertheless, the validity and generability of those results can be questioned because the data were based on daytime recordings of only one sleep cycle (110-120 min). The purpose of the present study was to investigate the relation between standard sleep stages and the automatic analysis of the SCSB signals registered during nocturnal sleep, and to further evaluate the parameters computed by the BR01 program.

### 4.3.1 Methods

The SCSB data of eight of the subjects (mean age 24.3) who participated in Study I were automatically analyzed and compared with the sleep stages[1]. EEG, EOG, EMG, and the SCSB signals were registered and the standard sleep

1 Unfortunately the tape recorded data of subject 8 of Study I were lost due to technical problems.

stages (Rechtshaffen & Kales, 1968) were defined by two persons as described in Study I. Only consensus data between the raters were used. The SCSB signals were analyzed in 3 min epochs by the BR01 which yields eight variability parameters and the AAI which is the sum score of them. As a rule, a higher score on each parameter indicates an increased irregularity of the autonomic signals or motility.

### 4.3.2 Results

The mean AAIs during REM sleep were significantly greater than those of S2 and SWS ($p < .001$). The difference between means during S2 and SWS was also significant ($p < .001$). As a consequence of this, SWS, S2, and REM sleep were coded as 1, 2, and 3 for the correlation analyses. Respiratory amplitude variation, slow variations in BCG, and the occurrence of small body movements (duration < 10 sec), showed the highest Spearman correlations with the principal sleep stages (Table 2). A revised activity index (AI) was calculated as the sum of these parameters. The values of the AI were classified into three operational categories according to their cumulative frequency; the lowest third were classified as QS, the second as IS, and the highest as AS. The SCSB data during W/MT, S1, and REM sleep were mostly classified as AS (85.0%, 73.1%, and 59.2% respectively). S2 was quite evenly distributed across the activity states, but QS and IS accounted for 72.5% of all S2. SWS was most often classified as QS (66.2%) and only occasionally as AS (8.0%). In turn, 93.4% of QS and 78.0% of IS consisted of S2 or SWS.

TABLE 2 Correlations between three sleep stages and BR01 parameters for individuals and for the data as a whole. AAI = autonomic activity index, Rav = respiratory amplitude variation, Rfv = respiratory frequency variation, Rtr = respiratory trends, mT = missed triggerings, Bsv = slow variation in the BCG, Btr = BCG trends, ABm = small movements.

| Subject | (epochs) | AAI | Rav | Rfv | Rtr | mT | Bsv | Btr | ABm |
|---|---|---|---|---|---|---|---|---|---|
| 1 | (115) | .51*** | .44*** | .40*** | .16 | .14 | .36*** | .16 | .54*** |
| 2 | (110) | .42*** | .61*** | .20* | .20* | -.01 | .31** | .13 | .17 |
| 3 | ( 99) | .41*** | .25* | .27** | .06 | .13 | .59*** | -.08 | .40*** |
| 4 | ( 70) | .39*** | .25* | .32** | .17 | .10 | .33** | .19 | .39*** |
| 5 | (102) | .65*** | .58*** | .26** | .47*** | .13 | .47*** | .30** | .49*** |
| 6 | (110) | .59*** | .54*** | -.03 | .28** | .36*** | .60*** | .28** | .51*** |
| 7 | ( 91) | .49*** | .56*** | .37*** | .30** | .15 | .29** | .01 | .25* |
| 8 | ( 86) | .58*** | .53*** | .56*** | -.03 | .43*** | .52*** | .31** | .48*** |
| Total | (782) | .47*** | .42*** | .30*** | .19*** | .21*** | .40*** | .16*** | .39*** |

$p < .001$ ***, $p < .01$ **, $p < .05$ *

The SCSB activity states reflected the cyclic changes in polygraphic activity. Some of the discrepancy between the two kinds of measures was attributable to the difference in epoch length applied in the SCSB analysis as compared to that used in sleep staging. For example with reference to momentary changes (W or MT) in the sleep polygraphy a substantially longer period usually became scored as AS in the SCSB analysis.

### 4.3.3 Discussion

Correlations between three polygraphic stages (SWS, S2, REM) and the SCSB data were significant for the single BR01 variability parameters and for the sum score (AAI). Similar overall relations, but with some inter-individual discrepancies, were previously reported for one cycle of daytime sleep (Pulli et al. 1994). In the present study on nocturnal sleep the correlations were systematic across the subjects. In general the results concerning the relationship between the sleep stages and automatic SCSB analysis were in concordance with the results of the visual analysis of the SCSB data (Study I) and with earlier findings using different algorithms for automatic SCSB analysis (Hasan & Alihanka, , 1981; Jansen & Shankar, 1993; Salmi & Leinonen, 1986). It can be questioned, however, whether the variability parameters used in the BR01 analysis or the fixed 3 min epoch length are the most appropriate. Nevertheless, the activity states defined according to three BR01 parameters reflected the cyclic changes in the stages of sleep, and consequently it is obvious that the relative nocturnal portions of QS, IS, and AS could serve as useful objective indices of sleep quality.

## 4.4 Study IV

The aim of the experiment was to behaviorally assess whether the SCSB activity states could be used as rough indicators of sleep depth. According to behavioral responses to auditory stimuli the depth of the NREM sleep stages are unambiguous. SWS is regarded as deep sleep, S2 as lighter, and S1 as the lightest stage of sleep. The results concerning REM sleep, however, have referred to either deep or light sleep (see section 2.6). In the present study behavioral responsiveness, electrophysiological measures of sleep, and the SCSB states were compared with each other.

### 4.4.1 Methods

Twelve healthy subjects (mean age 26.8) were instructed to switch off an auditory signal with a pressure transducer whenever they heard the stimuli during the night. Similar transducers were attached to both hands. A light flexing of the fingers or the palm of either hand produced a pulse sufficient to switch off the stimuli. The pressure signals from both hands were digitized at a

50 Hz sampling rate in 20 sec epocs starting from 10 sec before the stimuli onset. The stimuli were composed of a sequence of 1200 Hz/50 msec tones with a 625 msec interstimulus interval and a fixed intensity of 45 dB. The time between sequences varied pseudorandomly from 20 to 150 sec. The signal was interrupted automatically after the 11th stimulus (6800 msec) if no response took place before it.

The SCSB signals were tape-recorded and automatically analyzed as presented in Study III. EEG, EMG, and EOG were registered from the standard sites and digitized in 20 sec epochs that started from 10 sec before the stimuli onset. The epochs were scored as W, S1, S2, SWS or REM sleep. Reliability of the sleep stage scoring (agreement 92%) and the results concerning the hand asymmetry of responsiveness have been presented elsewhere (Lauerma, Kaartinen, Polo, Sallinen & Lyytinen, 1994). In order to illustrate the setting, Figure 6 shows the different kinds of polygraphic epochs present during the experimental trials.

### 4.4.2 Results

The mean response percentages showed a decrease in responsiveness from W to SWS. The probability of behavioral responses was high but not perfect during W (81.3%). When the sleep trials with alpha activity as a sign of momentary arousal after stimulus onset were excluded, the mean percentages of responding during S1, S2, REM, and SWS were 52.8%, 11.0%, 8.5%, 0.5%, respectively. Three subjects had quite low response percentages even during stage W trials. Three other subjects showed extraordinarily high response rates in either or both S2 and REM sleep. The low percentages for the "low group" in W were for the most part due to the decreased responsiveness during W episodes after initial sleep onset. The "high group" accounted for 47.0% of all behavioral responses during S2 and 65.6% of those during REM sleep.

The behavioral responses were most frequent during AS (37.2%), clearly less common in IS (16.9%), and rare in QS (5.6%). There was a decline in responsiveness during the course of the night in all states, but the most noticeable change for QS and IS occurred between the first and the second hour. Also, even though the response rates were relatively high during the first hour, there were already differences between the SCSB states. The percentages after this time showed a low responsiveness during QS (3.9%). The responses in IS (13.3%) were also rare, but quite common during AS (30.3%). If the "high group" was not included the percentages were even lower, especially in QS (1.2%) and IS (6.1%).

