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Ambient Temperature and Obstructive Sleep Apnea: Effects on Sleep, Sleep Apnea, and Morning Alertness

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Study Objectives: The aim of the study was to investigate the effect of ambient temperature on sleep, sleep apnea, and morning alertness in patients with obstructive sleep apnea.
Design: Randomized controlled trial.
Setting: In-hospital investigations.
Participants: Forty patients with obstructive sleep apnea naïve to treatment, with an apnea-hypopnea index of 10-30.
Interventions: Three different nights in room temperatures of 16°C, 20°C, and 24°C.
Measurements: Overnight polysomnography and Karolinska Sleepiness Scale.
Results: The obstructive apnea-hypopnea index was 30 ± 17 at 16°C room temperature, 28 ± 17 at 20°C, and 24 ± 18 at 24°C. The obstructive apnea-hypopnea index was higher at 16°C room temperature versus 24°C (P = 0.001) and at 20°C room temperature versus 24°C (P = 0.033). Total sleep time was a mean of 30 min longer (P = 0.009), mean sleep efficiency was higher (77 ± 11% versus 71 ± 13% respectively, P = 0.012), and the patients were significantly more alert according to the Karolinska Sleepiness Scale (P < 0.028) in the morning at 16°C room temperature versus 24°C. The amount of sleep in different sleep stages was not affected by room temperature.
Conclusions: Untreated patients with obstructive sleep apnea sleep longer, have better sleep efficiency, and are more alert in the morning after a night's sleep at 16°C room temperature compared with 24°C, but obstructive sleep apnea is more severe at 16°C and 20°C compared with 24°C.
Clinical Trial Information: This study is registered in ClinicalTrials.gov number NCT00544752.
Keywords: Sleep apnea syndromes, sleep quality, daytime sleepiness, treatment, ambient temperature, polysomnography, sleep stages, sleep time, randomized controlled trial
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INTRODUCTION

Subjects with obstructive sleep apnea suffer from fragmented sleep, with frequent arousals, hypoxemia, and blood pressure changes during sleep.[1,2] They are tired during the daytime and share an increased risk of traffic accidents, stroke, and early death.[3-5] Nasal continuous positive airway pressure and mandibular advancement devices during sleep have a documented effect on apneas and daytime sleepiness.[6,7] Obstructive sleep apnea is a prevalent disorder, and a number of other treatment modalities and lifestyle modifications have therefore been tested but without any proven effect.[8]

The ambient indoor temperature in Sweden is usually 20°C. Individual patients investigated at our department have told us that they sleep better in a colder environment and that they snore less in cold versus warm rooms. Basner et al. investigated the effects of inspired air temperature on upper airway dilator muscle activity in normal adults.[9] They observed an increase in genioglossus activity when breathing cold air (15°C) compared with baseline or warm air, and suggested the presence of superficially located nasal cold receptors that influence upper airway dilator muscle activity via reflexes. Based on the abovementioned observations, we hypothesized that obstructive sleep apnea would diminish in a colder environment. We aimed to investigate the effect of ambient temperature on sleep apnea, sleep, and morning alertness in patients with obstructive sleep apnea.

METHODS

Patients with obstructive sleep apnea and an apnea-hypopnea index of 10-30 naïve to treatment, according to overnight simplified sleep apnea recordings without electroencephalogram (EEG) monitoring at home using Embletta (ResMed, San Diego, CA), were invited to participate. All patients had been referred to the Department of Internal Medicine, following a suspicion of sleep apnea.

Fifty-two patients were invited to participate and 40 agreed to do so. There were 25 men and 15 women, with a mean age of 59.6 ± 9.4 years, a body mass index of 28.8 ± 4.4 kg/m^2, an Epworth Sleepiness Scale score of 9.1 ± 4.3, and a baseline apnea-hypopnea index of 19 ± 6.

The patients were investigated with overnight polysomnography and questions on morning alertness using the Karolinska Sleepiness Scale for 3 nights with ambient temperatures of 16°C, 20°C, and 24°C in random order. Closed envelopes were used for randomization to the 6 different study order alternatives. Investigators were blinded to the different room temperatures and patients were not informed about ambient temperatures. The investigation room had an air conditioner (Airwell, Arizona XLM-98.10, Essén Company, Tyrso, Sweden) and an electric radiator (Siemens 800W, Oslo, Norway) with sensitive thermistors. The room was soundproofed with

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Table 1—Ambient temperature (mean ± standard deviation) according to a thermometer close to the bed

