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Sleep propensity varies with behaviour and the situation in which it is measured: the concept of somnificity

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SUMMARY It is self-evident that we fall asleep more readily when lying down than when standing up. Nevertheless, the influence of this and more subtle changes in posture, activity and the situation in which sleep propensity is measured have been largely ignored. The term somnificity is introduced here, defined as the general characteristic of a posture, activity and situation that reflects its capacity to facilitate sleep-onset in a majority of subjects. The relative somnificities of different activities and situations in the Epworth Sleepiness Scale (ESS) were investigated in 23 groups, involving 2802 subjects from seven different countries. The means of the different ESS item-scores were ranked from highest to lowest in each group. There was a high concordance (Kendall's $C = 0.84$, $P < 0.0001$) among these ranks for all groups, whether of normal subjects or patients with sleep disorders, regardless of age, sex, or average sleepiness in daily life assessed by total Epworth scores. The ESS item-ranks formed an ordinal scale of somnificities with five different levels. Analysis of raw ESS item-scores for all 987 individual Australian subjects showed the same pattern of somnificities with six different levels, but with a lower concordance ($C = 0.39$, $P < 0.0001$). This was probably because of subject × situation-specific interactions that were averaged within groups. A conceptual model of sleepiness is outlined that includes interactions between separate sleep and wake drives as a possible way of including behavioural and situational influences on sleep propensity.

KEYWORDS Epworth Sleepiness Scale, sleep propensity, sleepiness, somnificity

INTRODUCTION

It is self-evident that we are more likely to fall asleep when lying down than when standing up. However, currently accepted thinking about sleep and wakefulness cannot explain this. The increased sleep propensity when we lie down must be distinguished from subjective sleepiness which reflects the presence or intensity of subjective feelings that accompany the drowsy state. Sleep propensity must also be distinguished from the state and process of fatigue. Among the many factors that influence sleep propensity, some can be quantified easily and are well understood. The time of day and the duration of prior wakefulness are two such influences, called Process C and Process S in the model of Borbély *et al.* (1989). The effects of sleep disorders such as narcolepsy or obstructive sleep apnea (OSA) are also important, although not so well understood. The level of environmental stimulation and the subject's perception of and response to that stimulation have sometimes been acknowledged as important (Dinges 1989) but, with few exceptions, the effects of the subject's posture and activity, both physical and mental, have been ignored (Bonnet and Arand 1998, 1999; Johns 1994; Webb 1988). They are not included in any of the currently accepted models of sleep and wakefulness (Borbély and Achermann 1992). Carskadon and Dement (1982, 1987) have referred to latent sleepiness that is unmasked to become manifest sleepiness when we are in a low-stimulus situation. However, this leaves many questions unanswered. By what process does the unmasking occur, for example, when we lie down? Is the unmasking partial or complete, and how would we know the difference?

It was within a different frame of reference that Johns developed the Epworth Sleepiness Scale (ESS) (Johns 1991) and a new conceptual model of sleep and wakefulness that

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attempted to address these issues (Johns 1994, 1998). This model involves a continuous interaction between a putative wake drive and a sleep drive in the central nervous system. Hypothetically, each of these drives has two components, one intrinsic in its activity (the primary sleep drive and primary wake drive), the other responsive to behaviour and the environment (the secondary sleep drive and secondary wake drive). The two components have additive effects in each drive. The primary wake drive is the same as Process C and has a circadian rhythm that covaries with core body temperature. The secondary sleep drive is the same as Process S, increasing progressively during wakefulness and being discharged during sleep. It is the identification of a secondary wake drive that makes this model unique. The secondary wake drive is derived from direct and indirect effects of inputs from all exteroceptive and enteroceptive nerve tracts to the wake-promoting system in the central nervous system (McCormick and Bal 1997). This includes proprioceptive inputs from all postural and other muscles, and all other sensory inputs from the internal and external environment, modified by the subjects' perception of them. It is by changing those inputs that the subject's posture, activity and environmental situation could influence sleep propensity. This is not to deny the importance of the time of day, the duration of prior wakefulness, the presence of sleep disorders, or the effects of psychophysiological traits on sleep propensity, all of which are included in Johns' (1998) model of sleep and wakefulness. We would fall asleep when our total sleep drive exceeded our wake drive, and wake again when our wake drive exceeded our sleep drive.

