Insomniacs’ Perception of Wake Instead of Sleep
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Study objectives: To establish if insomniacs’ underestimation of sleep time is due to reduced ability to discriminate between sleeping and waking states.

Design: Two night’s home polysomnography were compared to sleep diaries. Five laboratory nights employed a series of recorded questions regarding perception of prior sleep-wake state, which were presented during sustained wake and interrupted Stage 2 and REM sleep.

Setting: Sleep laboratory and participants’ homes

Participants: Fourteen insomniacs were compared to 8 good sleepers. Mean age for both groups was 58 years.

Interventions: None

Measurements and Results: A signal detection theory analysis was applied to participants’ responses to questions presented overnight in the laboratory concerning judgement of prior sleep-wake state and confidence in their decision. Insomniacs had reduced sleep-wake discriminability in addition to a greater bias toward reporting prior wakefulness in the laboratory compared to good sleepers. These measures correlated significantly with the degree of underestimation of total sleep and overestimation of wake recorded at home.

Conclusions: Insomniacs’ underestimation of total sleep time is the product of prior sleep being misperceived as wake time upon awakening overnight. This misperception may play a role in the perpetuation of insomnia.

Key words: Insomnia; sleep-wake perception; sleep-state misperception

INTRODUCTION

INSOMNIACS’ OVERESTIMATION OF TIME SPENT AWAKE OVERNIGHT HAS BEEN MAINLY INVESTIGATED THROUGH RETROSPECTIVE OBJECTIVE EVALUATION OF SLEEP COMPARED WITH OBJECTIVE POLYSOMNOGRAPHIC RECORDINGS. Insomniacs typically underestimate time asleep and overestimate time awake (eg,1,2). Frankel, et al3 compared overnight polysomnography (PSG) for five consecutive nights from 18 insomniacs reporting chronic difficulty initiating and/or maintaining sleep with age- and gender-matched controls. A questionnaire on the night’s sleep was completed following final awakening each morning. Insomniacs showed reduced PSG-defined total sleep time (TST) and increased time awake compared to good sleepers. Subjectively, insomniacs disproportionately overestimated wake time and underestimated total sleep time. Good sleepers, however, underestimated wake time and overestimated total sleep time.

Morning evaluation of sleep may be influenced by subjects’ expectations and beliefs surrounding their sleep. Insomniacs may have a bias toward a pessimistic evaluation of their sleep. In addition, insomniacs may be less able to discriminate between sleep and waking states. Specifically, insomniacs may have difficulty recognising an awakening from sleep and assume, instead, they have already been awake. The aim of the present study is to evaluate sleep-wake discriminability across the night and compare it with retrospective, whole-night reports of sleep.

Borkovec et al4 investigated this issue by comparing 25 insomniacs and 10 good sleepers on their reporting of prior wakefulness when questioned during stage 2 sleep. Subjects were called following the first 5 minutes of continuous Stage 2 sleep on two consecutive nights and during an intervening afternoon nap. Insomniacs were more likely than good sleepers to report having been awake immediately prior to being called on all three occasions. Furthermore, insomniacs expressed a higher degree of certainty regarding their decision when presented with a three-point scale of confidence.

Coates et al5 incorporated an awakening paradigm in a home recording of 12 good sleepers and 12 insomniacs. In addition to being asked about prior sleep-wake state overnight, subjects were asked to estimate elapsed time and total sleep since they were last called. As demonstrated by Borkovec, et al4, the insomniacs were more likely than good sleepers to report being awake already when questioned out of Stage 2 sleep at the beginning of the night. Subsequent probes during sleep were presented alternately in REM and Stage 2 sleep. These yielded no difference between groups in terms of the likelihood of reporting being awake, or accuracy of time and sleep estimates. Results from probes occurring during spontaneous awakenings, however, indicated that insomniacs underestimated time asleep and time elapsed since previously called. Conversely, good sleepers overestimated both elapsed time and sleep time following spontaneous arousal. In summary, insomniacs overestimated their difficulty sleeping early in the sleep period and upon awakening overnight, but their accuracy at detecting sleep when woken by external stimuli throughout the night was no different than for good sleepers.