Most of the trials without responses during QS (85.5%) and IS (65.1%) were scored as either S2 or SWS. In turn, approximately 90% of SWS non-response trials and more than 75% of those in S2 were found during QS or IS. Non-response AS trials were found most often during S2 and REM epochs. For all SCSB activity states the behavioral responses during the first hour in bed mainly occurred during W or S1 trials (QS: 85.8%, IS: 89.5%, AS: 85.5%). After the first hour S2 trials accounted for approximately one half and S1 trials for

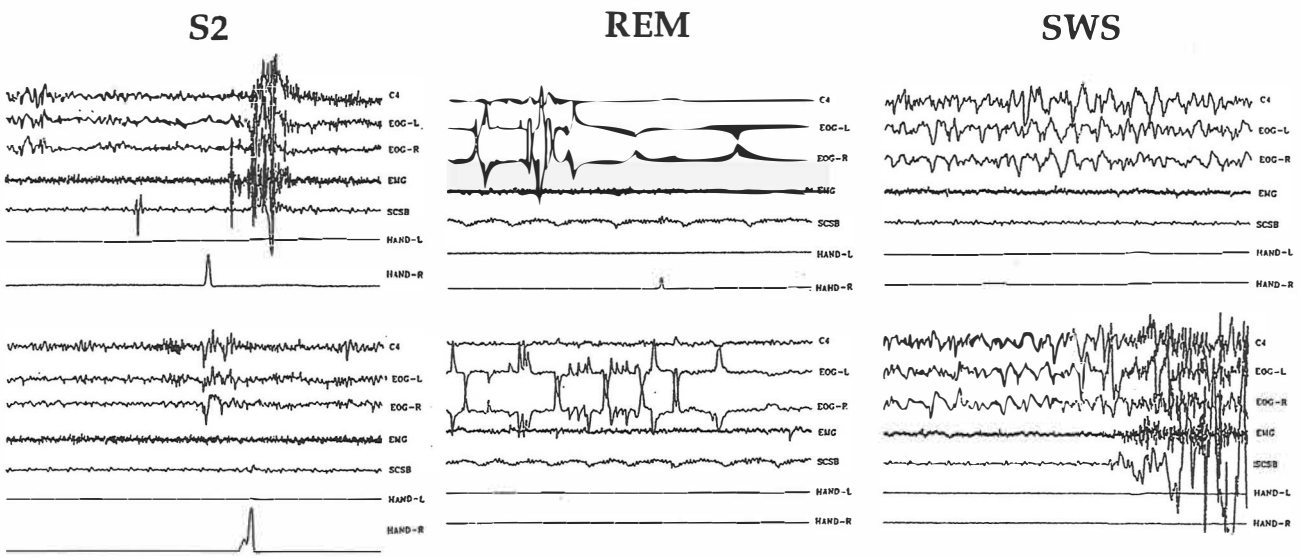


FIGURE 6 Polygraphic examples representing different types of trials. Behavioral responses during S2 trials with (upper) and without (lower) arousal. Successive REM trials with (upper) and without (lower) a behavioral response. SWS trials without instructed behavioral responses, but movement activity present in the lower sample.

one quarter of the responses in QS and IS. The AS responses were evenly distributed between W (28.0%), S1 (29.9%), and S2 (27.3%) trials. During each SCSB state approximately 15% of the responses took place during REM trials.

Among the response trials, movements were more than twice as frequent after the stimulus onset (21.6%) as before the stimuli (9.6%). According to a separate analysis some of the SCSB activity was caused by the behavioral responses. Indeed, the abandoning of all SCSB epochs containing motility during the 10 sec after stimulus onset, decreased the response rate for AS after the first hour to 17.7%. The percentages in QS and IS, howevér, remained practically intact, and thus the finding does not change the results as regards the role of QS and IS as measures of sleep depth.

### 4.4.3 Discussion

The response rates during the sleep stages were consistent with earlier findings. Responsiveness was highest in S1, lower in S2 and REM sleep and almost absent in SWS. It is obvious that instructed behavioral responses can be performed while one is electrophysiologically asleep and that response failures can occur during epochs which are scored as awake.

The relationships between the sleep stages and SCSB activity during the non-response trials were in concordance with those found in Study III for undisturbed sleep. The responses during the SCSB states revealed differences roughly comparable to those found between the standard polygraphic stages. The infrequency of behavioral responses during QS trials after the first hour indicates that it is also behaviorally a quiet state. The responses during QS were rare as compared with those during S2 and without the data of the three subjects who showed especially high response rates the probability of responding during QS came close to that in SWS. Responsiveness in IS resembled the rate in S2 but AS appeared more complicated. Responses were more common in AS occurring evenly during W, S1, and S2, and to a lesser extent in REM trials. Furthermore, some of the SCSB activity scored as AS was obviously due to movements related to the responses. None the less, QS seems to reflect a behaviorally deep sleep whereas IS appears to be a lighter state to some degree. The result especially suggests that the amount of QS could be used as an estimate of deep sleep.

## 4.5 Study V

The purpose of the study was to investigate the inter- and intra-individual variations in SCSB recordings across 14 consecutive nights. The SCSB data were compared with the subjective evaluations of sleep quality.

### 4.5.1 Methods

SCSB signals of 16 healthy subjects (mean age 26.2) were registered at their homes by using either an Oxford Medilog 4-24 or a Teac HR-30 recorder. The recordings started on a Monday evening and ended on a Monday morning two weeks later. Questionnaire data concerning subjective sleep quality were collected every morning. The number of small (duration < 5 sec) and gross movements (≥ 5 sec), the percentage of the movement time, and the proportions of the activity states (QS, IS, AS), were obtained using the BR01 software.

### 4.5.2 Results

Despite the increase in motility between nights 6 and 7 neither the body movements as such nor the activity states showed any systematic time-locked variation such as a FNE, or differences between the recording weeks, or between working days and days off. The inter-subject variation was significant for all SCSB movement parameters, and the differences between individuals accounted for more than 50% of the total variation of most of the parameters during the total time in bed (TIB). Considerable intra-subject changes also appeared between the individual extremes in motor based activity during the two weeks. The individual maximum values during TIB were on average twice as large as the minimums, and even greater differences were found in activity during the first hour in bed. Figure 7 presents several movement time profiles to give an illustration of the inter- and intra-individual variability of nocturnal motor activity.

A FNE was obvious in subjective quality, restfulness, and depth of sleep, as well as in subjective sleep efficiency and estimated sleep latency. In general, the correlation coefficients between the subjective and objective parameters were low or ambiguous and only between the percentage of nocturnal movement time and subjective sleep efficiency did more than half of the subjects show statistically significant coefficients. A more systematic relation was revealed by comparing the subjective evaluations representing the most and the least active nights according to various SCSB parameters. As a result, the individual extremes of movement time, the number of gross movements and the amount of AS were related to subjective sleep quality but no relation was found between the extremes of small movements and the subjective evaluations.

### 4.5.3 Discussion

Movement time and the number of gross body movements have traditionally been considered as quite stable sleep parameters (Moses et al. 1972). As previous studies have not shown any FNE in movements, one-night motility recordings have been suggested as sufficient for evaluating sleep quality (van Hilten et al., 1993; Kronholm et al., 1987). However, Kronholm et al. (1987) have already remarked that the absence of systematic variations in motility between

nights does not necessarily indicate that there are no intra-individually significant differences. The present results confirm their suggestion and, moreover, the differences between the subjects and the noteworthy intra-individual variations particularly point to the importance of repeated recordings for clarifying the individual baseline of motor activity. This applies especially to small experimental samples.

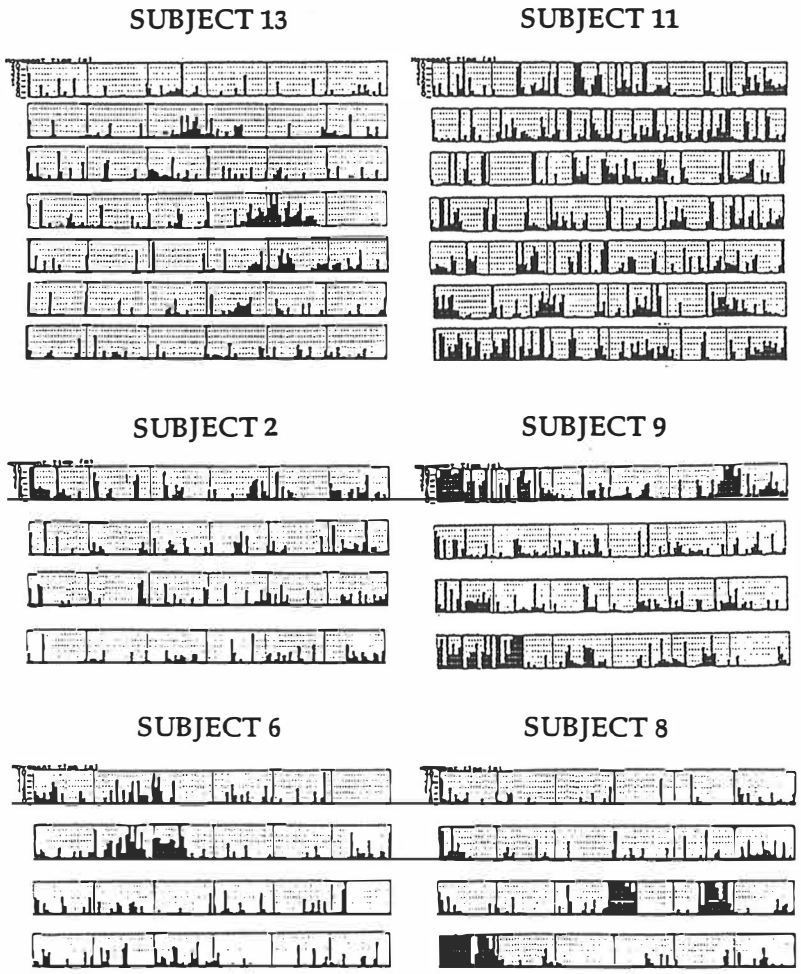


FIGURE 7 BR01 movement time profiles of the first six hours in bed. The first registering week is presented for the motorically most quiet (Subject 13) and the most restless (Subject 11) subjects. The rest of the profiles represent the first four nights of subjects showing different kinds of trends. Subjects 2 and 9 can be regarded as showing a FNE like development, but while the motor activity of subject 2 stabilized after the first night (actually almost permanently for the rest of the registering period), the motility of subject 9 returned to an elevated level during night 4. In subject 6 the decrease in activity took place after two nights, but a reverse effect can be seen in subject 8, who after two quiet nights had two considerably more restless nights according to the motor activity.

