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PRELIMINARY COMMUNICATION

Factor analysis of objective and subjective characteristics of a night's sleep

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SYNOPSIS Factor analysis was performed on objectively measured and subjectively reported characteristics of 46 nights' sleep in four healthy male subjects. The fragmentation of sleep by awakenings during the night, the delay before falling asleep, the total duration of sleep, and the amount of delta-wave sleep formed the bases of four separate factors.

The large volume of literature published in recent years on sleep attests to a widespread interest in this subject but leaves many basic questions unanswered. After periodic changes in the electroencephalogram (EEG) during sleep had been categorized into sleep stages and the importance of rapid-eye-movement (REM) sleep had been recognized (Dement and Kleitman, 1957), many experiments were carried out to determine the influence of age, physical and psychological disorders, and a wide variety of drugs upon the amount and proportion of sleep in each stage (Feinberg and Carlson, 1968; Kales and Tan, 1968; Oswald, 1968; Kupfer *et al*., 1970).

However, there are some wide variations in the characteristics of sleep obtained by different healthy subjects of the same age, the significance of which remains uncertain. The sleep of insomniacs who do not suffer otherwise from overt disease, and that of good sleepers of the same age, is not consistently distinguished by the proportions of sleep in each stage, which are commonly used to describe a night's sleep in the laboratory (Monroe, 1967; Kales, 1969; Karacan *et al*., 1973). Nevertheless, there are other physiological and psychological differences between good and poor sleepers (Rechtschaffen and Monroe, 1968; Johns *et al*., 1971a; Johns *et al*., 1974). The fact that many variables can be measured objectively and continuously during sleep may have led to an exaggerated sense of the biological significance of some of those variables, the relationship of which to the quality of sleep is not clear (Johnson, 1973). Indeed, there is no generally accepted definition either of the quality or of the functions of sleep.

Subjective reports of sleep have been omitted from many investigations in recent years because they are relatively inaccurate when compared with objective measurements of the same variables (Lewis, 1969). However, subjective reports of disturbed sleep have been, and will continue to be, the basis upon which millions of prescriptions for hypnotic drugs are written each year. In addition, responses to a sleep questionnaire provide information which electronic monitoring methods cannot easily provide—for example, the subject's ususal times of going to bed at night and of getting up next morning (Johns *et al*., 1971b). All the variables which have been used to describe patterns of sleep and wakefulness are derived from epiphenomena, related in various ways to those behavioural states, but not synonymous with them. At present, there is need for a set of variables to define the characteristics of sleep. It may be necessary to include a wider range of variables, both objective and subjective, than has been used hitherto.

Johns (1975) has previously used factor analysis as a method for investigating relationships between aspects of sleep habits defined entirely

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on the basis of responses to a sleep questionnaire. The present investigation was designed to extend this type of multivariate analysis to the characteristics of a particular night's sleep rather than sleep habits in general. Objective measurements of sleep in the laboratory and the subject's own reports were included in the analysis. The aim was to describe a small number of independent dimensions along which the characteristics of sleep in healthy subjects might vary simultaneously, taking into account relationships between each of the original variables which acted together. It was hoped that these preliminary results would indicate the usefulness or otherwise of this approach to further laboratory studies of sleep and insomnia.

METHODS

Four male volunteers, aged 24–55 years, each slept undisturbed in a separate bedroom for 12 weeknights over a period of three weeks. The subjects were healthy at the time and reported having only occasional, minor problems of falling asleep or of waking during the night. They did not take hypnosedative drugs, and drank alcohol only occasionally.

The subjects came to the laboratory about half an hour before the time they would otherwise have gone to bed at home. The latter times ranged from 2230 to 0015 on different nights. All-night recordings were made of the EEG, electro-oculogram (EOG), and the (DC) electrical resistance of palmar skin (Johns, 1971). Subjects nominated the times when recordings were to end each morning (0645 to 0800) and either awoke spontaneously or were woken by the experimenter.