Sewitch6 used a Signal Detection Theory analysis of responses to sleep-wake probes overnight in order to separate discriminability of sleep-wake status from the bias toward reporting being already awake when woken from sleep. Over five nonconsecutive nights in the laboratory, subjects were required to identify if they were awake or asleep just prior to hearing a bell ring.
and whether they were positive, pretty sure, or not so sure about their decision. These probes occurred during PSG-defined wake, and after 60 seconds of Stage 2 or (REM) sleep. A Signal Detection Theory analysis produced measures of sleep-wake discriminability for each subject derived from responses to the first question. A similar analysis incorporating both the first and second question yielded a measure of bias toward reporting prior wakefulness. Compared with 11 good sleepers, the one insomniac subject in the study showed both decreased sleep-wake discriminability and increased bias toward reporting being awake.

The present investigation incorporated a Signal Detection Theory analysis of sleep-wake perception in the laboratory on a larger sample of insomniacs. These laboratory measures were then compared with subjective and objective home sleep measures for both groups, in order to investigate the relationship between sleep-wake discriminability and whole-night retrospective sleep misperception of insomniacs.

Compared to good sleepers, we predicted that insomniacs would demonstrate both reduced sleep-wake discriminability and increased bias toward reporting prior wakefulness in the laboratory. These measures were expected to correlate with the degree to which participants underestimated sleep time at home.

METHOD

Subjects

Participants were recruited through appeals in the media. Selection was based on self-reported sleep at home as recorded using a 7-day sleep-wake diary and confirmed with initial PSG. All participants were required to be between 18 and 70 years of age and medically fit. Participants were free from medication for sleep, heart, blood pressure, thyroid, and psychiatric problems and were excluded if they reported excessive consumption of alcohol or caffeine or tobacco. In addition, participants were excluded if they reported symptoms indicative of sleep apnea, periodic limb movements in sleep or restless legs syndrome in a sleep-habits questionnaire. Insomniacs who described a sleep pattern that may be primarily attributable to poor sleep hygiene or circadian factors were also excluded. Insomniac participants reported patterns of sleep and daytime functioning consistent with a diagnosis of chronic moderate or severe psychophysiological insomnia.1

Based upon responses from 7-day sleep-wake diaries, insomniacs (10F, 4M) reported a mean sleep onset latency (SOL) of greater than 30 minutes and mean total time awake after sleep onset (WASO) of greater than 40 minutes. Their resulting sleep efficiency (percentage of time in bed spent asleep) was required to be less than 80%. Controls (4F, 4M) reported mean SOL of less than 20 minutes, mean WASO of less than 20 minutes, and a subsequent sleep efficiency of greater than 90%. The mean (sd) age of insomniacs was 58.14 (6.80) years, and was 58.38 (8.38) years for controls. While the insomniac participants reported difficulty both initiating and maintaining sleep, the primary complaint in this sample is sleep maintenance insomnia, which is typical for this age group.

The experimental protocol was approved by the Research and Ethics Committee of the Daw Park Repatriation General Hospital, South Australia. Informed consent was obtained from all participants prior to commencing the study. All participants were offered a gratuity of AU$290 for their participation.

Home Polysomnography

Home recordings were conducted using the Compumedics (Melbourne, Australia) P series portable PSG recorder. This was configured to record two (EEG) channels, two (EOG) channels, one (EMG) channel and light level, which was used to calculate lights-out time and total time available for sleep. Grass 10mm gold-plated silver electrodes with connectors specific to this recorder were used for all placements. Subjective reports of sleep overnight were gathered by sleep diary.

Laboratory Polysomnography

Laboratory recordings were conducted in a sleep laboratory consisting of four climate-controlled, sound attenuated bedrooms and a central control room. Sleep data was gathered using the Compumedics S series PSG system, which allowed display of on-line analysis of EEG frequencies by 30-second epochs in addition to the recording and display of raw PSG data, from all bedrooms. The EEG data were sampled at 250 Hz at a gain of 125 µV and low pass filter setting of 30kHz.