# 5 GENERAL DISCUSSION

The drive to find simpler techniques in sleep research suggests that many investigators consider standard sleep polygraphy with EEG, EOG, and EMG criteria as too complicated for some applications. Furthermore, the modern polysomnogram (PSG), which is necessary in clinical diagnoses of various sleep disorders, entails the recording of even more physiological parameters than the "standards". The EEG based procedures are important tools but they are rather expensive, laborious, and time-consuming. They also usually require a well designed laboratory environment, and the strange setting, together with the electrodes and wires attached to the body may be considered disturbing by many subjects, at least at the beginning of recording. These methods are suitable for laboratory experiments with few subjects but have seldom been used in long-term follow up studies or field experiments with an extended number of subjects. Therefore, there is an obvious need in some fields of sleep research for objective methods which are less expensive and complicated. Simple and cost-effective methods are especially needed for the objective long-term evaluation of sleep quality in natural environments.

The SCSB is an unobtrusive movement sensor which is capable of registering not only ordinary body motility in bed but the BCG and respiratory movements as well (Alihanka & Vaahtoranta, 1979; Alihanka et al., 1981). Even though the method was originally developed for clinical use in medical research, empirical data concerning ANS functions and motility during different phases of sleep suggest that the SCSB could also be used in psychological or psychophysiological studies. Intuitively, gross body movements as such appear as promising indicators for assessing the general restfulness of sleep, but the combination of activities available by using the SCSB implies a broader range of utilization for this method. In regard to this,

Alihanka and his colleagues (Alihanka et al., 1983; Alihanka 1987) introduced a three-way classification system, QS, IS, and AS, representing the combined activity of the SCSB signals. The categories, which were proposed to show a good correlation with the sleep stages, were based on the regularity of respiration and the BCG and on the number of small body movements. Computerized classification systems, more or less comparable to Alihanka's (1987) visual scoring procedure, have also been presented (Hasan & Alihanka, 1981; Jansen & Shankar, 1993; Salmi & Leinonen, 1986). Unlike the other automatic analysis methods, the BR01 however, makes use of all three SCSB channels and it is also the only software commercially available. Even though the BR01 has been previously evaluated in relation to EEG delta activity during daytime sleep (Pulli et al., 1994), neither it nor the visual scoring procedure have been adequately compared with the EEG based sleep stages during a whole night's sleep.

The present series of studies were performed to test the applicability of the SCSB activity analysis beyond its established use in medical research. The relationship between the standard sleep stages and the SCSB activity states based either on visual or BR01 analysis was investigated in Studies I and III, respectively, whereas a straightforward application of the visual SCSB analysis for dream research was attempted in Study II. While the continuum of sleep depth can be regarded as "a convenient abstraction" (Rechtschaffen et al., 1966) without strict empirical reference, as the changes in behavioral, physiological and subjective parameters do not entirely coincide, it does, however, have everyday meaning and is also useful scientifically, at least as regards NREM sleep. Snyder and Scott (1972) have pointed out that any measure suggested as an indicator of the depth of sleep should be behaviorally tested. In this vein, Study IV was carried out in order to assess the SCSB activity states by using instructed behavior as a criterion. Finally, the inter-subject differences and intra-subject stability of various SCSB variables and their relationship with the subjective estimations of sleep quality were the topics of Study V. A slight modification of the criteria presented by Alihanka (1987) was applied in Studies I and II. The only significant difference concerned the definition of small movements, which was based on the earlier work of Hasan and Alihanka (1981), i.e. the upper limit for the duration was set to 5 sec instead of 10 sec. As a consequence of the correlations found between the various BR01 parameters and the principal sleep stages in study III, the SCSB activity states in studies III-V were based on one cardiac, one respiratory and one motor variable.

## 5.1 Evaluation of the SCSB activity states and the scoring parameters

The variability scores in Study I, and most of the various BR01 parameters in Study III, indicated that patterns of breathing and cardiac activity and the frequency of small movements roughly reflect NREM-REM cycles during sleep.

The NREM vs. REM sleep differences in ANS variables have been well documented in earlier studies (see section 2.8), but differences within the NREM stages have not always been found. The present Study I indicated significant differences in both respiratory and BCG scores between S1, S2, and SWS, the mean values during S1 being in the same range as those in wakefulness and REM sleep. While cyclicity was apparent in the single SCSB variables (Figure 4), it seems that the sum score (AI) and the categorized total activity better represent the cyclic changes of sleep stages. QS, in general, refers to immobility with regular respiratory and BCG signals. AS is characterized by considerable variations in autonomic signals often together with short body movements, whereas IS indicates a moderate amount of variability between QS and AS.

The relationships between the SCSB states and sleep stages were examined in Studies I and III, as well as during non-response trials in Study IV. Almost all QS and a great majority of IS took place in SWS and S2. AS consisted of REM sleep, S2, and wakefulness. In turn, the majority of wakefulness, S1 and REM sleep was scored as AS and to some extent also as IS. While S2 epochs were quite evenly distributed across the SCSB states, SWS almost exclusively consisted of QS and IS. According to the BR01 results (Study III) the percentages of AS decreased and those of IS and QS increased from wakefulness, through S1, REM sleep and S2 to SWS. Visual scoring yielded an approximately equal result except for REM sleep which showed the highest AS percentage. In general, the results were concordant with earlier findings (Hasan & Alihanka, 1981, Salmi & Leinonen, 1986; Jansen & Shankar, 1993) although the SCSB data have been analyzed in various ways in different studies. Previously, Pulli et al. (1994) did not find a linear correlation between the sum score of all of the parameters provided by the BR01 and the amount of EEG delta activity in NREM sleep during the first cycle of daytime sleep and some inter-individual discrepancy was also evident. In Study III however, concerning nocturnal sleep, the correlations between three polygraphic stages (SWS, S2, REM) and the BR01 sum score were significant systematically across the subjects. The same was found between the stages and four of the BR01 variability parameters. Moreover, the activity states based on those parameters which had the highest correlations with the polygraphic measures evidently reflected the cyclic variation of the sleep stages. As a matter of fact Pulli et al. (1994) also found a similar tendency, as they reported that the autonomic sleep stages, based on three categories of the sum score, quite well differentiated between the averaged EEG delta amplitude classified as high or low.

In Study IV behavioral responding was lowest in QS and highest in AS, and even if not in exact percentages, the response rates during QS and IS after the first hour in bed resembled those found in SWS and S2, respectively. The infrequency of instructed responses during QS shows that, in addition to immobility and regular autonomic activity, it is also a behaviorally quiet state. Furthermore, while dreaming proper was reported after about 80% of AS awakenings in Study II this kind of recall was significantly less frequent following IS and QS. Practically all the reports without any recalled mental

activity were obtained during QS and IS, also indicating the relationship between these states and NREM sleep. The relationships found in Study I between the SCSB activity states and the principal sleep stages are presented in Figure 8 as a function of time. Altogether, QS and IS, referring to low and moderate levels of SCSB variability respectively, seem to be useful indicators of the amount of NREM sleep throughout the night. According to Study IV, the amount of QS especially could be used as an estimate of deep sleep regardless of the sleep stages.

The role of AS which reflects considerable simultaneous variation in different SCSB parameters was more complicated both on a behavioral basis and in the light of the sleep stages. Study II, however, revealing that dream recall is as closely associated with AS as it is usually associated with REM sleep suggested a temporal relationship between these two states. This does not mean, however, that REM sleep and AS are the same thing. Importantly, as the standard polygraphy was not used in Study II, it is unknown whether the AS awakenings were made during REM periods or during NREM sleep showing increased phasic ANS and motor activities, the more so as the occurrence of phasic phenomena is not entirely restricted to REM sleep, but can be found during NREM sleep as well (for reviews, see e.g. Grosser & Siegal, 1971; Molinari & Foulkes, 1969). Similarly, some of the QS or IS awakenings might have taken place during tonic REM sleep. Since previous studies have suggested a noticeable variation in the percentages of NREM dream recall, the more exact nature of the relationship between dreaming, SCSB states, and conventional sleep stages should be examined, in order to clarify whether the presence of increased autonomic activity plays a crucial role in NREM dreaming. When the data of Study I were analyzed in more detail it was found that 80% of the continuous AS (duration $\geq$ 12 min) after the first hour in bed took place during REM sleep. In undisturbed sleep, by inference, AS is particularly related to REM sleep and thus it can be obviously utilized in dream research. Nevertheless, the overlapping of AS with S2 also is evident, especially during the morning hours (Figure 8), and as such its value as a measure of sleep quality is as yet unclear. The data for subjects 4 and 6 (Figure 5) show that a large frequency of AS during the first few hours in bed can be used as a sign of some unspecific sleep disturbance. Moreover, the results on long-term recordings and subjective sleep quality in Study V also indicated the same.