The sleep recordings were scored visually in 30 second epochs, according to the main criteria of Rechtschaffen and Kales (1968) for sleep stages. However, stages 3 and 4 were combined into a single measurement of delta-wave sleep because of the relatively low reliability in scoring these stages separately (Monroe, 1969). The delay before falling asleep was measured from the time lights were put out until sleep spindles first appeared in the EEG. Awakenings during the night were defined by the presence of a waking pattern in the EEG and EOG, combined with a marked and sustained decrease in skin resistance, indicating an increase in the tonic level of sympathetic nervous system activity (Johns, 1971). The final period of wakefulness was that time between the subjects' waking or being woken in the morning and the recordings being stopped. The length of sleep cycles was the average interval, in minutes, between the beginnings of the first three successive REM sleep periods for a particular night. The total duration and number of awakenings, between the time of first entering stage 2 sleep and finally waking up next morning, were included as separate variables in the analysis. Half an hour after rising each day, the subjects filled in a daily sleep report in which the subjective quality of sleep was rated on a 5-point scale (1 = very poor sleep; 5 = very good sleep).

Comparisons between subjects were made by analysis of variance for each of 19 variables. Principal components analysis was carried out separately for each subject using 14 variables. Then a similar analysis was performed on the combined results from all subjects. Only those factors associated with Eigenvalues greater than 1.0 were retained, and Varimax rotation was performed to simplify the structure of each factor (Harmon, 1967). Factor loadings above 0.45 were considered to be 'significant'.

RESULTS

The results from 46 nights' sleep in the laboratory are summarized in Table 1. Two of the 48 recordings were technically unsatisfactory. The number of minutes spent in each stage of sleep is reported, as well as the percentage which each stage comprised of the total. There were highly significant differences between subjects for most variables.

The average amount of sleep obtained by each subject varied from six hours to 7¾ hours per night. The total time available for sleep varied from an average of seven hours 20 minutes to eight hours 15 minutes. Variations in the time available for sleep, within the same subject, were caused mainly by changes in the time of going to bed at night. The times of getting up in the morning were more constant and determined by the requirements of the daily routine of work. Subject D awoke much less frequently and for shorter periods during the night than did the other subjects. He had to be woken on most mornings and, despite his relatively long delays before falling asleep, spent a higher proportion of the time in bed asleep than did the other subjects.

The subjective estimates of delays before falling asleep for all subjects were highly correlated with the corresponding objective measurements ($r = 0.56$; $P < 0.001$), although the former were sometimes in error by about 10 minutes. A re-inspection of the EEG records, after they had

TABLE 1

OBJECTIVE AND SUBJECTIVE CHARACTERISTICS OF SLEEP IN LABORATORY (MEAN ± SD) FOR EACH SUBJECT, AND STATISTICAL SIGNIFICANCE OF DIFFERENCES BETWEEN SUBJECTS

	Subject				*Significance of differences* (P<)
	A	*B*	*C*	*D*	
Subject's age (yr)	55	43	52	24	
Number of nights	11	12	12	11	
Objective measurements of sleep					
Time available for sleep (min)	443.9±12.8	440.4±12.7	435.9±23.0	495.4±10.8	.001
Total duration of sleep (min)	390.4±25.6	358.3±24.3	367.1±23.8	467.4±22.2	.001
Sleep as % of time available	87.9± 4.1	81.4± 5.1	84.2± 4.1	94.4± 4.3	.001
Delay before falling asleep (min)	12.0± 7.2	5.1± 2.8	26.5± 7.0	24.5±19.6	.001
Total duration of awakenings (min)	33.2±14.8	69.0±21.5	34.1±14.2	4.1± 2.9	.001
Number of awakenings	7.6± 2.8	8.9± 4.0	6.4± 2.4	2.6± 1.5	.001
Final period of wakefulness (min)	8.4±12.2	6.5± 7.4	8.6± 8.2	1.2± 6.0	NS
Cycle length (min)	69.4± 8.7	86.5±14.0	105.0±16.2	100.8±13.6	.001
Min. of stage 1	13.0± 6.5	11.8± 7.6	8.5± 2.6	5.0± 3.0	.01
Min. of stage 2	193.1±26.4	209.9±19.8	208.5±19.4	258.6±26.9	.001
Min. of stage 3+4	82.9±23.4	66.8±15.8	65.3±12.7	89.9±11.4	.005
Min. of stage REM	101.5±16.7	68.2±19.6	84.8± 8.0	113.4± 4.3	.001
Percent stage 1	3.4± 1.8	3.3± 2.2	2.3± 0.8	1.1± 0.7	.001
Percent stage 2	49.5± 6.5	58.7± 5.6	56.8± 3.1	55.3± 4.1	.001
Percent stages 3+4	21.2± 5.7	18.6± 4.3	17.8± 3.5	19.3± 3.1	NS
Percent stage REM	25.9± 3.6	18.8± 4.7	23.1± 1.4	24.2± 2.8	.001
Subjects' own reports					
Quality of sleep (1–5)	3.7± 0.5	2.7± 0.7	4.3± 0.9	4.1± 0.3	.001
Estimated delay before falling asleep (min)	6.8± 2.5	8.0± 4.8	25.8±22.2	22.7±11.0	.001
Number of remembered awakenings	1.5± 0.8	1.4± 0.7	1.8± 1.2	1.3± 0.8	NS