Output from a PC sound card could be directed to one of the four bedrooms through a switching box that connected to a speaker at the head of each bed. Material presented to participants through the speakers was recorded and replayed digitally on a PC using Cool Edit 96 audio software from Syntrillium Software, Scottsdale, AZ. An independent intercom system allowed personnel in the control room to monitor verbal reports from subjects. An infrared camera mounted in the ceiling of each bedroom and connected to monitors in the control room facilitated visual monitoring of participant’s position and movement during recording. Nicolet 10mm gold-plated silver electrodes were used for all head placements. Subjects completed a morning questionnaire immediately following each laboratory session.

PROCEDURE

Home recordings

Two overnight PSG recordings were conducted in the participants’ home in order to compare subjective and objective sleep in the home setting. Although reduced sleep time due to a first-night effect has not been reported in home PSG,8,9 these recordings occurred with one to six nights of potential recovery sleep intervening.

Electrodes were placed according to the international 10 to 20 system. Two EMG electrodes were placed on the chin. Left and right EOG electrodes were placed 1cm out and 1cm below the left and right outer canthus of both respective eyes. Both EOG electrodes were referenced to a single electrode placed 2 cm above the nasion. Two pair of EEG electrodes were placed on the scalp, with the C3-A2 configuration as the primary channel and a backup pair in the C4 and A1 positions. Following cleaning and light abrasion of electrode sites, electrode cups were filled with conductive gel and cemented or taped into position as required. Impedances between electrode pairs were checked using the recorder’s on-board impedance meter and were required to be below 5Kohm before recording commenced.

Recording was started prior to the experimenter leaving the
participant’s home. Participants were instructed on how to disconnect and reconnect a single cable that attached the electrodes to the main recording unit. This allowed participants to go to bed at their normal time and get up as required overnight and upon final awakening in the morning. While the laboratory recordings employed a series of overnight probes of sleep-wake discriminability, subjective sleep in the home sessions was recorded the following day using a sleep diary. The sleep-wake diary was completed as soon as possible following rising in the morning. An experimenter arrived at the participant’s home at a prearranged time in the morning to remove the electrodes and collect the sleep diary and recorder.

**Laboratory Recordings**

Participants slept overnight in the laboratory once a week for five weeks. They were instructed to arrive approximately one hour prior to their usual lights-out time, after which they were prepared for recording in the same manner as for the home studies. In addition to EEG, EOG, EMG and light measures, participants were fitted with a Vitalog respiratory effort band and (ECG) electrodes in the Lead II position. Participants elected their own lights-out time and wake-up time.

Prior to lights-out, participants were familiarised with the questions that were to be asked overnight. Experimenters were careful not to give feedback or otherwise influence participants’ expectations of the likelihood of the questions being delivered from wake or sleep.

Probes of sleep-wake discriminability occurred throughout the laboratory sessions. These consisted of a 200 Hz tone that was delivered through the speaker at the head of the bed and continued until the participant verbally acknowledged hearing the tone. A series of four recorded questions was then delivered through the speaker, and the verbal responses were monitored and recorded by the experimenters. The questions were as follows: 1) Just prior to hearing the tone, were you awake or asleep? 2) How sure are you of that decision? Positive, pretty sure, not so sure? 3) How long has it been in minutes since I last called you? 4) How long in minutes have you been asleep since I last called you?

An initial probe was presented 5 minutes following lights out, which was excluded from analysis. This provided a reference point for responding to questions 3 and 4 for the following probe. Each subsequent probe occurred in one of three conditions: 1) non-REM: Five minutes following the onset of Stage 2 sleep, uninterrupted by AASM criteria arousals. 2) REM: Five minutes of uninterrupted REM sleep following the first eye movement. 3) Wake: Following five minutes of continuous wakefulness without movement.

Non-REM and REM probes were alternated in order to preserve sleep architecture and provide an even distribution of both types of sleep probe across the night. This schedule typically yielded 12 probes per night for each participant, approximately four from each of the three conditions. Figure 1 illustrates the placement of probes on a typical laboratory night.

**Polysomnographic Scoring**

Sleep data from both home and laboratory recordings were analysed in 30-second epochs according to Rechtschaffen and Kales criteria by one of three trained scorers. Five percent of sleep records were randomly allocated for reanalysis by a second scorer to ensure interrater concordance remained above 90%.