Relatively high agreement rates were reached for the activity states both when the same SCSB recordings were scored twice by one experimenter (87.4%, Study I) and when scoring was performed independently by two persons (81.3%, Study II). Detection of the so called "slow BCG variation" appeared to be the most problematic point of the criteria. As opposed to the other rules which are based on the calculation of relatively exactly defined amplitude or frequency variations, the scoring of this phenomenon presupposes a different kind of pattern recognition task (Alihanka, 1987), which is difficult among borderline epochs and may have therefore an impact upon the categorization of the activity states. However, only rarely were some epochs scored as QS or AS as a consequence of whether the critical features of the slow variation were

detected or not. In any case the results indicated a reasonably high reliability for the visual scoring system.

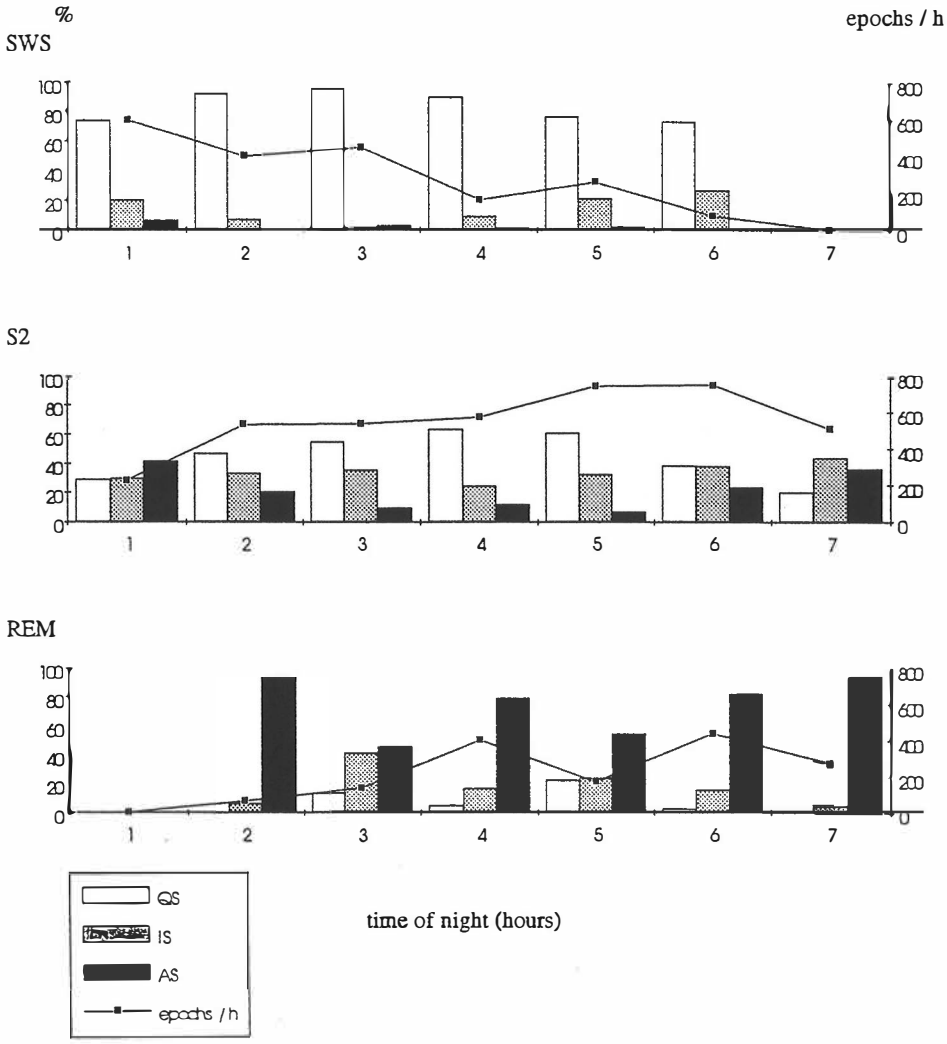


FIGURE 8 The relationships between the SCSB activity states and the principal sleep stages as a function of time in bed in Study I. The continuous line indicates the number of EEG epochs within each comparison point. Regardless of time SWS was usually scored as QS. During the mid-hours S2 was mainly scored as QS or IS, but in the beginning (due to subjects 4 and 6, see Figure 5) and during the morning hours a noticeable portion of S2 took place during AS. The role of AS in REM sleep was evident throughout the night, although a momentary fall can be found during the third hour. No REM sleep occurred during the first hour in bed.

The long epoch length used in both the visual scoring and in the BR01 analysis was problematic as regards to comparisons with the EEG polygraphy, as markedly shorter intervals are recommended for standard sleep stage scoring. The difference in the epoch length brings about some bias, as a single SCSB epoch with one activity state score may actually include different sleep stages during transition periods, as can be seen in Figure 9. It was not attempted, however, to apply shorter SCSB epochs in Study I, since this would have presupposed major changes in the scoring rules. The long epoch length certainly has its drawbacks, but on the other hand, it makes the scoring faster. While 3 min is convenient for visual scoring of SCSB data, shorter epochs might be more appropriate for automatic analysis. This kind of change would be reasonable and realizable, and especially as it seems that the present analysis system may over-emphasize the temporal significance of some short-term changes, shorter epochs would also provide a more valid basis for comparison with polygraphic recordings. Finally, as body movements lasting more than 5 sec (visual scoring) or 10 sec (BR01) were not taken into account a significant part of further information was also excluded. Whether and how gross motility could be included into this kind of activity analysis system still remains, however, an open question.

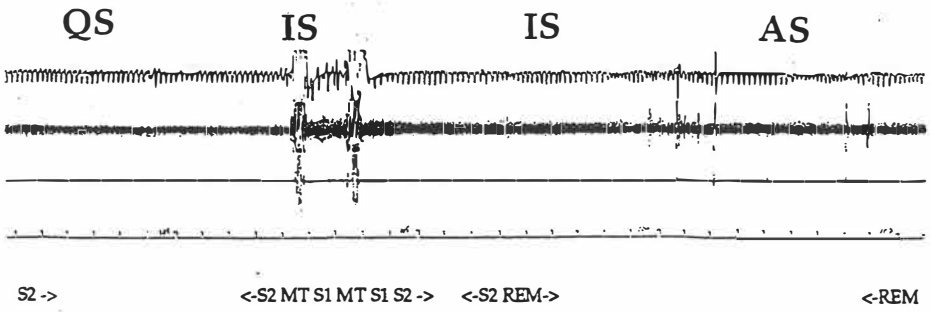


FIGURE 9 The SCSB signals during a transition period from NREM to REM sleep. The sleep stage scores are shown below the bars indicating 20 sec intervals. AS often started a few minutes before or after REM onset and, on the other hand, was shorter or longer than the REM period.

The sensitivity of the SCSB for detecting body motility as compared with other methods is obvious (Alihanka, 1982; Markkula, Kaartinen, Arikka & Lauerma, submitted; Rauhala, Erkinjuntti & Polo, 1996). On the other hand, the categorization of body movements into four classes according to their duration ($A < 5$ sec, $5 \leq B < 10$ sec, $10 \leq C < 15$ sec, $D \geq 15$ sec) is questionnable. These classes, originally suggested by Alihanka (1982, 1987) and applied in various

studies (e.g. Kaartinen & Lyytinen, 1990; Kronholm et al., 1987) are also provided by the BR01 software. In Study V classes B-D were combined as gross movements and class A as small movements, although it is apparent that more than short twitches are included in class A, a fact easily demonstrated, for example, by moving an arm for 4.9 sec and imagining that a top sprinter can run approximately 50 meters during that time! It is noteworthy in this respect that Erkinjuntti (1988) in his SCSB study on infants used a category of twitching movements (duration < 1 sec) and including a similar class into the analysis system for adults would likewise be advisable.