	Evening temperature	Morning temperature	Difference between evening and morning temperature
16°C	16.2 ± 0.4°C	15.9 ± 0.4°C	0.3 ± 0.3°C
20°C	20.2 ± 0.5°C	20.0 ± 0.6°C	0.2 ± 0.4°C
24°C	24.2 ± 0.5°C	24.2 ± 0.6°C	0.1 ± 0.4°C

triple glazing, and the door to the room was never opened during the night. The temperature was controlled during the daytime, in the evening, and in the morning using a thermometer close to the bed (Table 1). Patients were offered free access to sheets and blankets during the night. Electrodes for polysomnograms were attached during the daytime, and patients were connected to the polysomnogram in bed at 22:00. The mean (± standard deviation) times for lights out were 10.18 ± 00.22 at 16°C, 10.17 ± 00.21 at 20°C, and 10.19 ± 00.19 at 24°C. All the subjects were awakened at 08:00, apart from 2 subjects who had to get up between 07:00 and 07:30. These two subjects were awakened at the same time during all 3 recordings.

Physical examination, age, weight, height, and daytime sleepiness according to the Epworth Sleepiness Scale were recorded at the start of the study.[10] Body mass index was defined as weight divided by height in meters squared.

Approval for the study was obtained from the medical ethics committee at the University of Umeå, Sweden. All patients gave their written consent.

Outcome Measurements

Primary outcome measurements were the apnea-hypopnea index and the Karolinska Sleepiness Scale. Secondary outcome measurements were sleep stages, total sleep time, and sleep efficiency.

Polysomnography

Overnight polysomnography (Embla, Flaga hf, Iceland) included continuous recordings of EEGs (C3-A2, C4-A1), electrooculograms, electromyograms (submental), airflow with a nasal pressure cannula sensor (Medcare, ResMed, San Diego, CA), respiratory effort from piezoelectric belts (Resp-EZ, EPM Systems Midlothian, VA), finger pulsoximetry (Embla A10 flex Sensor), electrocardiograms (V5), and a body position sensor.

Sleep stages were scored manually in 30-sec epochs according to Rechtschaffen and Kales.[11] Time in bed was defined as lights off to final wake-up in the morning. Sleep efficiency was defined as total sleep time divided by time in bed. An obstructive apnea was defined as cessation of airflow for at least 10 sec with continuing abdominal and thoracic movements.[1] An obstructive hypopnea was defined as a 50% reduction in nasal pressure for at least 10 sec, compared with baseline, accompanied by abdominal and thoracic movements in combination with an arousal or an oxygen desaturation of 3% or more. The obstructive apnea-hypopnea index was the mean number of obstructive apneas and hypopneas per hr of sleep.

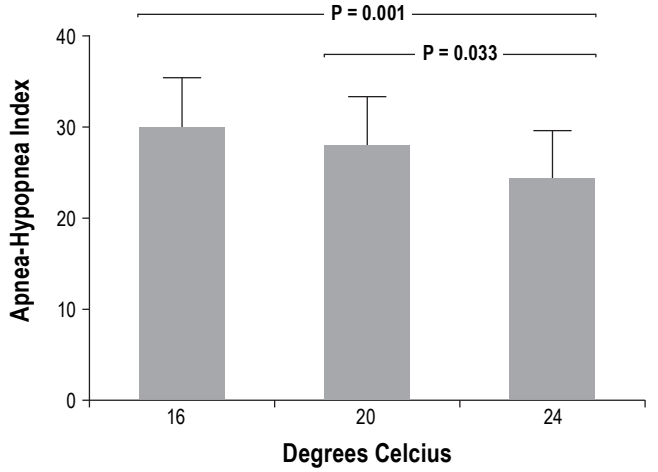

Figure 1—Mean obstructive apnea-hypopnea index at 16, 20, and 24°C (95% CI).

Karolinska Sleepiness Scale

The Karolinska Sleepiness Scale questionnaire was answered immediately upon awakening, while the patients were still in bed after each polysomnographic investigation.[12] It consists of a 10-grade scale in which the patient assesses his or her level of sleepiness as: 1. Extremely alert, 2. Very alert, 3. Alert, 4. Fairly alert, 5. Neither alert nor sleepy, 6. Some signs of sleepiness, 7. Sleepy, but no effort to stay awake, 8. Sleepy, some effort to stay awake, 9. Very sleepy, great effort to stay awake, 10. Extremely sleepy, fall asleep all the time.

Statistical Analysis

Data were summarized as means and standard deviation. A linear mixed model approach was used to evaluate the development over temperature levels for the end point variables of apnea-hypopnea index, total sleep time, sleep efficiency, sleep stages as a percentage of total sleep time, and the Karolinska Sleepiness Scale. Adjusted analysis included body mass index, time in supine position divided by total sleep time, and sleep stage on awakening. A difference with a P value of < 0.05 was considered significant.