A corollary of Johns' model of sleep and wakefulness is that some postures, activities and environmental situations will be more conducive than others to sleep-onset. This is the basis of the ESS which involves brief descriptions of eight different situations, chosen on *a priori* grounds to differ in what Johns has previously called their soporific nature (Johns 1994). Subjects rate their chances (0–3) of dozing off in each situation in the course of their usual daily lives based on their experience over recent times. Each of the eight ESS item-scores represents a different subjectively reported situational sleep propensity (SSP). The total Epworth score (0–24) gives a subjectively reported measure of the subject's average sleep propensity (ASP) across the eight ESS situations that are met commonly in daily life. A subject with an abnormally high ASP tends to doze off in situations in which normal subjects do not, i.e. in situations of a low soporific nature. There is evidence that the ESS has a unitary structure with a high internal consistency and high test–retest reliability, accuracy and validity (Johns 1992, 1993, 1994, 1998, 2000a). A subject's sleep propensity can also be measured objectively, on the one hand by a multiple sleep latency test (Carskadon and Dement 1982), and on the other hand by a maintenance of wakefulness test (Sangal *et al.* 1992). Within the conceptual framework outlined above, the mean sleep latencies in these two tests within the same subject represent different, but moderately correlated, objectively measured SSPs (Johns 2000a, b).

Johns (1994) has previously described the relationships between different subjectively reported SSPs within the same subject, based on ESS item-scores in four groups of Australian subjects, taking into account their differences in ASP. The relative soporific nature of the eight ESS situations was very similar in those groups. Other researchers later commented on the similarity of those results with their own (Hirshkowitz *et al.* 1996; Kingshott *et al.* 1998). Johns has suggested that sleepiness cannot be measured without reference to the subject's posture, activity and situation at the time. However, to complicate matters, each different SSP in individual subjects evidently includes a subject × situation interaction, depending on how that subject perceives and responds to each situation (Johns 1994).

It is proposed here to introduce the term somnificity (from the Latin, the making of sleep) to replace the phrase, soporific nature of a situation. Somnificity is the general characteristic of a posture, activity and environmental situation that reflects its capacity to facilitate sleep-onset in a majority of subjects. Different activities and situations might then be said to be more or less somniferous. The aim of the present investigation was to examine the concept of somnificity by investigating the relative somnificities of situations in the ESS. For that purpose, ESS item-scores for 23 groups of subjects were studied, 10 from Australia and 13 from other countries, involving a total of 2802 subjects. It was hoped that this investigation might provide some clues to the physiological mechanisms underlying consistent differences in somnificity. At the least, it was anticipated that the results would indicate more clearly what needs to be explained by any theoretical method of sleepiness, and hence increase our understanding of the problem.

METHODS

The ESS questionnaire has been described elsewhere (Johns 1991). The activities and situations described in the eight ESS-items will be referred to here by their item numbers as shown in Table 2. The mean ESS item-scores were available for each of the 23 groups of subjects, involving a total of 2802 men and women of all ages. There were 10 groups from Australia and 13 from other countries – England, Scotland, Spain, Sweden, Switzerland and the USA. These groups were all those for which data were available at the time of writing. Among the Australian subjects, some were patients seen at Epworth Sleep Centre with sleep disorders such as with narcolepsy, idiopathic hypersomnia, OSA, periodic limb movement disorder, restless legs syndrome, etc. (Johns 1991, 1994). Others were third-year medical students (Johns 1992). Others again were industrial workers, aged between 22 and 59 years, among whom men and women were considered separately (Johns and Hocking 1997). The four remaining Australian groups were of ostensibly healthy students, either at Swinburne University of Technology or the associated Swinburne College of Tertiary and Advanced Education in Melbourne. Those subjects had previously taken part anonymously in a questionnaire survey of sleepiness and car crashes and had completed the ESS (Johns and Patterson 2000, unpublished data). They were divided into four groups here on the basis of age and gender. Those aged 17–25 years were called 'young', and those 26–72 years were called 'older' men and women. The ESS item-scores were available for each of the 987 Australian subjects. The 13 groups of subjects who were not Australian included normal subjects and patients with a variety of sleep disorders such as narcolepsy, OSA, insomnia and 'gulf-war illness'. They had been investigated in a variety of sleep laboratories by other researchers. The mean scores for each ESS item were available for all groups. The item-scores for individual subjects were available for the Australian subjects, not for the others.