**Signal Detection Analysis**

Responses to the first two questions presented overnight were subjected to a SDT analysis as described by McNichol and used by Sewitch. Responses to the first question (“Just prior to hearing the tone, were you awake or asleep?”) were used to obtain a non-parametric measure of discriminability P(A). This measure reflects the ability to detect a signal (in this case PSG-defined wake) in the presence of background noise (PSG-defined sleep). The allocation of wake as the signal is somewhat arbitrary, but as in Sewitch’s case, the focus of the work is documenting the error of judging PSG-defined sleep to be wakefulness. Reporting being awake during PSG-defined sleep is therefore considered a false alarm according to Table 1.

The proportion of hits and false alarms were used to obtain P(A) measures in the manner described by McNichol for both insomniac and good sleeper groups. In SDT analyses, P(A) varies between 1.0 (perfect discriminability) and 0.5 (chance level, no discriminability).
RESULTS

Perception of Sleep and Wake: The Signal Detection Theory Analysis

Table 2 shows the mean hit rate, false alarm rate and P(A) values of the insomniac and good sleeper groups derived from the laboratory sessions. Independent samples t-tests indicated that insomniacs overall had a significantly higher false alarm rate (probability of identifying prior sleep as wake) and P(A) (non-parametric measure of sleep-wake discriminability) compared to good sleepers. The non-parametric measure of discriminability P(A), which is derived from both these measures, was significantly lower for the Insomniac group.

Response Bias

Responses to the first question in conjunction with the second yield a six-point scale of confidence in identifying being awake just prior to hearing the tone. This ranges from a very high degree of certainty of being awake (“wake, positive”), to a very low degree of certainty of being awake (“sleep, positive”). Probabilities of responding in one of the six possible ways to probes in both PSG-defined sleep and wake are presented in Table 3. Response probabilities are cumulative starting from response 1 to response 6, so that category 6 incorporates all possible responses and, as such, has a probability of 1. Data within the two groups is combined to yield a representative cumulative probability distribution for each group.

A receiver operating characteristics (ROC) curve can be plotted using these data for each group as a whole (Figure 2). The pairs of numbers for the six levels of certainty in the tables above are plotted as hits (responses from a wake probe) on the y-axis and false alarms (responses from a sleep probe) on the x-axis. The area beneath the curves represents the P(A) measure of discriminability and shows the decreased value of P(A) and thus reduced discriminability for the insomniac group. The points on the insomniacs’ ROC curve are distributed further to the right of the graph compared to controls. This is indicative of an increased response bias toward reporting prior wakefulness. As with Sewitch’s study, calculation of a non-parametric measure of response bias is precluded due to the high hit rates in both groups. However, insomniacs’ cumulative probabilities of reporting prior wake during sleep (cells 1, 2, and 3 of Table 3) are more than twice that of Controls, which is a clear indication of increased response bias.

Differences in false alarm rate alone contributed to the significantly lower P(A) coefficient for the insomniac group. Therefore, false alarm rate is in this case an indicator of discriminability, as the probability of accurately detecting the waking state is the same between groups and displays low variability. The accuracy in detecting prior sleep upon awakening is the major focus of the present work and, therefore, a more detailed analysis of false alarm rates is warranted. False alarm rate data allows further analysis of between-group differences in the categories of Sleep stage and time of night where subdivision of the data precludes P(A) calculations.

Reporting Prior Wake at Probes Occurring in Non-REM and REM Sleep

Probes conducted during sleep occurred alternately in non-REM and REM sleep. As the nature of mentation in REM sleep should be more conducive to detecting the sleeping state, the probability of reporting already being awake was analysed sepa-

Table 3—Probabilities of responding in one of six ways to probes presented during wake or sleep, cumulated from response 1 to 6.

<table>
<thead>
<tr>
<th>Response:</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insomniacs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stimulus: Signal (wake)</td>
<td>.918</td>
<td>.975</td>
<td>.975</td>
<td>.984</td>
<td>.992</td>
<td>1.00</td>
</tr>
<tr>
<td>Noise (sleep)</td>
<td>.378</td>
<td>.592</td>
<td>.700</td>
<td>.748</td>
<td>.929</td>
<td>1.00</td>
</tr>
<tr>
<td>Controls</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stimulus: Signal (wake)</td>
<td>.852</td>
<td>.975</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Noise (sleep)</td>
<td>.140</td>
<td>.222</td>
<td>.284</td>
<td>.385</td>
<td>.634</td>
<td>1.00</td>
</tr>
</tbody>
</table>
rately for the two types of sleep probe. Figure 3 illustrates the mean False alarm rates for insomniacs and controls when probed from both non-REM and REM sleep.