RESULTS

All the included 40 patients completed the study protocol.

Sleep Apnea

The obstructive apnea-hypopnea index was 30 ± 17 at 16°C room temperature, 28 ± 17 at 20°C, and 24 ± 17 at 24°C. The obstructive apnea-hypopnea index was significantly higher at 16°C room temperature versus 24°C (P = 0.001) and at 20°C room temperature versus 24°C (P = 0.033) (Figure 1). These differences remained after adjustments for percentage of sleep in the supine position of total sleep time and body mass index. There were no significant differences in central and mixed apnea-hypopnea index with ambient temperature, which was 1.5 ± 3.5 at 16°C room temperature, 1.3 ± 3.2 at 20°C, and 2.7 ± 7.9 at 24°C. Different apnea-hypopnea indices with regard to ambient temperature are given in Tables 2 and 3.

Table 2—Mean ± standard deviation of sleep, sleep apnea, and daytime sleepiness at different indoor temperatures

	16°C	20°C	24°C
Total apnea-hypopnea index	31 ± 18	29 ± 18	27 ± 18
Obstructive apnea-hypopnea index	30 ± 17	28 ± 17	24 ± 17
Obstructive apnea index	18 ± 16	18 ± 17	15 ± 17
Obstructive hypopnea index	12 ± 8.7	10 ± 7.7	9.0 ± 7.3
Central and mixed apnea-hypopnea index	1.5 ± 3.5	1.3 ± 3.2	2.7 ± 7.9
Total apnea-hypopnea index in REM	39 ± 20	37 ± 22	32 ± 18
Total apnea-hypopnea index in non-REM	29 ± 20	27 ± 19	25 ± 19
Time in bed (min)	558 ± 36	561 ± 36	558 ± 36
Total sleep time (min)	428 ± 62	420 ± 66	397 ± 70
Sleep efficiency (%)	77 ± 11	75 ± 11	71 ± 13
Awake after sleep onset (min)	84 ± 56	84 ± 52	99 ± 63
Stage 1/total sleep time (%)	17 ± 9.4	18 ± 11	18 ± 10
Stage 2/total sleep time (%)	56 ± 11	56 ± 11	57 ± 11
Slow-wave sleep/total sleep time (%)	10 ± 6.0	9.6 ± 6.9	9.7 ± 6.6
REM/total sleep time (%)	17 ± 6.0	17 ± 5.9	16 ± 6.6
Karolinska Sleepiness Scale	4.1 ± 1.4	4.4 ± 1.6	4.7 ± 1.6

REM, rapid eye movement.

Total Sleep Time, Sleep Efficiency, and Sleep Stages

Total sleep time was 428 ± 62 min at 16°C room temperature, 420 ± 66 min at 20°C, and 397 ± 70 at 24°C. Total sleep time was significantly higher at 16°C room temperature versus 24°C, with a difference of 30 min (95% confidence interval (CI) 8-32), P = 0.009. This difference remained after adjustments for percentage of sleep in the supine position of total sleep time and body mass index (Figure 2, Tables 2 and 4). Sleep efficiency was significantly higher at a room temperature of 16°C versus 24°C, (77 ± 11% and 71 ± 13%, respectively) P = 0.012 (Tables 2 and 4).

The proportion of sleep in different sleep stages in relation to total sleep time did not differ at different room temperatures.

Morning Alertness

The Karolinska Sleepiness Scale score was 4.1 ± 1.4 at 16°C room temperature, 4.4 ± 1.6 at 20°C, and 4.7 ± 1.6 at 24°C. The Karolinska Sleepiness Scale was significantly lower at 16°C room temperature versus 24°C, with a difference of 0.6 (95% CI 1.2-0.1), P = 0.028. This difference remained after adjustments for percentage of sleep in the supine position of total sleep time and body mass index (Figure 3, Tables 2 and 4).

The order of the experimental nights had no effect on the outcome measures.

DISCUSSION

This is the first study investigating the effect of ambient temperature on patients with sleep apnea. The obstructive apnea-hypopnea index was significantly higher at 16°C room temperature versus 24°C (P = 0.001) and at 20°C room temperature versus 24°C (P = 0.033). Total sleep time was a mean of 30 min longer (P = 0.009) at a room temperature of 16°C compared with 24°C, and sleep efficiency was significantly higher at 16°C and 20°C versus 24°C. Patients were significantly more alert in the morning at a room temperature of 16°C compared with 24°C.