Within each of the 23 groups the mean ESS item-scores were ranked from 8 to 1, from the highest to the lowest (Table 1). This was to overcome the large differences in ASP between groups whose mean Epworth scores ranged from 4.5 to 20.0. The ESS item-ranks were then compared between groups by non-parametric methods – Friedman's ANOVA, Kendall's coefficient of concordance – C, Wilcoxon's matched pairs *t*-tests and Mann–Whitney *U*-tests. The same methods, as well as Spearman's non-parametric correlation, factor analysis (extracting factors with eigenvalues > 1.0) and Cronbach's α-statistic were used for the analysis of raw ESS item-scores for each of the 987 subjects that together formed the ten groups Australian subjects. Statistical significance was accepted at $P < 0.05$ in two-tailed tests.

RESULTS

The somnificities of ESS situations for groups of subjects

The mean ESS item-scores, ranked from 8 (highest) to 1 (lowest) within each of the 23 groups of subjects, are shown in Table 1. There is a striking similarity in these rankings, reflected in a high Kendall's coefficient of concordance, $C = 0.84$ ($P < 0.0001$). The same analysis performed on the mean ESS item-scores gave $C = 0.86$, demonstrating that the high concordance was not a product of the ranking procedure. Thus, within groups of subjects, the mean ESS item-scores

Table 1 The ranks of mean ESS item-scores within each of 23 groups of subjects. The means of those ranks for the Australian groups (1–10) and for the groups from six other countries (11–23) are shown at the bottom

Group no.	Country, subjects	No. of subjects	Mean Epworth score	*Rank of mean ESS item score for item no.* 1	2	3	4	5	6	7	8	Reference
	Australia											
1	Sleepy patients	40	17.2	6	7	4	5	8	2	3	1	Johns (1994)
2	Sleep disorder patients	150	10.2	6	7	4	3	8	1	5	2	„
3	Sleep disorder patients	50	13.1	6	7	3	5	8	2	4	1	„
4	Medical students	104	7.6	6	3	4	7	8	1	5	2	Johns (1992)
5	Male workers	267	5.8	6	7	3	5	8	2	4	1	Johns and Hocking (1997)
6	Female workers	64	5.7	5	7	4	6	8	2	3	1	„
7	Young male students	83	5.6	6	7	4	5	8	1	3	2	Johns and Patterson (2000) (unpublished)
8	Older male students	74	6.6	6	7	3	5	8	1	4	2	„
9	Young female students	82	6.7	6	7	4	5	8	2	3	1	„
10	Older female students	73	5.7	7	6	4	5	8	2	3	1	„
	England											
11	Controls	188	4.5	5.5	7	3	4	8	1.5	5.5	1.5	Parkes *et al.* (1998)
12	Possible narcolepsy	111	19.3	4	4	4	7.5	7.5	2	6	1	„
13	Probable narcolepsy	57	20.0	6	6	4	6	8	2	3	1	„
14	Definite narcolepsy	15	19.6	7	4.5	4.5	4.5	8	2	4.5	1	„
15	Other sleepy patients	62	16.9	5	6.5	3	6.5	8	2	4	1	„
16	Severe OSA patients	10	18.4	4.5	6.5	4.5	6.5	8	2	3	1	„
	Scotland											
17	OSA patients	129	–	6	7	3	4	8	2	5	1	Kingshott *et al.* (1998)
	Spain											
18	Controls	193	6.1	5	6	3	4	8	1	7	1	Izquierdo-Vicario *et al.* (1997)
	USA											
19	OSA patients	78	–	6	7	3	5	8	1	4	2	Hirshkowitz *et al.* (1996)
20	Veterans with PTSD	149	11.6	7	6	3	5	8	2	4	1	Moore *et al.* (2000)
	Switzerland											
21	Patients	174	13.0	6	7	3	4.5	8	2	4.5	1	Bloch *et al.* (1999)
22	Controls	159	5.7	4.5	7	4.5	4.5	8	2	4.5	1	„
	Sweden											
23	Elderly females	490	6.6	6	7	4	5	8	1	3	2	Broman *et al.* (2000)
Mean for groups 1–10		987	7.6	6.0	6.5	3.7	5.1	8.0	1.6	3.7	1.4	
Mean for groups 11–23		1815	9.3	5.6	6.3	3.6	5.2	8.0	1.7	4.5	1.2	