False alarm rates for both non-REM and REM sleep probes were incorporated into a two-way analysis of variance comparing Insomniacs and controls.

Both insomniacs and controls were more likely to report already being awake when probed during non-REM sleep compared to REM (F = 34.6, p < .001) There was no interaction between group (insomniac vs control) and type of sleep probe (Non-REM vs REM), F = .446, n/s.

**False-Alarm Rates in the First Half of Laboratory Nights Compared to Second Half**

A two-way ANOVA compared false alarm rates of both insomniacs and controls in the first half or second half of laboratory nights. The first half of the night was defined as before 3am. No significant main effect of time of night was observed (first half vs second half, F = .114, n/s), nor was there any interaction with group (F = .131, n/s).

**Change in False-Alarm Rate Across Laboratory Sessions**

To investigate whether sleep-wake discriminability for either insomniacs or controls improved across laboratory sessions, a two-way ANOVA compared averaged false alarm rates from nights 1 and 2 with those from nights 4 and 5.

No main effect of laboratory night was observed (F = .241, p = .629, n/s), nor was any interaction between Lab Night and Group observed (F = .382, p = .545, n/s).

**Home Studies Before Lab Sessions Vs. After**

Six subjects had their home sleep recorded before the laboratory sessions, and 16 subjects had home recordings following completion of the laboratory protocol. A one-way analysis of variance was conducted to investigate whether the order of data collection influenced either laboratory or home variables. There were no significant differences in the major laboratory or home measures as a result of whether home recordings were conducted before or after the laboratory sessions.

**Sleep Between Probes**

Differences between groups in the quality or quantity of PSG measured sleep between each probe may account for differences in discrimination of sleep state. Table 4 presents mean time (SD) spent awake and asleep between probes in the laboratory. Wake time is expressed as total wake time, SOL, and WASO. Sleep time is expressed as a total in addition to a breakdown by sleep stage. There were no group differences in any of the sleep-wake measures obtained between probes.

**Objective Vs. Subjective Total Time and Total Sleep Between Probes**

In order to investigate whether global underestimation of

### Table 4—Mean (SD) sleep and wake time in minutes between laboratory probes for good sleepers and insomniacs.

<table>
<thead>
<tr>
<th></th>
<th>Total sleep</th>
<th>Total wake</th>
<th>SOL</th>
<th>Stage 1</th>
<th>Stage 2</th>
<th>Stage 3</th>
<th>Stage 4</th>
<th>REM</th>
<th>WASO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insomniac</td>
<td>46.9</td>
<td>17.4</td>
<td>11.3</td>
<td>3.20</td>
<td>25.9</td>
<td>8.35</td>
<td>2.28</td>
<td>7.09</td>
<td>6.01</td>
</tr>
<tr>
<td>(11.7)</td>
<td>(8.84)</td>
<td>(7.61)</td>
<td>(1.28)</td>
<td>(8.52)</td>
<td>(4.21)</td>
<td>(2.66)</td>
<td>(2.72)</td>
<td>(3.49)</td>
<td></td>
</tr>
<tr>
<td>Good sleeper</td>
<td>41.9</td>
<td>15.5</td>
<td>7.49</td>
<td>3.24</td>
<td>20.7</td>
<td>7.62</td>
<td>3.20</td>
<td>7.14</td>
<td>7.97</td>
</tr>
<tr>
<td>(5.52)</td>
<td>(7.05)</td>
<td>(3.55)</td>
<td>(0.91)</td>
<td>(4.78)</td>
<td>(1.93)</td>
<td>(2.36)</td>
<td>(2.38)</td>
<td>(3.95)</td>
<td></td>
</tr>
<tr>
<td>t</td>
<td>1.11</td>
<td>.515</td>
<td>1.34</td>
<td>-0.69</td>
<td>1.59</td>
<td>.464</td>
<td>-0.81</td>
<td>-0.049</td>
<td>-1.21</td>
</tr>
<tr>
<td>p</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
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</table>
sleep in insomniacs is a product of the overestimation of elapsed time or the underestimation of sleep time, objective sleep and elapsed time measures were compared to subjective measures gained from questions 3 and 4 at each probe. These questions were “How long has it been in minutes since I last called you?” and “How long have you been asleep since I last called you?”

