Letter to the Editor

Differentiating sleep continuity effects from sleep stage effects

Wesensten et al. [Journal of Sleep Research (1999) 8, 237], in their review of sleep fragmentation, suggest that sleep fragmentation reduces sleep restoration primarily by increasing stage 1 sleep, which they view as having 'little or no recuperative value', rather than by destroying the sleep process (i.e. by limiting sleep continuity). Their review reinforces several important concepts: (i) sleep fragmentation studies were originally performed as a means of understanding the restorative nature of sleep, rather than as a model of sleep pathology; (ii) sleep fragmentation studies traditionally entailed changes in sleep-stage distributions as well as changes in sleep continuity; (iii) because sleep stage and arousal parameters vary together, it may be difficult to tease out causal factors without careful empirical studies. The authors present a good deal of data which suggest that amounts of stage 1 sleep and next day performance and alertness vary together, but they do not consider that fact that in almost all of the studies they cite, the amount of stage 1 sleep and rate of sleep fragmentation are confounded (i.e. also vary together).

Under normal circumstances, there will always be a high correlation between the rate of sleep fragmentation and amount of stage 1 sleep because sleep fragmentation has historically been defined by the appearance of stage 1 or waking EEG patterns. As the rate of fragmentation increases, the amount of stage 1 will also increase. Of course, this means that in any typical study of sleep fragmentation, there will be a positive correlation between the amount of stage 1 sleep and residual sleepiness. Obviously, this cannot be taken as 'proof' that stage 1 sleep is nonrestorative, because, in such designs, sleep fragmentation and stage 1 sleep are confounded variables.

Only one study (Bonnet 1986b) was specifically designed to independently vary sleep stage amounts and sleep fragmentation in an attempt to split apart fragmentation effects from sleep stage effects. That study included repeated observations under several conditions including sleep disturbance after each min of sleep; sleep disturbance after each 10 min of sleep; and 2.5 h of undisturbed sleep followed by sleep disturbance at the appearance of any spindle or k-complex (the last condition to specifically increase stage 1 sleep after a period of nonfragmented sleep). This study was difficult for both subjects and experimenters, and subject numbers were small (N = 5–8). However, the results made it possible to differentiate the effects of sleep continuity and sleep stages in ways not possible in clinical studies, and a major goal was to determine which sleep stage or fragmentation combinations best predicted subsequent alertness and performance. That study concluded that sleep continuity, not stage 1 sleep, was a more likely underlying factor in sleep restoration for the following reasons.

Stage 1 sleep was increased only ~20 min in the 10-min condition compared with baseline, but the increases in stage 1 were much larger in the 2.5-h sleep and 1-min conditions (~90 and 120 min increases, respectively). Despite the large increase in stage 1 in the 2.5-h sleep condition, nap latency was not different from the 10-min condition (latency was actually nonsignificantly longer after the increased stage 1 sleep in the 2.5-h sleep condition). Also, the vigilance hit rate was nonsignificantly better, and significantly more correct additions were performed following two nights of the 2.5-h sleep condition compared with two nights of the 10-min sleep fragmentation (t = 5.925, P < 0.01, with five subjects). All of these data show worse performance with small amounts of stage 1 sleep (and periodic sleep fragmentation) and better performance when stage 1 was greatly increased.

Regression was also used to predict whether subjects had better or worse performance and alertness in the experimental conditions based upon changes in four EEG sleep parameters: total sleep time (TST); amount of slow-wave sleep (SWS); amount of SWS and rapid-eye movement (REM); and TST with amount of stage 1 sleep eliminated. The latter condition was formulated to specifically test whether stage 1 was 'nonrestorative'. In general, nap latencies were shorter than predicted by either TST or TST – stage 1 in both the 1-min and 10-min conditions. Also, all subjects in the 2.5-h condition performed better than predicted by their TST with stage 1 deleted, whereas only 37% of subjects performed better than predicted by their TST with stage 1 deleted in the 10 min condition. These proportions (1.00 vs. 0.37) were significantly different.

In summary, alertness and performance were consistently improved and in some instances significantly better when subjects had ~100 min of stage 1 sleep (24% of SPT) than when they had only 37 min of stage 1 sleep (9% of SPT) but with a pattern of brief arousals every 10 min.

Correspondence: Michael H. Bonnet, PhD (151N), Dayton Department of Veteran Affairs Medical Center, 4100 W. Third Street, Dayton, OH 45428, USA. Tel: (937) 267 3910; fax: (937) 267 5317; e-mail: Bonnet.Michael@DAYTON.VA.GOV
What additional reasons make increased stage 1 sleep itself a poor explanation for reduced sleep restoration?