Even though it is evident that the BR01 was created by applying obsolete computing procedures, a technical evaluation of this software goes beyond the scope of the present purposes. More though should be said about the parameters used in the BR01 analysis. Beginning with the definition of small movements, the solution of including both movement classes A and B into this category does not seem easily intelligible. As regards the rest of the parameters, while some of them (variations in respiratory amplitude and frequency) refer to well established and commonly used psychophysiological variables, others appear to be new and somewhat unusual. The slow BCG amplitude variation, also applied in visual scoring, was introduced by Alihanka (1987) as a new REM sleep phenomenon, but no physiological definition or description was presented. However, the present results (Study I) also refer to the REM connection, even though a considerable amount of slow BCG variation was found also in S2. In any case, all the above mentioned variables correlated with the sleep stage data systematically across the subjects in Study III. In addition to the slow BCG variation, two other variables are somewhat peculiar, namely the trends in respiratory and BCG amplitudes. It is unknown to the author, whether these parameters have been studied in relation with more conventional physiological variables, but in Study III, only for accidental subjects did these show significant correlations with the standard polygraphy. Another BR01 parameter, "missed triggerings", is neither behavioral nor physiological since it refers to the software's incapability in detecting certain respiratory phenomena. Moreover, one "physiological" parameter linked to the respiratory wave form analysis was revealed as a null variable without any variation. According to Pulli et al. (1994) the shortcomings of the BR01 scoring may be due to the fact that the system has not been designed for evaluating normal sleep but rather for clinical diagnoses. This explanation is, however, unlikely, as Alihanka (1987) used the terms QS, IS, and AS to describe normal sleep and quite definitely stated that these were to be separated from "pathological epochs". In this presentation on the visual analysis, Alihanka also made several allusions to a forthcoming computerized analysis system, which clearly meant the BR01. However, in full agreement with Pulli and her co-workers, it must be doubted whether the BR01 parameters (even the best of them) are at all close to optimal.

Neither visual scoring nor the BR01 analysis have been explicitely designed for differentiating between sleep and wakefulness. However, Alihanka (1987) proposed that epochs with a movement time exceeding 40 sec should be scored as movement active wakefulness (MAW) and the same is

found as a default criterion in the BR01 software. In Study I MAW turned out to be insufficient in detecting even the major portion of wakefulness in bed and was abandoned as an invalid category. Consequently, it was also not considered in the BR01 analyses of Studies III-V. As it is questionable whether SCSB activity in W actually differs from that in S1 or REM sleep terms such as autonomic sleep stages or equivalents referring to classified SCSB data should be avoided, even though such terminology has been previously used in the literature (Alihanka, 1987; Härmä, Hakola, Åkerstedt & Laitinen, 1994; Hilakivi, Alihanka, Airikkala & Laitinen, 1992; Pulli et al., 1994; Kronholm et al., 1996). Categories of SCSB activity cannot be regarded as alternatives to sleep stages proper but should be seen as they are, that is, as indicators of nocturnal variations in autonomic nervous system functions and motor activity.

To summarize, the activity states applied in the present studies were defined operationally by categorizing the sum of three variability parameters: one of them respiratory, the other cardiac, and the third an index of small body movements. All of them are relevant as regards nocturnal NREM/REM cyclicity and, not surprisingly, the present results also are compatible with the data concerning ANS and motor activities reviewed in sections 2.8 and 2.9. It is however evident, that since AS, for example, can be a result of different combinations of activities, categories such as these should not be regarded as absolute entities or definite physiological states. Even though SCSB analysis appears to be a useful method for revealing the general cyclic changes during sleep, further research is obviously necessary. For example, while it seems that the nocturnal distribution of the present three activity states can be used as a simple objective measure of sleep quality, it is not clear what number of activity categories would be needed or sufficient for assessing, for instance, the restorative functions of sleep.

Unavoidably, as for any new sleep research method, the validity of the SCSB analysis had to be assessed against the standard sleep stages (Rechtschaffen & Kales, 1968). The latter have served as a useful tool over many years but, in order to redress the balance, the idea of a "golden standard" should also be evaluated. Some critical comments on the existing concept of sleep stages will be presented in the following section.

## 5.2 Critique on the standard stages of sleep

> "This handbook should be viewed as a working instrument rather than a statute. ... Experience with the manual may suggest possible revisions. When these suggestions accumulate appreciably, it would seem in order to have a review of the manual."
> - Rechtschaffen and Kales (1968)

In his recent review on computerized sleep analysis Hasan (1996) questioned the validity of the standard staging rules (Rechtschaffen & Kales, 1968) by arguing that they are both inadequate and ambiguous, doubting, if it is

reasonable to apply criteria which are almost 30 years old based on knowledge which is 40 years old as a reference for modern analysis methods. Indeed, as presented in sections 2.1 and 2.2 of the present report, the origin of the standard sleep stages dates back even more than four decades. The Rechtschaffen-Kales system was based on the consensus of a group of scientists ("standardizing committee") in the late 1960's. In order to "provide continuity" the Dement & Kleitman (1957a) criteria were used as the guiding principle when establishing the standard rules and the decisions concerning the form of the stages were derived from Loomis et al.'s (1937) "definitive states of sleep". The Dement-Kleitman system was only a slightly modified version of the former but with the electro-oculographic detection of eye movements included, as a consequence of the findings of Aserinsky and Kleitman (1953). The diminishing of EMG activity concomitantly with REM periods (Berger, 1961; Jacobson et al., 1964; Jouvet & Michel, 1959) was discovered soon after, and consequently the recording of muscle tone also became a standard sleep parameter.

The necessity for standardization became apparent with the findings of Monroe (1968; 1969a). The latter report (Monroe, 1969a) on inter-rater reliability, subtitled as *Phase 1*, indicated the unreliability of the existing scoring rules, especially when the same recordings were analyzed at different laboratories. According to Dement and Mitler (1974), Monroe set about checking the effects of the new manual on reliability but to the best of the present author's knowledge no results of the later phases of this work were ever published. Recommendations for acceptable agreement rates between scientists have been presented (Williams et al., 1974) as well as reports on these percentages at different laboratories. Thorough comparisons between laboratories, however, appear to be lacking. Karacan et. al (1978) reported an approximately 90% overall agreement between three laboratories, but as extra inter-laboratory standardization was applied the results cannot be used in evaluation of the Rechtschaffen-Kales criteria. The standard sleep stages have apparently forced scientists to communicate in the same language, but as it is unclear whether they have a common understanding of the meaning of the words, the original purpose, i.e. the universal comparability of the results, is questionable.

Dement & Kleitman (1957a) have stated that the categorization of sleep records into stages on the basis of epochs of defined duration makes the division somewhat arbitrary. Indeed, arbitrariness is not just restricted to the fixation of epoch length as the whole essence of the stages can be questioned. This holds particularly for S1. On a behavioral basis the results of Study IV support those studies which indirectly doubt whether S1 as such should be considered as a sleep stage at all (e.g. Bonnet & Moore, 1982; Ogilvie & Wilkinson, 1988). As regards the criteria for the other stages, those for differentiating between S3 and S4, for example, are so vague that these stages are nowadays commonly combined as SWS. Nevertheless, because of the definite amplitude (75 μV) and frequency (≤ 2 Hz) criteria for EEG delta even this broader category does not include all of the sleep EEG with slow activity (e.g. Hasan, 1996; Martin et al., 1971; Webb, 1986; Webb & Dreblow, 1982;

Williams et al., 1974). REM sleep, on the other hand, was defined in great detail in the standard manual and much effort went into ascertaining a difference between REM sleep and stages 1 and 2. However, the tonic and phasic components of REM sleep were still ignored, even though a basic understanding concerning this distinction (Moruzzi, 1963) would apparently have been known. Most of REM sleep in the present studies (I, III, IV) was scored as AS, but periods of autonomic and motor quiescence were also found. Moreover, recent results from our laboratory (Sallinen, Kaartinen & Lyytinen, 1996) among other parallel findings suggest a significant difference between tonic and phasic REM sleep as regards to the processing of external auditory stimulation. Consequently, apart from the appearance of the EEG pattern there is not much evidence supporting the idea of REM sleep as a homogeneous state.

Although SWS and REM sleep are not exclusive categories they still appear to be more valid sleep variables than S2 which can be, coarsely speaking, regarded as the trash can of sleep research, as almost everything discordant with the other stages can be included in it. During the early hours of sleep, for example, the polygraphic data falling between the criteria of S1 and SWS are scored S2 which means that a state hardly distinguishable from wakefulness falls into the same category as some slow EEG activity which does not fulfill the necessary criteria for SWS. Moreover, as is evident to anyone familiar with the sleep EEG, S2 during the beginning of sleep (approximately the first and the second cycles) is essentially different from S2 during the late morning hours. The former is often composed of a relatively high amplitude EEG lacking the features of SWS proper. For the latter, on the other hand, S2 refers to the occurrence of EEG spindles and/or K-complexes against a generally low amplitude background EEG often not distinguishable from that of S1 or REM sleep. Not to mention all the critical literature on S2, findings from our laboratory concerning ANS functions (Studies I, III, and IV) and event related brain potentials (Sallinen, Kaartinen & Lyytinen, 1994) during S2 also question its very nature as a unitary stage.

The standardizing committee managed to reach a consensus regarding some of the knowledge accumulated since the 1930's. The problem concerning the partial desynchrony of the cyclic changes in EEG, EMG, and EOG recordings, for instance, was evidently noticed by the group and avoided by using additional rules. This, of course, did not get round the fact that different physiological parameters do not fully coincide but overlap to some degree. Indeed, the committee seem to have made a deliberate decision to ignore other physiological phenomena relevant for the cyclic changes during sleep. Changes in ANS activity and motility concomitantly with regularly occurring REMs, for example, had already been reported by Aserinsky and Kleitman (1953). For some reason, these and later findings concerning these parameters were not regarded as worth including in the sleep staging system. After the coining of the abbreviation "REM sleep" (Dement & Kleitman, 1957b) rapid eye movements were indeed "on the stage", and consequently, the presence or absence of them became a way of labelling the two major states of sleep.