NS=Not significant.

been scored, showed that some such errors arose when the subject woke up within a few minutes of first falling asleep. Apparently, the subject was unaware of the brief period of sleep and, hence, overestimated the time taken to fall asleep. The number of awakenings during the night reported by each subject was always less than the number measured objectively. Many awakenings were very brief, of the order of one minute, and were not remembered next day. In addition, two brief awakenings separated by a few minutes were recalled as a single, longer period of wakefulness. The subjective quality of sleep on particular nights in the laboratory varied from 'poor' (scored as 2) to 'very good' (scored as 5).

The results of factor analysis for 46 nights in all four subjects are shown in Table 2. The pattern of relationships between variables was similar when the results from each subject were analysed separately.

Factor 1 described one aspect of the quality of sleep which could be called its fragmentation. This factor was associated with more than a quarter of all the original data variance and included both objective measurements and subjective reports of awakenings during the night, the amounts of stage 1 and of REM sleep (related inversely), and one component of variation in the total duration of sleep.

Factor II could be called the length of sleep. The amount of sleep obtained on any one night was influened more by variations in the time of going to bed at night and in the time of finally waking up—that is, the time available for sleep—than it was by the fragmentation of sleep. The amount of stage 2 sleep was a more important determinant of the total duration of sleep than was the amount of REM or of delta-wave sleep.

The delay before falling asleep, measured objectively and also estimated subjectively, formed the basis of a separate factor (III), unrelated to the fragmentation of sleep. The amount of delta-wave sleep (Factor IV) was also independent of

TABLE 2

LOADINGS FOR FACTORS DERIVED FROM OBJECTIVE AND SUBJECTIVE CHARACTERISTICS OF 46 NIGHTS' SLEEP IN LABORATORY*

	Factor			
	I	*II*	*III*	*IV*
Objective measurements				
Time available for sleep		.81		
Total duration of sleep	.54	.79		
Delay before falling asleep			.74	
Total duration of awakenings	−.83			
Number of awakenings	−.83			
Final period of wakefulness		−.70		
Cycle length			.51	−.60
Min of stage 1	−.73			
Min of stage 2		.79		
Min of stage 3+4				.73
Min of stage REM	.68			
Subjects' own reports				
Quality of sleep	.80			
Estimated delay before falling asleep			.89	
Number of remembered awakenings	−.46			
Percent of variance associated with each factor	28.6	20.4	13.7	10.7

*Only those loadings greater than 0.45 after Varimax rotation are included.

changes in the length and the fragmentation of sleep but was related inversely to the length of sleep cycles. However, this association must remain tentative because, in one subject, delta-wave sleep varied directly rather than inversely with cycle length.

DISCUSSION

The present finding of a similar pattern of relationships between the variables used to describe a night's sleep in several subjects, despite widespread differences between those subjects, suggests that the factors described may apply more generally. Factor analyses of results from other subjects and under different circumstances would be required to establish this.

The results show important similarities with an earlier factor analysis of sleep habits among healthy young adults, although the latter involved only subjective reports of sleep habits in general (Johns, 1975). The first factor in both analyses was based on the frequency and duration of awakenings during the night. Thus, the fragmentation of sleep is a relatively independent dimension of variation, not only in the general description of sleep habits in different people but also in the accurate description of a particular night's sleep. The degree of fragmentation is the main determinant of the subjective quality of sleep.