pertaining to any two of the situations were highly correlated, with an average Spearman's ρ of 0.86 (range 0.67–0.93), accounting for a mean of 74.0% of variance. The mean values of item-ranks for the Australian groups (groups 1–10) and the others (groups 11–23) are shown separately at the bottom of Table 1. There were no significant differences between the paired means when each was tested by a Mann–Whitney U-test ($P > 0.1$ for each). Consequently, the results from all 23 groups were combined for further analysis.

The item-ranks for each group were very similar regardless of whether the groups involved normal subjects with low Epworth scores and consequently low ASPs, or sleepy patients with high ASPs caused by a variety of sleep disorders, and whether male or female, younger or older, or from different sleep laboratories in English-speaking or non-English-speaking countries. This confirms and extends the findings reported previously for four of the Australian groups (Johns 1994). This shows that the different postures, activities and situations that ESS items represent are associated with differences in subjectively reported sleep propensity that are generally consistent and widespread among groups of subjects.

Despite the consistency reported here, there were a few differences between groups that need to be explained. Group 4 involved healthy young adults who were fourth year medical students in clinical training at various hospitals in Melbourne (Johns 1992). For them, watching TV (item 2) was much less somniferous than for all other groups, including other young tertiary students (groups 7 and 9). Perhaps this reflects differences in the usual times and circumstances of their watching TV depending on their attitudes and routines of daily life. Similarly, the situation in item 7 (sitting quietly after lunch without alcohol) was more somniferous for the Spanish subjects in group 18 than for all other groups. This may reflect a strong positive attitude towards a siesta as part of Spanish culture, whereas in some other countries a siesta may be viewed negatively.

Considering all 23 groups together, there were significant overall differences in rank among the eight ESS items, tested by Friedman's non-parametric ANOVA ($P < 0.00001$). The mean of ranks for each item is shown in Table 2. These numbers represent the relative somnificities of the different ESS situations, ranked from the highest (item 5) to the lowest (items 6 and 8) for 23 groups of subjects. This is an ordinal scale of somnificities that we cannot assume to be linear. Differences between pairs of somnificities were tested, posthoc, by Wilcoxon's matched paired t-tests. Of the 28 possible pairs, there were significant differences ($P < 0.01$) between all except three pairs, items 1 and 4 ($P > 0.1$), items 3 and 7 ($P > 0.1$) and items 6 and 8 ($P > 0.4$). On this basis, the somnificities of the eight ESS activities might tentatively be assigned to five levels on a scale from 1.3 to 8.0, each level differing significantly from the others (Table 2). However, the power of these tests of difference was relatively low because there were only 23 groups. This issue is addressed in another way below by comparing the raw ESS item-scores within individual subjects.

Differences between the ESS situations for individual subjects

The 10 Australian groups comprised 987 subjects whose Epworth scores, and hence their ASPs, varied widely between 0 and 24. They included men and women of all ages. Some were sleepy patients with sleep disorders, others were ostensibly normal in their sleep habits and ASP. Friedman's ANOVA showed highly significant differences overall between the scores on the eight ESS items ($P < 0.000001$). Post-hoc comparisons between pairs of item-scores by Wilcoxon's matched pairs t-tests allowed for the differences in ASP between subjects (Table 2). As above, Items 3 and 7 did not differ significantly ($P > 0.4$), nor did items 6 and 8 ($P > 0.4$). However, all other items differed significantly from each other ($P < 0.001$). In particular, items 1 and 4 that were not significantly different in the previous analysis for groups, were significantly different here within individual subjects ($P < 0.00001$). Thus, the somnificities shown in Table 2 probably should be considered on a 6-level scale. As the Australian and non-Australian groups were shown to be very similar in their item-ranks, this scale of somnificities may be widely applicable.