Although REMs apparently signal significant periods different from the rest of sleep, it is unclear whether they are per se of such importance or whether some other term would perhaps be more preferable. In the present author's view, for instance, even the old-fashioned terms paradoxical (*phase paradoxal,* Jouvet et al., 1959) and orthodox sleep referring to REM and NREM sleep respectively, could still be regarded as relevant and scientifically accurate. This is despite the fact that Jouvet (1967) later viewed the dichotomy as referring to the investigators' astonishment when observing something unexpected rather than to any physiological fact (for the terminology previously used, see e.g. Hartmann, 1967; Jouvet, 1967).

Sullivan (1980, p. 216) made the following pertinent comment regarding the terminology: "A rapid and irregular breathing pattern was part of the original description of REM sleep ..., and had those investigators been respiratory physiologists, we would undoubtedly call this state rapid erratic respiratory movement (RERM) sleep!". Even though there is a certain "tongue-in-cheek" element behind this suggestion, he certainly directs our attention to an interesting question. That is, what would the sleep stages look like if changes in other physiological phenomena, such as respiratory patterns, were taken into account in classifying adult sleep. Indeed, it is worth noting that respiration forms an essential part in defining the sleep states of newborn infants (Anders et al., 1971; Prechtl, 1974). In any case it is advisable that any measure of sleep, be it EEG based or not - or a behavioral one, should be compared with the existing sleep stages. Nevertheless, in principle, any combination of cyclically variating phenomena during sleep can be regarded as equally valid measures of sleep typology, as the EEG, EMG, and EOG are merely overt manifestations of processes which are taking place in the brain. The EEG, as commented on by Lesch and Spire (1990, p. 14) for instance, while undoubtedly the most valuable psychophysiological indicator of these processes, merely measures the "hum of the machine".

As evident from the citation at the beginning of this section, the standardizing committee did not intend to create an ever lasting list of rules as it appears to be today. On the contrary, in their conclusions they stated that future research may prove wrong conceptions underlying the organization of the stages, and if so, the manual would need to be revised. This, however, has not happened and the stages today still appear as they did in 1968. This is not surprising as the history of sleep staging from the very beginning has indicated an aspiration to establish definite rules. After the invention of the EEG, the early studies on sleep electrophysiology began by attempting to delineate the nature of brain activity in a sleeping person, implying that the pioneers of sleep research had an implicit behavioral definition of sleep. This idea was soon turned on its head, however, and sleep became defined according to the presence and absence of certain kinds of brain waves. The enthusiasm of early workers in the search for "definite states" was understandable but the longevity of the stages based, as they were, on partly arbitrary decisions is somewhat curious. In a Kuhnian sense (Kuhn, 1970) the sleep stages (Dement & Kleitman, 1957a; Loomis et al. 1937; Rechtschaffen & Kales, 1968) have become a

paradigm within sleep research which cannot be altered without a complete change in ideas concerning the nature of sleep. Whatever, for those who investigate sleep related phenomena from different points of view, sleep manifests itself in a variety of ways and consequently varying approaches to its study might arise. Those who concentrate on the microstructure of sleep, for example, presumably will focus their attention on more limited segments of EEG records (or other measures of CNS activity). On the other hand, researchers interested in macro phenomena (e.g. longitudinal studies) will be in search of procedures affording data reduction as compared with the existing stage scores. Even though different in appearance these kinds of approaches should not be contradictory. For although the former will split the existing stages into micro states, the latter should not regard sleep as merely a unitary state opposite to wakefulness, as cyclic changes must be taken into account, be they EEG based, as in syncronization vs. desynchronization, or some other non-EEG phenomena. Similarly, those focusing on the micro phenomena cannot avoid taking into account the two cyclically alternating states (NREM-REM). It can be speculated that modern models indicating oscillations brought about by homeostatic, circadian and ultradian processes (for review, see Borbely & Acherman, 1992) may constitute a common frame of reference for these two approaches.

## 5.3 Long-term variation in SCSB activity and subjective sleep

In Study V the only systematic difference between consecutive nights across the subjects and in both subjective and objective variables appeared between nights 6 and 7. This difference, perhaps indicating the beginning of a new recording week, was manifested as an increase in SCSB based activities and as a deterioration in experienced sleep quality. No FNE was found in relation to body movements but, on the other hand, its appearance was obvious in most of the subjective measures. It can be speculated whether a subjective FNE is a natural response when serving as a subject whose somatic functions are recorded and whose subjective experiences are questioned, even if this takes place in a familiar environment.

The differences in the SCSB parameters between individuals were to be expected (van Hilten et al., 1993; Kronholm et al., 1987). In addition to the great inter-individual variation, considerable intra-individual changes in the SCSB variables also appeared during the two weeks. The correlations between subjective and objective measures across the 14 nights were rather low, but in the light of the literature (section 2.7) this cannot be considered as surprising. As regards Study V it can be questioned whether the subjects were able to reliably evaluate their sleep quality over a prolonged period and whether or not these many estimations were comparable to each other. Further, it is apparent that ratings on a five point scale cannot absolutely reflect more precise nightly changes in motility. Preliminary results (Kulhomäki, Peura & Kaartinen, 1992)

suggest a relation between anxiety and the accuracy of the subjective evaluation of sleep quality. While all subjects scored within the non-pathological range, those showing low intra-individual correlations had higher trait anxiety scores on the State-Trait Anxiety Inventory (Spielberger, 1983) than did those with high correlations. As it seemed that even a slight increase in anxiety can weaken the ability to evaluate the quality of sleep, the sole use of subjective methods without objective references was questioned. However, a more systematic relation between subjective and objective variables was found in Study V when the subjective evaluations of the nights representing the extremes of activity (distinguishable and thus more valid differences) were compared with each other. The extremes of movement time, the number of gross movements and the amount of AS were all related to subjective sleep quality but no relation was found between the extremes of small movements and the subjective measures. The latter is most likely due to the fact that some small movements are naturally occurring phenomena during REM sleep, and as such their frequency might be conversely related to the restlessnes of sleep.

Previous studies concerning the relationship between nocturnal motility and sleep quality have usually concentrated on the group differences between good and poor sleepers (De Koninck et al., 1983; Hobson et al., 1978; Kronholm et al., 1987) or between specific patient groups and controls (Hyyppä & Kronholm, 1995; Laihinen et al., 1987; Sjöholm et al., 1992). Kronholm et al. (1987), for instance, found an almost twice higher movement frequency in poor sleepers than in good sleepers, although there were great inter-individual differences in gross body movements in the latter group. Study V, however, not only emphasizes the significance of inter-individual differences in both small and large body movements in normal sleepers but also a noteworthy intra-subject variation. As the long-term changes in various SCSB parameters were investigated amongst good sleepers who slept at home the findings point to natural variations in normal sleep. Further information about the relationship between nocturnal motor activity and sleep quality could be obtained in experimental settings in which interventions, for example using medication or an intentional fragmentation of sleep are combined with EEG and SCSB recording.

Because a systematic FNE has not been found in nocturnal motility, single-night recordings of motor activity have been proposed as providing sufficient information. However, the absence of a FNE in movements does not always imply the adequacy of a study of one night's motor activity for the reliable evaluation of sleep quality. Most evidently, one registering night might be sufficient when large scale random samples are studied. On the other hand, the great inter-individual differences and the unsystematic but noteworthy variation within subjects suggest that, as regards to experimental settings with a limited number of subjects or other small samples homogeneous in some aspect, very little can be inferred from a single movement recording. Consequently, it is important to know the individual motor baseline, if motility is intended to be used as an objective indicator of sleep quality. In many cases this presupposes more than one recording night.