Table 5 presents mean (sd) subjective estimates of total sleep and total time between probes compared with PSG-derived sleep and elapsed time measures. Subjective and objective sleep time was then expressed as a percentage of subjective and objective total elapsed time for both groups.

Both groups significantly underestimated total time between probes (Main Effect of Objective vs Subjective Time, F = 9.12, p = .007) to a comparable extent (Interaction, F = .075). Both groups also significantly underestimated sleep time (F Objective vs Subjective Sleep = 37.5, p < .001). However, Insomniacs disproportionally underestimated sleep time, despite obtaining slightly more PSG-defined sleep (Interaction F = 8.71, p = .008). A corresponding significant difference in objective and subjective % time asleep was observed (F = 17.6, p < .001), with insomniacs reporting a disproportionately lower percentage of estimated time asleep (Interaction F = 22.5, p < .001).

**Sleep During Home PSG Recordings**

Data collected from the home recordings was averaged over the two nights for analysis. Table 6 shows that insomniacs’ PSG-defined sleep varied from controls in only a few respects. The lower amount of TST and longer SOL for insomniacs approached significance. Insomniacs demonstrated significantly less Stage 2 sleep compared to controls, and a greater amount of WASO. Diary reports of Total Sleep Time, WASO and sleep efficiency were compared with their equivalent PSG-derived values for both insomniacs and controls using two-way ANOVAs. Insomniacs underestimated TST, whereas Controls overestimated the amount of sleep obtained (Interaction F = 9.37, p = .006). Insomniacs overestimated WASO in contrast to Controls’ underestimation (F = 7.51, p = .013). Consequently, Insomniacs disproportionally underestimated Sleep Efficiency (F = 7.52, p = .013).

**Correlation Between Perception of Sleep During Home PSG and Laboratory Measures of Sleep Discriminability**

The SOL, TST and WASO measures averaged over the two nights of home PSG recordings were compared to sleep-diary responses completed the following morning. Objective measures were subtracted from corresponding subjective measures to produce discrepancy scores for SOL, TST, and WASO. Subjective and objective sleep efficiency scores were calculated from these measures for each subject to express the percentage of time in bed spent asleep. Objective sleep efficiency was subtracted from subjective sleep efficiency to calculate a sleep efficiency discrepancy score.

A decrease in P(A) value and an increase in false alarm rate both indicate reduced ability to discriminate between sleeping and waking states in the laboratory. Both of these measures are significantly correlated with overestimations of WASO and underestimations of TST and sleep efficiency in the home recordings.

**DISCUSSION**

The present investigation demonstrated that when insomniacs are awakened from PSG-defined sleep, they are much more likely than good sleepers to report having been already awake. This effect occurs in awakenings from REM sleep and particularly from Stage 2 sleep, irrespective of whether they occur early or late in the sleep period.

The SDT analysis provides measurements of the two constructs of discriminability and response bias. An SDT analysis was applied to participants’ judgement of sleep-wake state for the period just prior to hearing the tones. When compared with good sleepers, insomniacs were found to have reduced sleep-wake dis-

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**Table 5**—Mean (SD) objective vs. subjective sleep time and total time in minutes between laboratory probes, with percentage of total time spent asleep (% Asleep). ANOVAs compare objective PSG measures with subjective estimates for both insomniacs and good sleepers.