Table 2 The situations described in ESS items, ranked according to their relative somnificities, from highest to lowest. The somnificities are based on the means of item-ranks for 23 groups of subjects involving 2802 subjects. The means of item-scores (not ranks) are also shown for 987 Australian subjects. The latter means are significantly different from each other ($P < 0.001$), except for items 3 and 7 and items 6 and 8 ($P > 0.4$), tested by Wilcoxon's matched pairs t-tests

ESS item no.	*Situation*	*Somnificity Mean ± SD*	*Item-scores for 987 Australian subjects Mean ± SD*
5	Lying down to rest in the afternoon when circumstances permit	8.0 ± 0.1	1.86 ± 1.08
2	Watching TV	6.4 ± 1.1	1.40 ± 1.04
1	Sitting and reading	5.8 ± 0.8	1.21 ± 1.04
4	As a passenger in a car for an hour without a break	5.1 ± 1.0	0.96 ± 1.03
7	Sitting quietly after a lunch without alcohol	4.1 ± 1.1	0.83 ± 0.96
3	Sitting, inactive in a public place (e.g. a theatre or meeting)	3.6 ± 0.6	0.85 ± 0.93
6	Sitting and talking to someone	1.7 ± 0.5	0.28 ± 0.62
8	In a car, while stopped for a few minutes in the traffic	1.3 ± 0.5	0.30 ± 0.68

The highest somnificity was with item 5, 'lying down to rest in the afternoon when circumstances permit'. The rank of mean item-scores for item 5 was either the highest or equal highest for all 23 groups of subjects. In addition, 74.6% of all individual subjects in groups 1–10 reported their highest or equal highest item-scores for item 5. Viewed another way, there was discordance between the relative SSPs represented by scores on item 5 and other items for 25.4% of those subjects. Item 5 is the only one that clearly involves lying down. All other items involve variations of the sitting posture, except perhaps item 2 ('watching TV') in which the posture is not specified. However, even when sitting, the 987 Australian subjects reported significantly higher chances of dozing off when 'sitting and reading' (item 1) than when 'sitting, inactive in a public place' (item 3) ($P < 0.00001$), which in turn were higher than when 'sitting and talking to someone' (item 6) ($P < 0.001$). What may appear to be minor differences in physical and mental activity when sitting can have major effects on subjectively reported sleep propensity. These effects can now be quantified, at least on an ordinal scale. Such effects are independent of the subjects' general level of sleepiness, as measured by total Epworth scores.

Correlation between different situational sleep propensities in individual subjects

Other researchers have analysed the relationships between different ESS item-scores in the same subjects by correlation, factor analysis and item analysis following Johns' (1992) initial report (Broman *et al.* 2000; Kingshott *et al.* 1998). The ESS usually has one main dimension in its variance, with approximately equal contributions from each of the eight items. This was confirmed here by the analysis of ESS item-scores from all 987 Australian subjects in groups 1–10. The scores for each of the 28 pairs of item-scores were significantly intercorrelated, with ρ ranging from 0.33 to 0.57 (each $P < 0.0001$). Factor analysis confirmed that there was only one factor with an eigenvalue of 3.75 and high normalized factor loadings (0.57–0.75) for all ESS items. With item analysis Cronbach's α was 0.87, indicating a high internal consistency for the questionnaire. These results give credence to the general concept of a subject's ASP, reflecting an average level of sleepiness in daily life rather than sleepiness in any one situation.