In mild sleep fragmentation paradigms, such as the placement of arousals following 10-min periods of sleep (Bonnet 1986b), significant sleepiness accumulated after two nights (a 39% reduction in sleep latency), but the increase in stage 1 sleep (which accounted for only 9% of SPT in the 1986 paper) was trivial. For comparative purposes, it is common for patients with insomnia (and normal controls for those patients) to have 10–15% stage 1 sleep (Hauri 1981; Bonnet and Arand 1995). It is well known that patients with insomnia are not excessively sleepy during the day, and typically have longer than normal sleep latencies (Bonnet and Arand 1995). Similarly, the 9% stage 1 sleep reported in the 1986 paper is within 1 SD of the values reported for normal healthy males in the standard Williams et al. (1974) reference for 30-, 40-, 50- and 60-year-old age groups. Clearly, a case cannot be made that large numbers of normal, healthy adult males are excessively sleepy secondary to having 9% stage 1 sleep as a continuing normal pattern.

One recent sleep fragmentation paper (not referenced in the review) reported significantly increased daytime sleepiness on the MSLT after ‘nonvisible’ sleep fragmentation (Martin et al. 1997). By ‘nonvisible’ the authors meant fragmentation with tones designed to increase heart rate or blood pressure without producing any change in ongoing EEG. In that study, subjects had 3.3% stage 1 sleep on baseline and 3.7% stage 1 on fragmented nights \( (P = 0.5) \). That study makes it even more clear that it is not stage 1 sleep which controls restoration during sleep. Unfortunately, despite the hope to produce ‘nonvisible’ sleep fragmentation, the Martin et al. (1997) study did have a significant reduction in stage 4 sleep on the fragmentation nights. I also could not eliminate SWS as a possible explanatory variable in my 1986 study (Bonnet 1986b) because amounts of SWS were also proportional to the changes found in alertness and performance. To examine the role of SWS vs. fragmentation in sleep restoration, another study examined sleep fragmented in a manner which either maximized or minimized SWS while producing similar periodic sleep fragmentation (Bonnet 1986a). In that study, similar decrements were found regardless of whether SWS was minimized or maximized. It was, therefore, concluded that it was the interruption of the sleep process rather than the need for SWS per se that was more important for sleep restoration.

Finally, to my knowledge, there are no empirical studies which show that amounts of stage 1 sleep, independent of sleep fragmentation, have any significant impact on daytime alertness or performance.

In their review, Wesensten et al. wish to persuade the reader that it is the large increases in stage 1 sleep rather than the discontinuity of sleep which makes fragmented sleep nonrestorative. Unfortunately, empirical tests that can differentiate these hypotheses are few. We will benefit more from carefully designed empirical studies than from review or re-analysis of studies which were not designed to address this issue.

Wesensten et al. proposed a clear hypothesis which is at odds with the previous data specifically examining sleep continuity vs. stage 1 sleep. What is needed to show support for their hypothesis is a better experiment which splits the effects of stage 1 sleep and sleep continuity.

REFERENCES


Michael H. Bonnet

Dayton Department of Veteran Affairs Medical Center,

Dayton, OH, USA

Reply

We thank Dr Michael Bonnet for his thoughtful critique of our review paper. In his comments, Dr Bonnet states that we wish to persuade the reader that it is increased stage 1 sleep rather than discontinuity of sleep that makes fragmented sleep relatively nonrestorative. This is an oversimplification of our position. Our main point is that previous studies purporting to demonstrate an independent effect of ‘sleep continuity’ can alternatively, and more parsimoniously, be explained by changes in sleep architecture. While it is true that we focused on the effects of sleep fragmentation procedures on stage 1 sleep amounts (because increased stage 1 is typically manifest when sleep is fragmented), we do not suggest that differences in stage 1 sleep amounts account for all of the differences in recuperative value between two sleep periods of equal duration. As we point out in our review (p. 243), other observable changes in sleep architecture (e.g. reduced stages 3–4 sleep) might also impact recuperation.

Dr Bonnet further suggests that we have failed to consider the fact that fragmentation rate and amounts of stage 1 sleep are typically confounded. Actually, this fact serves as the

Correspondence: Nancy Jo Wesensten PhD., Department of Neurobiology and Behaviour, Division of Neuropsychiatry, Walter Reed Army Institute of Research, Washington DC, 20307–5100, USA. Tel: (301) 295 7826; fax: (301) 295 7445