<table>
<thead>
<tr>
<th></th>
<th>Sleep Time</th>
<th>Total Time</th>
<th>% Asleep</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Objective</td>
<td>Subjective</td>
<td>Objective</td>
</tr>
<tr>
<td>Insomniac</td>
<td>46.9 (11.8)</td>
<td>19.5 (15.1)</td>
<td>64.2 (14.3)</td>
</tr>
<tr>
<td>Good Sleeper</td>
<td>41.9 (5.52)</td>
<td>32.4 (12.3)</td>
<td>57.4 (11.1)</td>
</tr>
<tr>
<td>F Insomniac vs.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Good sleeper</td>
<td>.755, p = .395</td>
<td>2.52, p = .128</td>
<td>11.9, p = .003</td>
</tr>
<tr>
<td>F Objective vs</td>
<td>37.5, p &lt; .001</td>
<td>9.12, p = .007</td>
<td>17.6, p &lt; .001</td>
</tr>
<tr>
<td>Subjective</td>
<td>.075, p = .787</td>
<td>.075, p = .787</td>
<td>22.5, p &lt; .001</td>
</tr>
</tbody>
</table>
criminability as well as increased bias toward reporting being awake, which is consistent with the findings of Sewitch. The SDT predicts a shift in response bias as a result of expectations of the frequency of signals. If prior wakefulness is expected, there will be a response bias toward reporting wakefulness. This bias toward reporting prior wake can be explained by greater previous experience of nocturnal wakefulness at home. The present study has shown that this is not simply a retrospective exaggeration of the insomniacs' problem but a perceptual bias that can be demonstrated when people are questioned overnight.

The inability of insomniacs to discriminate between sleeping and waking states, which can be calculated independently of a response bias, is indicative of a sleep-wake perceptual deficit in poor sleepers. As laboratory sessions occurred in an environment free of time cues, participants rely upon internal cues to determine if they were awake or asleep just prior to hearing the tone presented overnight. It is established that mentation persists into PSG-defined sleep. Insomniacs' reduced sleep-wake discriminability may be caused by either a greater amount of mentation during sleep, mentation that more closely resembles awake mentation, or a misattribution of normal nocturnal mentation as wakeful cognitive activity. Therefore, the qualitative and quantitative differences in sleep mentation between insomniacs and good sleepers warrants further investigation. Prior sleep was more accurately identified by both groups when they are probed during REM sleep. It is likely that the recollection of a dream following REM probes served as a cue for prior sleep. Mentation during Stage 2 sleep may be less distinguishable from nocturnal wake mentation and results in reduced discrimination between these states.

If insomniacs experience higher cortical activation during sleep (ie, hyperarousal), they would be expected to experience more mental activity during sleep, increasing the difficulty of discriminating between sleep and wake.

Reduced sleep-wake discriminability observed in insomniacs may potentially be explained by qualitative differences in their sleep compared to good sleepers. If insomniacs experienced less sleep or had significantly lighter sleep between probes than did controls, they may be expected to demonstrate less discriminability. The schedule of probes presented during sleep, however, ensured that no difference between good and poor sleepers was observed in the amount of the various stages of sleep gained between probes. Differences in sleep quality between probes therefore do not appear to account for the group differences in sleep-wake discriminability.

Increased reporting of wake time overnight may be attributable to the misperception of time awake rather than an

| Table 6—Mean (SD) subjective and objective sleep during home recordings for insomniacs and good sleepers (averaged over two nights of home recording). |
|-----------------------------------------------|-------------------|---|-----------------|
| **Insomniac** | **Good sleeper** | **F** | **p (1 tailed)** |
| Total PSG sleep | 351.2 (76.7) | 396.0 (38.8) | 2.45 | .067 |
| Total diary sleep | 246.8 (96.1) | 418.1 (58.0) | 20.8 | <.001* |
| PSG sleep efficiency | 78.8 (12.7) | 88.7 (5.4) | 4.38 | .025* |
| Diary sleep efficiency | 57.1 (22.1) | 91.9 (5.6) | 18.7 | <.001* |
| SOL | 30.4 (27.7) | 16.3 (7.6) | 1.51 | .116 |
| Stage 1 | 23.1 (10.1) | 29.1 (12.5) | 3.26 | .043* |
| Stage 2 | 164.7 (56.3) | 204.8 (36.0) | .874 | .181 |
| Stage 3 | 74.9 (37.6) | 60.5 (29.0) | 23.4 | .318 |
| Stage 4 | 20.1 (30.4) | 14.2 (21.2) | 3.57 | .037* |
| REM | 68.4 (26.2) | 88.4 (18.8) | 3.45 | .039* |
| WASO | 61.7 (32.9) | 36.4 (26.3) | 16.6 | .001* |