The concordance between the eight ESS item-scores reported by all 987 individual Australian subjects was 0.39 ($P < 0.00001$), i.e., an average of 15.2% of variance in one SSP was shared by that of a different SSP in the same subjects. Similar analyses in each of the 10 groups of Australian subjects showed that the concordance of item-scores varied between 0.33 and 0.54. That is, 10.9–29.2% of variance was shared by two different subjectively reported SSPs measured in the same subjects. This is in marked contrast to the 74.0% of variance shared by two mean SSPs in groups of subjects, in which random errors and the differences between individual subjects were averaged. Johns (1994, 1998) has suggested previously that this difference arises from specific subject-situation interactions, by which the somnificity of each situation and the subject's ASP are modified in particular situations by the subject's unique perception of and response, physiologically and psychologically, to each situation. This is presumably learned, at least partly.

DISCUSSION

The results suggest the potential importance of the concept of somnificity to our understanding of sleepiness, in the sense of sleep propensity. The somnificities of different activities and situations described briefly in the ESS items differ significantly and can be ranked on an ordinal scale with five or six levels. The effects on sleep propensity of those situations were independent of the subject's ASPs that varied widely between groups that included sleepy patients with sleep disorders such as narcolepsy or OSA, normal subjects, young and old, male and female, English-speaking and non-English-speaking subjects. The results are consistent with those published previously and extend their relevance (Johns 1994).

The results do not explain the psychophysiological mechanisms involved, but they offer some clues. To lie down from the sitting position increases the subjectively reported sleep propensity markedly for the majority of subjects. This is normally how the process of sleepening, as Johns (1990) calls it, begins at our usual bed-time, well before the appearance of stage-1 sleep. When we lie down and support our head on a pillow this releases our postural muscles from the task of holding our head erect and of supporting our trunk. The consequent relaxation of those muscle would reduce the proprioceptive inputs to the brainstem reticular activating system and thalamocortical neuronal systems that are so important for the maintenance of wakefulness (McCormick and Bal 1997). These effects of postural and behavioural changes are also manifested as changes in heart rate, blood pressure (Lechin *et al.* 1995), baroreceptor reflexes (Cole 1989) and core temperature (Kleitman 1963). Within the conceptual framework suggested above, these changes reflect a reduction in the secondary wake drive without a direct effect on the sleep drive.

It could be argued that most of us would 'lie down to rest in the afternoon' (item 5) only when we feel very 'tired' or 'sleepy', for whatever reason, and that is why we would have a high chance of falling asleep then. It may be that our 'fatigue' rather than our change of posture raises our sleep propensity. But that begs the question of why we would not usually fall asleep standing up, even when 'fatigued'.

We have seen that 'sitting and reading' (item 1) is usually much more somniferous than 'sitting inactive in a public place' (item 3). Perhaps the presence of other people and the potential for interaction with them influences sleep propensity. By contrast, 'watching TV' (item 2) is more somniferous again for most people. Perhaps this is because it typically involves little movement of the head, only small saccadic eye movements, and neither talking to others nor interacting much with them while attention is focussed on the TV screen. It may also be because many of us watch TV mainly when we relax, physically and mentally, after the day's work. Whatever different behavioural and postural changes may be involved, the results here suggest that many people have a similar set of circumstances when watching TV that influences their sleep propensity in a predictable way. Much more research is needed to investigate these matters.