## 5.4 Suggestions for the scope of applications of the SCSB in psychological and related sleep research

The cost and laboriousness of the standard sleep polygraphy makes it difficult to be applied in follow up sleep studies with a lot of subjects. The unobtrusive recording of nocturnal movement activity, on the other hand, appears to be a promising alternative. Wrist-worn piezoelectric actigraphs, for example, have unchallenged advantages as measures of general circadian activity and can also be used in automatic sleep/wake differentiation (e.g. Cole et al., 1992; Sadeh et al., 1989; Webster et al., 1982). However, in studies on nocturnal motor activity actigraphs have inevitable limitations, partly because they usually provide an activity measure of one limb only. For example, by using long sampling time windows (10-30 sec), moderately high percentages of motility have been reported (e.g. van Hilten et al., 1993, Middelkoop et al., 1993) and even higher values have been "achieved" when extended time windows (2.5 min) have been used (Smilde-Van den Doel, Middelkoop, Conrads, Schorno & Kamphuisen, 1994). Nevertheless, such measures, which indicate the percentage of epochs with movement activity exceeding the zero value (movement index %) (e.g. van Hilten et al., 1993; Middelkoop et al., 1993) make no distinctions between the number or between the duration of movements during the epoch and thus systematically produce overestimations of the total motor activity. Indeed, preliminary results of Markkula et al. (submitted) indicate that even the whole night motility percentage registered by a unilateral wrist actigraph with a more accurate time window (1.5 sec) is only about 25% of the percentage of the movement time detected by the SCSB, which counts the movements in seconds, and furthermore, that a bilateral actigraphy of both upper limbs increases the percentage only to about 40%. This is reasonable because the SCSB is designed to register movements from all parts of the body. As such the SCSB can evidently provide a method which is superior to actigraphic recording. Further, in addition to conventional body motility, respiratory movements and those caused by the pumping of the heart (BCG) can also be detected by the SCSB. This is not the case with actigraphs even though some use for them in studies on sleep related respiratory disturbances has been thought possible (Aubert-Tulkens, Culee, Harmant-Van Rijckevorsel & Rodenstein, 1987; Sadeh et al., 1989). Therefore SCSB recording provides a good general view of overall activity in bed although the location or origin of a body movement cannot be detected; for example, twitches of the head, a hand or a leg are similarly displayed. If needed, this kind of information can only be differentiated by using multiple EMG channels, actigraphs, or other sensors at different locations on the body. Consequently, the SCSB and actigraphs should not be regarded as competing but as complementary methods. For example, it is not reasonable to use the SCSB for the registering of circadian changes in activity, unless the subjects are continuously bedridden, as the method presupposes a lying position in bed.

Attempts to automatically differentiate between NREM and REM sleep or to identify more accurate sleep stages using the SCSB have been promising but unsatisfactory (Hasan & Alihanka, 1981; Salmi & Leinonen, 1986; Jansen & Shankar, 1993). There have been only a few reports applying some forms of SCSB activity states (Härmä et al., 1994; Hilakivi et al., 1992; Kronholm et al., 1996). Their infrequency might be due to the disappointment caused by the unsuccessful efforts to achieve sleep staging proper. In any case, it should be questioned whether sleep staging in the conventional sense should be seen as a goal for SCSB analysis. More realistically, it appears to be a dead-end, because of the simple fact that the electrical activity of the brain is not measured by the SCSB. Furthermore, while the comparison with sleep stage data is an unavoidable part of the validity testing of a new method, the phenomena registered in SCSB analysis and standard sleep polygraphy are different, and thus a one-to-one relationship cannot be achieved. The same also holds for other non-EEG measures of sleep but this does not challenge or weaken their value for other purposes.

By using the BCG and movement channels Jansen and Shankar (1993) also attempted to identify a sleep/wake discrimination which yielded a better result as compared with staging, resembling the systems which have been developed for actigraphs. However, the potential advantage of the SCSB and comparable methods (e.g. Siivola, 1989) over such pure movement recordings is that the registering of certain ANS functions is simultaneously available. On the other hand, although both of the scoring systems used in the present studies used all three SCSB channels, neither of them were designed to distinguish wakefulness. However, it should not be impossible to combine the results of Jansen and Shankar (1993) or those of Salmi and Leinonen (1986) with the present findings in order to produce a system utilizing the different SCSB signals to provide a general measure of sleep quality based on autonomic and motor data. Therefore, a reasonable objective for SCSB analysis should be looked for somewhere between sleep staging and sleep/wake classification. Whatever the possible forthcoming solutions might be, it should be recommended that they are not anchored to the existing sleep stages, since in the future new ideas of EEG based sleep analysis may emerge.

Even though SCSB analysis cannot substitute for EEG in sleep staging proper it is evident that the method readily provides a rough measure of the amount of NREM sleep and of the course of the sleep cycles. The temporal relationship between cyclic changes in sleep stages and the SCSB parameters can be perhaps best visualized by using the activity index (see AI in Figure 4), whereas the relative portions of the three categories, QS, IS, and AS, could serve as indices to describe nocturnal activity as a whole. For the researcher it is inexpensive, easy to use, and fast to analyze. For the subject, the SCSB setting is more natural and convenient than the traditional one with EEG and other biopotential recordings. As it presupposes no attachments to the subjects the research environment can be arranged to resemble normal home conditions or the recordings can also be performed at home. In clinical settings the method suits well for non-cooperative patients and for those who feel anxious or

stressed in a laboratory environment when electrodes are attached and then connected to the equipment. Indeed, because no electrodes are needed, the subjects can move freely and change position without worrying about the wires, which is not always the case with the standard polygraphy. They can also go to bed and get up whenever they wish, and thus home recordings can be made by the subjects themselves, as at least adults are easily taught to use the equipment.

The SCSB is suitable for registering autonomic and motor activities in bed during times when sleeping is sought, be them nocturnal or in the daytime, as in shift-work studies. Single-night cross-sectional comparative studies using a limited number of subjects are questionable, because there are great inter-subject differences in sleep motility. As a simple and low cost method the SCSB seems to be especially useful for long-term recordings of sleep quality in studies using a large sample of subjects. For instance, the method can be used in longitudinal field studies on the effects of chronobiological and environmental factors and in follow-ups of different kinds of interventions and treatments. The latter may include, for example, the effects of excercise, medication, psychotherapy, or rehabilitation. For dream research SCSB offers a potential method which permits a less disturbing and more natural laboratory situation without any stimulation related to measurement. Study II indicates that when a detection of the likely phases of sleep mentation are needed, time, subjects' discomfort, and money can be saved through the use of the SCSB instead of the standard procedure.

# 6 CONCLUSIONS

The present studies show the potential use of the SCSB in sleep research by implying that the recording of motility in bed, together with the motor manifestation of some autonomic nervous activities, could be applied as a simple and inexpensive objective indicator of sleep quality. Simple motility based recordings can be regarded as especially useful when data on multiple nights are needed, and the present results also indicate the necessity of repeated recordings under many circumstances. SCSB registering seems to be especially suitable for follow-up field studies. In addition to the simple movement profiles the nocturnal distributions of the three activity states provide a useful objective measure of sleep quality. QS and IS are generally related to NREM sleep, and according to behavioral criteria, QS in particular represents deep sleep. When exhibited at the beginning of the time in bed AS seems to reflect disturbed sleep, but during later hours it is mostly related to REM sleep, and as a result can be utilized in dream reseach.

Further experimental research is needed to examine the range of applicability of the SCSB method. The search for the most valid SCSB scoring parameters also needs further scrutiny. It can be questioned whether the rules governing the visual analysis are the most appropriate and the same must be stressed as regards to the parameters used in the BR01 analysis, as other programs exist for the automatic analysis of SCSB data, each of them using different parameters and algorithms. Nevertheless, the BR01 was used in Studies III-V because it is the only software commercially available for the off-line analysis of tape-recorded SCSB signals and therefore, in principle, the results refer to this particular method only. Further elaboration of the analysis methods for SCSB data is advisable, but it is obvious that the present forms already provide methods fit for recording the cyclic changes in physiological and motor phenomena during sleep in an easy and inexpensive way.

# YHTEENVETO

Viidestä osaraportista koostuvan tutkimuksen tavoitteena oli selvittää, missä määrin SCSB-unipatjamenetelmällä (static charge sensitive bed) rekisteröityä kehon yöllistä motoriikkaa sekä liikkeinä ilmeneviä autonomisen hermoston säätelemiä toimintoja voitaisiin käyttää unen laadun objektiivisessa arvioinnissa ja unennäkemistä tarkastelevassa tutkimuksessa perinteisten unitutkimusmenetelmien sijasta. Yleisesti käytetyn standardin mukaan valvetila ja uni sekä unen eri vaiheet määritellään aivosähkökäyrän (elektroenkefalogrammi, EEG) sekä silmien liikkeiden (elektro-okulogrammi, EOG) ja lihasjännityksen (elektromyogrammi, EMG) rekisteröinnin perusteella. Standardiluokituksen mukaan unessa erotetaan vaiheet S1, S2, S3 ja S4 sekä nopeiden silmänliikkeiden (rapid eye movements) luonnehtima vilke- l. REM-uni. Vaiheista S1-S4 käytetään yhteisesti nimitystä NREM-uni (non-REM, ei-REM) ja syvimpiä univaiheita S3 ja S4 kuvataan usein yhteisnimellä hidasaaltouni (slow wave sleep, SWS). Perinteisen univaiheluokituksen tuottamiseen tarvittava menetelmä on kuitenkin tutkijan kannalta sangen kallis ja työläs käyttää. Unta rekisteröidään yleensä laboratorio-olosuhteissa ja menetelmä edellyttää, että tutkittavaan henkilöön kiinnitetään lukuisia biosähköistä aktiviteettia mittaavia elektrodeja johtoineen. Viimeksi mainittujen seikkojen tiedetään heikentävän joidenkin henkilöiden unen laatua etenkin ensimmäisenä tutkimusyönä (ns. "ensimmäisen yön vaikutus").