A relationship between the fragmentation of sleep and the amount of REM sleep on a particular night has been described previously (Kupfer *et al.*, 1970). However, in different circumstances —for example, when first taking barbiturates— the amount of REM sleep is reduced when the fragmentation of sleep is decreased, not increased as in the present experiment (Evans and Lewis, 1968). Similarly, monoamine oxidase inhibitors, used in the treatment of depression, often enable a subject to sleep soundly, by subjective and objective criteria, although REM sleep is virtually eliminated (Wyatt *et al.*, 1971). Thus, the amount or proportion of REM sleep does not provide an accurate measure of the quality of sleep over a wide range of circumstances.

Subjective reports and objective measurements of the frequency of awakenings during the night formed part of the same factor (Factor I) and were presumably measuring similar phenomena. However, a subject's reports made next day are likely to underestimate the number of times he woke up during the night. Many awakenings which can be demonstrated objectively from recordings made in the laboratory are very brief and are not remembered later (Baekeland and Hoy, 1971). Thus, if a subject claims to wake up frequently during the night, he almost certainly does suffer from a sleep disorder.

There are marked differences in the usual delay before falling asleep in different subjects. Both in the present investigation and in the earlier one among medical students, much of this variation was unrelated to awakenings during the night (Johns, 1975). There are long-term psychological differences between subjects who usually take a long time to fall asleep compared with those who fall asleep quickly but who wake up during the night (Johns *et al.*, 1974). Falling asleep quickly depends, at least in part, on the ability to relax and inhibit conscious mental activity. To remain asleep must involve other mechanisms which are less well understood and which are beyond conscious control. The present results have shown that differences in the relative abilities of initiating sleep and of maintaining it exist not only between different subjects but also in the same subject from one night to the next.

Attempts to define specific needs or functions for delta-wave sleep, as for REM sleep, have not been very successful so far (Johnson, 1973), although some sleep researchers believe that delta-wave sleep is necessary for anabolism of macromolecules and physical restoration from tiredness (Hartmann, 1973). An inverse relationship between the amount of delta-wave sleep and the length of sleep cycles has been suggested previously on the basis of comparisons between the sleep of a variety of mammals whose metabolic rates differed widely (Zepelin and Rechtschaffen, 1973). Delta-wave sleep is increased in thyrotoxicosis (Dunleavy, Oswald, Brown and Strong, 1974) and reduced in hypothyroidism (Kales *et al.*, 1968). Variations in delta-wave sleep from night to night in healthy young men have also been shown to be related to normal variations in thyroid function (Johns *et al.*, 1975). Whether or not this might explain the variations in delta-wave sleep in the present experiment could not be ascertained because thyroid function was not measured. Other factors may well be involved also.

It may seem trite to report that the amount of sleep obtained varies with the time of going to bed at night, yet this simple fact has been neglected by some sleep researchers—for example, in laboratory studies of changes in sleep habits with increasing age (Feinberg and Carlson, 1968). Although many elderly people have highly fragmented sleep, they often obtain as much overall as young adults do by going to bed earlier and thereby increasing the time available for sleep (Johns *et al.*, 1970). The present findings confirm that the total duration of sleep is affected by night awakenings but that, by itself, it is not a good measure of the quality or disturbance of sleep, either within the same subject or between different subjects.

The delay before getting out of bed in the morning was related inversely to the duration of sleep in the laboratory. However, in previous factor analyses of sleep habits, this delay formed the basis of a separate factor (Johns, 1975). It was not related in any straightforward manner to early-morning awakening, as one manifestation of a sleep disorder. The length of the final period of wakefulness in the laboratory may depend to some extent on the circumstances in the laboratory (with the need to remove electrodes before the subject arises) and may not be a true reflection of the subject's behaviour in the morning when at home.

There were no reports of nightmares or disturbing dreams from the subjects in the present experiment, but previous factor analysis of sleep habits suggest that their presence would form another, relatively independent, dimension of variation in sleep (Detre, 1966; Johns, 1975). Similarly, the times at which subjects went to bed at night and woke up next morning were not included in the present analysis. However, previous factor analyses have indicated that whether a subject tends to be an 'early' or a 'late' sleeper may form yet another dimension of his sleep habits.

A subject's pattern of sleep and wakefulness on a particular day, or measured over longer periods, results from the interactions between many factors, including biological, psychological, social and environmental factors, and the use of drugs. These interactions may occur at several different levels, from the structure and function of particular groups of neurons to psychosocial behaviour. Factor analysis is one technique which can help to define these various interactions although, clearly, other methods are required to elucidate their causal nature.

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