The influence of somnificity on sleep propensity was very apparent when comparing average results between different groups of subjects, but less so within individual subjects, although the differences were still statistically significant. That this was not simply because of the relative inaccuracy of subjective reports in the ESS is demonstrated by considering the results of objectively measured sleep propensity in two different situations, the multiple sleep latency test (MSLT) and the maintenance of wakefulness test (MWT), in the same subjects. The majority of subjects take longer to fall asleep in the MWT than in the MSLT (Sangal *et al.* 1992), i.e. the MSLT situation is more somniferous than the MWT situation. The difference may reflect differences in the subject's posture, lying down with the head supported by a pillow vs. sitting propped up in bed by pillows with less support for the head, the eyes being closed vs. open, and the subject's intention to fall asleep vs. stay awake, as instructed. The mean sleep latencies in MSLTs and MWTs performed on the same subjects are moderately correlated [e.g. $r = 0.41$, $n = 258$, $P < 0.001$ (Sangal *et al.* 1992); $r = 0.52$, $n = 522$, $P < 0.001$ (Sangal *et al.* 1997)], i.e. 20–25% of variance in one test is shared by the other, comparable with the 10.9–29.2% of variance shared by pairs of subjectively reported SSPs, as above. Thus, the relationships between different SSPs in the same subjects are similar whether the SSPs are measured objectively by MSLTs and MWTs, or subjectively by ESS item-scores. However, there is discordance in the results of MSLTs and MWTs for about 30% of subjects, i.e. some are relatively sleepy in one test but not in the other. This, too, is comparable with 25% discordance between different subjectively reported SSPs, mentioned above. A few subjects actually fall asleep more quickly in the MWT, when trying to stay awake, than in the MSLT when trying to fall asleep (Sangal *et al.* 1992). The response of those subjects to the different test situations evidently involves subject × situation-specific interactions that modify the usual effects simply because of the relative somnificities. This would also explain why patients with psychophysiological insomnia can fall asleep in a chair watching TV, but as soon as they lie down in bed they cannot fall asleep. However, on their first night in a sleep laboratory, in a different cognitive setting, they can fall asleep normally, rather than show the 'first night effect' seen in most normal subjects (Hauri and Olmstead 1989).

The results here indicate the existence of several influences on sleep propensity that are separate from the time of day (Process C) and the duration of prior wakefulness (Process S). The first is the subject's ASP, an abstract parameter measured by the Epworth score which varies widely and independently from other factors. The second is the somnificity of different situations in which sleep propensity is measured. This has a highly predictable effect on mean SSPs for groups of subjects. The third, which is less predictable, involves situation-specific interactions for each subject that reflect how he/she perceives and responds to each situation. These results are in accord with the views of Webb who pointed out, prophetically in 1988, that in addition to processes C and S, it is 'not only desirable but also crucial' that 'behavioural facilitators and inhibitors of sleep' be included in any model of sleep and wakefulness. Webb also stressed the importance of individual differences in this regard. How best to incorporate these influences into a better model remains to be clarified. However, recognition of the roles of separate but interacting sleep and wake drives, particularly of a secondary wake drive as outlined above, may be helpful in that.

REFERENCES

Bloch, K. E., Schoch, O. D., Zhang, J. N. and Russi, E. W. German version of the Epworth sleepiness scale. *Respiration*, 1999, 66: 440–447.

Bonnet, M. H. and Arand, D. L. Sleepiness as measured by the MSLT varies as a function of preceding activity. *Sleep*, 1998, 21: 477–483.

Bonnet, M. H. and Arand, D. L. Level of arousal and the ability to maintain wakefulness. *J. Sleep Res.*, 1999, 8: 247–254.

Borbély, A. and Achermann, P. Concepts and models of sleep regulation: an overview. *J. Sleep Res.*, 1992, 1: 63–79.

Borbély, A. A., Achermann, P., Trachsel, L. and Tobler, I. Sleep initiation and sleep intensity: interaction of homeostatic and circadian mechanisms. *J. Biol. Rhythms*, 1989, 4: 149–160.

Broman, J.-E., Bengtson, H. and Hetta, J. Psychometric properties of a Swedish version of the Epworth sleepiness scale. *J. Sleep Res.*, 2000, 9 (Suppl. 1): 27.

Carskadon, M. A. and Dement, W. C. Daytime sleepiness: quantification of a behavioural state. *Neurosci. Biobehav Rev.*, 1987, 11: 307–317.

Carskadon, M. A. and Dement, W. C. The multiple sleep latency test: what does it measure? *Sleep*, 1982, 5 (Suppl. 2): S67–S72.

Cole, R. J. Postural baroreflex stimuli may affect EEG arousal and sleep in humans. *J. Appl. Physiol.*, 1989, 67: 2369–2375.

Dinges, D. F. The nature of sleepiness: causes, contexts and consequencxxes. In: A. J. Stunkard and A. Baum (Eds) *Perspectives in Behavioural Medicine: Eating, Sleeping and Sex*. Lawrence Erlbaum Assoc., Hillsdale, NJ, USA, 1989: pp. 147–179.