Tässä tutkimuksessa käytetty SCSB on tavallisen patjan alle sijoitettava herkkä liikeanturi, jonka tuottamasta raakasignaalista voidaan tavanomaisten kehon liikkeiden lisäksi suodattaa esiin hengitysliikeet ja sydämen lyöntien aiheuttamat vartalon liikahdukset (ballistokardiogrammi, BCG). Entuudestaan tiedetään, että kehon liikkeissä ja autonomisen hermoston säätelemissä toiminnoissa esiintyy vaihteluita, jotka ovat yhteydessä perinteisten univaiheiden säännölliseen vuorotteluun yön aikana. Tutkimuksen tarkoituksena

oli tutkia, miten alunperin lääketieteellisiin tarkoituksiin kehitetty menetelmä soveltuu muun unitutkimuksen käyttöön. SCSB:n avulla rekisteröitävissä ilmiöissä yön kuluessa tapahtuvia muutoksia verrattiin perinteisillä menetelmillä määriteltyihin univaiheisiin, unennäkemiseen, ulkoisiin ärsykkeisiin reagoimiseen sekä koehenkilöiden subjektiivisiin arvioihin unensa laadusta. Tutkittavat koehenkilöt olivat terveitä nuoria aikuisia.

Tutkimuksen ensimmäisessä osassa verrattiin visuaalisesti analysoitua SCSB-aineistoa perinteisiin univaiheisiin. Hiljainen (quiet state, QS), välimuotoinen (intermediate state, IS) ja aktiivinen (active state, AS) tila määriteltiin hengityksen ja BCG:n säännöllisyyden ja pienten kehon liikkeiden esiintymisen perusteella. Yleisesti ottaen QS:lle on tyypillistä autonomisten toimintojen säänöllisyys ja liikkumattomuus, kun taas pienet nykäyksittäiset liikkeet ja hengityssignaalin ja BCG:n huomattavat faasiset vaihtelut ovat luonteenomaisia AS:n aikana. Kaikissa kolmessa SCSB:n avulla rekisteröidyissä signaalissa havaittiin vaihtelua, joka noudatti univaiheiden syklistä vuorottelua. QS ja IS olivat pääasiallisesti yhteydessä NREM-uneen; yhteensä 97% SCSB-signaaleista hidasaaltounen ja 81% S2:n aikana luokiteltiin joko QS:ksi tai IS:ksi. AS oli univaiheiden suhteen ongelmallisempi. REM-unen, valvetilan ja S1:n aikana valtaosa SCSB-aineistosta luokiteltiin AS:ksi, mutta kaikenkaikkiaan AS muodostui lähinnä REM unesta ja S2:sta. Tulosten perusteella QS ja IS ovat käyttökelpoisia NREM unen määrän indikaattoreita. AS on ensimmäisten vuoteessa vietettyjen tuntien jälkeen yhteydessä REM-uneen, mutta yön varhaisina tunteina sen suuri osuus ilmentää häiriintynyttä unta.

Toisessa tutkimuksessa tarkasteltiin unennäkemisen ja SCSB-rekisteröinnin välisiä yhteyksiä herättämällä koehenkilöitä QS:n, IS:n ja AS:n aikana ja pyytämällä heitä kertomaan, mitä heillä oli mielessään juuri ennen herätystä. Varsinaisia unia, joissa oli mukana kaksi tai useampia visuaalisia mielikuvia ja ajallista jatkuvuutta, raportoitiin n. 80%:ssa AS-herätyksistä ja huomattavasti harvemmin IS:n (25%) ja QS:n (20%) yhteydessä. Toisaalta, lähes joka toisen QS-herätyksen jälkeen ja yli kolmanneksessa IS-herätyksistä koehenkilöt eivät kyenneet palauttamaan mieliinsä minkäänlaisia herätystä edeltäviä ajatuksia, elämyksiä tai mielikuvia. Tulokset osaltaan vahvistivat käsitystä QS:n ja IS:n yhteydestä NREM-uneen, mutta ennen kaikkea ne osoittavat, että AS-herätykset tuottavat uniraportteja samalla todennäköisyydellä, mitä aiemmin on havaittu REM-unen yhteydessä. Tämän perusteella SCSB soveltuu hyvin yöllisten unennäkemisjaksojen erottamiseen.

Kolmas osatutkimus käsitteli automaattisesti analysoidun SCSB-aineiston ja standardin mukaisten univaiheiden suhdetta. Lähes kaikkien BR01:n tuottamien SCSB-signaalien variabiliteettia kuvaavien muuttujien havaittiin korreloivan merkitsevästi SWS:n, S2 ja REM-unen vaihtelun kanssa. Kolmen systemaattisesti korkeimpia korrelaatioita osoittaneen muuttujan summan perusteella SCSB-aineisto luokiteltiin kolmeen kategoriaan, QS, IS ja AS, joiden yhteydet perinteisiin univaiheisiin olivat pääpiirteissään samanlaiset, mitä havaittiin visuaaliseen analyysiin perustuen ensimmäisessä tutkimuksessa. Tätä luokittelua sovellettiin kahdessa viimeisessä osatutkimuksessa.

Ulkoisiin ärsykkeisiin reagoimisen katsotaan ilmentävän unen syvyyttä. Neljännessä tutkimuksessa tarkasteltiin ennakolta annettujen ohjeiden mukaista reagointia kuuloärsykkeisiin eri EEG-univaiheiden sekä QS:n, IS:n ja AS:n aikana. Koehenkilöiden tehtävänä oli sammuttaa äänisignaali aina sen kuullessaan puristamalla pientä kämmeneen kiinnitettyä paineanturia. Yleisesti ottaen behavioraalisessa reagoinnissa havaitut erot SCSB-luokkien välillä muistuttivat univaiheissa havaittuja. Tulosten perusteella QS on paitsi motorisesti ja autonomisen hermoston perusteella rauhallinen tila myös käyttäytymisen perusteella lähes hidasaaltouneen verrattavissa olevaa syvää unta.

Viidennessä osatutkimuksessa koehenkilöiden unta rekisteröitiin SCSB-menetelmällä heidän kotonaan kahden peräkkäisen viikon ajan. Tutkimuksessa analysoitiin sekä koehenkilöiden että öiden välillä esiintyviä eroja QS:n, IS:n ja AS:n sekä erilaisten liikkeiden yöllisessä määrässä. Öiden välisiä eroja tarkasteltiin suhteessa subjektiivisesti koettuun unen laatuun. Koehenkilöiden väliset erot useimpien SCSB-muuttujien suhteen olivat merkittäviä. Öiden välillä ei esiintynyt merkittäviä systemaattisia vaihteluita esim. viikonpäivien välillä. "Ensimmäisen yön vaikutusta" ei havaittu SCSB:n rekisteröimissä parametreissa, mutta ilmiö esiintyi subjektiivisena kokemuksena. Kahden rekisteröintiviikon ajalta lasketut korrelaatiokertoimet subjektiivisen unen laadun ja SCSB-muuttujien suhteen olivat tilastollisesti merkitseviä vain alle puolella koehenkilöistä. Systeemaattinen yhteys subjektiivisten ja objektiivisten muuttujien välillä kuitenkin paljastui, kun verrattiin keskenään kunkin koehenkilön motorisesti rauhallisinta ja aktiivisinta yötä l. motorinen levottomuus oli kaikilla koehenkilöillä yhteydessä heikentyneeksi koettuun unen laatuun.

Neljän ensimmäisen osatutkimuksen tulokset osoittavat, että SCSB-menetelmä soveltuu hyvin unen laadun arviointiin ja todennäköisten unennäkemisvaiheiden erotteluun. SCSB on EEG-tutkimukseen verrattuna yksinkertainen, edullinen ja nukkujan kannalta luonnollisempi tutkimusmenetelmä, sillä tutkittavaan ei kiinnitetä elektrodeja tai muita antureita. Koska SCSB-rekistöröinnit voidaan helposti suorittaa myös kotiolosuhteissa, menetelmä voisi mahdollistaa myös kenttätutkimukset, joissa laajamittainen aivosähköisten ilmiöiden mittaminen on useimmiten käytännössä mahdotonta toteuttaa. Viidennessä tutkimuksessa havaitut suuret koehenkilöiden väliset erot ja merkittävät öiden väliset vaihtelut SCSB-muuttujissa viittaavat kuitenkin siihen, että yhden yön SCSB-rekisteröinnin tuloksia tulkittaessa tulisi ainakin pienillä aineistoilla noudattaa varovaisuutta. Mikäli kehon liikkeitä tai QS:n, IS:n ja AS:n kaltaisia luokituksia halutaan käyttää objektiivisina unen laadun indikaattoreina, on koehenkilöiden yksilöllinen motorinen perustaso jollain tavoin varmennettava, mikä edellyttää useampaa kuin yhtä tutkimusyötä. SCSB tuntuukin luontevimmin soveltuvan erilaisiin seurantatutkimuksiin luonnollisissa nukkumisolosuhteissa.

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