| Table 7—Correlations (r) between subjective and objective discrepancies in home recordings vs laboratory-derived signal detection theory measures. |
|-----------------------------------------------|-------------------|-----------------|
| Subjective vs. Objective Discrepancy in Home Sleep | **Hit Rate** (Probability of accurately identifying prior wake) | **False Alarm Rate** (Probability of identifying prior sleep as wake) | **P(A)** (Non-Parametric measure of sleep-wake discriminability incorporating Hit Rate and False Alarm Rate) |
| Sleep Onset Latency | .084 | .350 | .011 |
| Total Sleep Time | -.134 | -.703 | .548 |
| Wake Time After Sleep Onset | .256 | .827 | -.685 |
| Sleep Efficiency | -.206 | -.761 | .528 |

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underreporting of sleep time. If insomniacs have a tendency to exaggerate the passage of time overnight, the perceived proportion of time spent asleep would be reduced regardless of sleep perception. However, insomniacs did underestimate the amount of sleep between probes compared to good sleepers, while accuracy of estimated elapsed time between probes did not vary between groups. This illustrates that insomniacs’ overestimation of wake time is the product of perceiving time asleep to be wake time rather than a distortion of time perception.

These results are in contrast to those found by Coates et al, who concluded that sleep-state misperception in insomnia occurs only at the initial sleep onset and at spontaneous arousals, not from experimental awakenings from REM or Stage 2 sleep. Furthermore, their insomniacs were found to underestimate both sleep time and elapsed time in association with this misperception. The present study employed a slightly different awakening protocol than did the Coates study and involved five nights instead of one, which resulted in many more data points and opportunities to sample sleep-wake perception. Additionally, potential experimenter feedback to subjects was controlled in the present study using prerecorded questions and specific instructions for experimenters to avoid giving feedback on the likelihood of probes occurring in wakefulness or sleep (something known to effect response bias). These differences in methodology may account for the divergent results. Furthermore, the insomniac population in the Coates study consisted primarily of sleep-onset insomniacs, with a lower average age than the present sample. It is possible that sleep-onset insomniacs will demonstrate greatest sleep misperception at initial sleep onset, whereas sleep-maintenance insomniacs’ misperception persists throughout the night.

There may be some differences between spontaneous awakenings at home, typically, toward the end of the sleep cycle, and our protocol of forced awakenings in the laboratory. However, prior sleep should, if anything, be easier to identify if the awakening is in response to an external stimulus. A protocol could be developed to exploit spontaneous arousals and compare them to forced awakenings to resolve this issue.

Insomniacs showed a significantly greater discrepancy between objective PSG-defined sleep and subjective sleep-diary reports during home recordings compared with good sleepers. This objective and subjective discrepancy correlated significantly with laboratory measures of sleep-wake discriminability and the probability of reporting prior wakefulness when probed during sleep. The correlation between laboratory and home-study measures suggests that insomniacs’ inaccurate retrospective reports of TST across the night reflects a deficiency in overnight sleep-wake perception.

Insomniacs perceive that they have not been asleep upon waking overnight and assume that they have been awake for an extended period. This increases their expectation of experiencing wakefulness, reinforcing the bias toward perceiving wakefulness. Furthermore, subsequent sleep onset may be delayed because of insomniacs’ negative reaction to what is perceived to be an extended period of wakefulness overnight. The frustration and increased activation that accompanies the perceived inability to sleep serves to compound the problem.

Cognitive therapy may be useful for correcting insomniacs’ bias toward reporting wakefulness. This would consist of providing information and reassurance that mental activity persists during sleep and extended periods of wakefulness overnight are often interspersed with undetected sleep periods. This therapy would, of course, be more effective if PSG recordings were available to support this information.

Sleep-wake discriminability may be improved through perceptual retraining using immediate accurate feedback following awakening. If insomniacs’ discriminability is improved, it should result in a more accurate assessment of time awake and time asleep overnight and has the potential to break the proposed cycle of insomnia perpetuated by sleep-state misperception.

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