Hauri, P. J. and Olmstead, E. M. Reverse first night effect in insomnia. *Sleep*, 1989, 12: 97–105.

Hirshkowitz, M., Gokcebay, N., Moore, C. A. and Zebrak, A. Epworth sleepiness scale: item analysis in patients with obstructive sleep apnea. *Sleep Res.*, 1996, 25: 256.

Izquierdo-Vicario, Y., Ramos-Platón, M.-J., Conera-Peraleja, D., Lozano-Parra, A. B. and Espinar-Sierra, J. Epworth sleepiness scale in a sample of the Spanish population. *Sleep*, 1997, 20: 676–677.

Johns, M. W. Sleepening: the process of falling asleep. Paper presented at Australasian Sleep Research Association, Annual Scientific Meeting, Adelaide, April, 1990.

Johns, M. W. A new method for measuring daytime sleepiness. The Epworth sleepiness scale. *Sleep*, 1991, 14: 540–545.

Johns, M. W. Reliability and factor analysis of the Epworth sleepiness scale. *Sleep*, 1992, 15: 376–381.

Johns, M. W. Daytime sleepiness, snoring and obstructive sleep apnea: the Epworth sleepiness scale. *Chest*, 1993, 103: 30–36.

Johns, M. W. Sleepiness in different situations measured by the Epworth sleepiness scale. *Sleep*, 1994, 17: 703–710.

Johns, M. W. and Hocking, B. Daytime sleepiness and sleep habits of Australian workers. *Sleep*, 1997, 20: 844–849.

Johns, M. W. Rethinking the assessment of sleepiness. *Sleep Med. Rev*., 1998, 2: 3–15.

Johns, M. W. Sensitivity and specificity of the multiple sleep latency test (MSLT), the maintenance of wakefulness test and the Epworth sleepiness scale: failure of the MSLT as a gold standard. *J. Sleep Res*., 2000a, 9: 5–11.

Johns, M. W. Reply to a letter to the editor by R. B. Cherwin. *J. Sleep Res*., 2000b, 9: 399–401.

Kingshott, R., Douglas, N. and Deary, I. Mokken scaling of the Epworth sleepiness scale items in patients with the sleep apnea/hypopnea syndrome. *J. Sleep Res*., 1998, 7: 293–294.

Kleitman, N. *Sleep and Wakefulness*. University Chicago Press, Chicago, 1963, 2nd edn, pp. 58–59.

Lechin, F., van der Dijs, B., Orozco, B., Lechin, M. E., Baez, S., Lechin, A. E., Rada, I., Acosta, E., Arocha, L., Jimenez, V., Leon, G. and Garcia, Z. Plasma neurotransmitters, blood pressure, and heart rate during supine-resting, orthostasis, and moderate exercise conditions in major depressed patients. *Biol. Psychiatry*, 1995, 38: 166–173.

McCormick, D. A. and Bal, T. Sleep and arousal: thalamocortical mechanisms. *Ann. Rev. Neurosci*., 1997, 20: 185–215.

Moore, C. A., Johnson, V., Smith, J. M. and Hirshkowitz, M. Self-reported sleepiness in patients with Gulf War Illness. *Sleep*, 2000, 22 (Suppl. 1): S321–S322.

Parkes, J. D., Chen, S. Y., Clift, S. J., Dahlitz M. T. and Dunn G. The clinical diagnosis of the narcoleptic syndrome. *J. Sleep Res*., 1998, 7: 41–52.

Sangal, R. B., Mitler, M. M. and Sangal, J. A. M. US modafinil in narcolepsy multicenter study group. MSLT, MWT and ESS indices of sleepiness in 522 drug-free patients with narcolepsy. *Sleep Res*., 1997, 26: 492.

Sangal, R. B., Thomas, L. and Mitler, M. M. Maintenance of wakefulness test and multiple sleep latency test: measurement of different abilities in patients with sleep disorders. *Chest*, 1992, 101: 898–902.

Webb, W. B. An objective behavioural model of sleep. *Sleep*, 1988, 11: 488–496.