Based on single patient reports on reduced snoring in colder environments and a trial reporting increased genioglossus activity in normal adults in a cold environment,[9] we hypothesized that obstructive sleep apnea would diminish in a colder envi-

Table 3—Difference and adjusted difference* of apnea and hypopnea index at 16°C and 20°C compared with 24°C

	Difference (95% CI)	P value	Adjusted difference* (95% CI)	P value
Total apnea-hypopnea index				
16°C	4.4 (1.0–7.8)	0.011	4.2 (0.8–7.7)	0.016
20°C	2.2 (−1.2–5.6)	0.198	2.2 (−1.2–5.6)	0.204
Obstructive apnea-hypopnea index				
16°C	5.6 (2.3–8.9)	0.001	5.6 (2.2–9.0)	0.001
20°C	3.6 (0.3–6.9)	0.033	3.6 (0.3–7.0)	0.033
Obstructive apnea index				
16°C	2.8 (0.2–5.3)	0.033	2.7 (0.4–5.0)	0.025
20°C	2.7 (0.2–5.2)	0.035	2.7 (0.4–5.0)	0.022
Obstructive hypopnea index				
16°C	2.8 (0.9–4.7)	0.004	2.9 (1.0–4.8)	0.004
20°C	0.9 (−1.0–2.8)	0.347	0.9 (−1.0–2.8)	0.345
Central and mixed apnea-hypopnea index				
16°C	−1.2 (−3.2–0.8)	0.243	−1.3 (−3.3–0.8)	0.215
20°C	−1.4 (−3.4–0.6)	0.168	−1.4 (−3.5–0.6)	0.163
Total apnea-hypopnea index in REM				
16°C	6.7 (0.7–13)	0.03	6.8 (0.7–13)	0.03
20°C	4.7 (−1.3–11)	0.122	4.7 (−1.3–11)	0.124
Total apnea-hypopnea index in non-REM				
16°C	4.1 (0.6–7.5)	0.021	3.9 (0.4–7.4)	0.03
20°C	1.7 (−1.7–5.1)	0.327	1.7 (−1.8–5.1)	0.337

*Adjusted for body mass index and time slept in supine position divided by total sleep time. CI, confidence interval; REM, rapid eye movement.

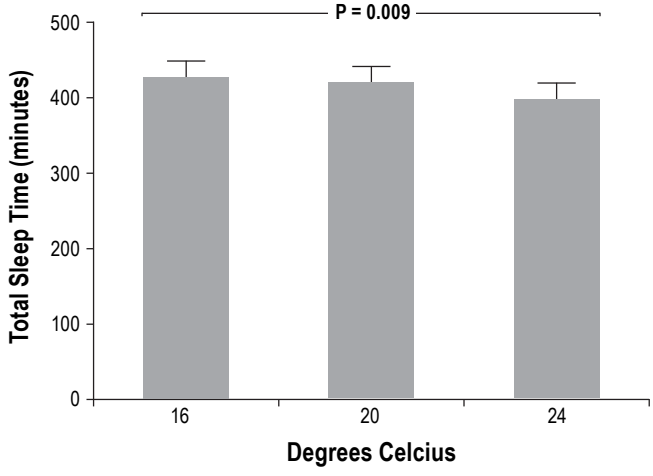

Figure 2—Mean total sleep time at 16, 20, and 24°C (95% CI).

Table 4—Difference and adjusted difference* of outcomes at 16°C and 20°C compared with 24°C

	Difference (95% CI)	P value	Adjusted difference* (95% CI)	P value
Time in bed (min)				
16°C	0.1 (−11 – 11)	0.983	−0.5 (−11 – 10)	0.928
20°C	3.7 (−7.0 – 14)	0.490	3.6 (7.1 – 14)	0.504
Total sleep time (min)				
16°C	30.0 (7.7 – 52.2)	0.009	28.5 (5.9 – 51.1)	0.014
20°C	22.1 (−0.1 – 44.3)	0.051	21.8 (−0.5 – 44.2)	0.056
Sleep efficiency (%)				
16°C	5.2 (1.2 – 9.3)	0.012	5.1 (0.9 – 9.1)	0.017
20°C	3.2 (−0.0 – 7.3)	0.124	3.1 (−0.9 – 7.2)	0.129
Wake after sleep onset (min)				
16°C	−15 (−34 – 4.5)	0.131	−14 (−34 – 5.1)	0.145
20°C	−15 (−34 – 4.3)	0.127	−15 (−34 – 4.5)	0.130
Sleep stage 1 as a percentage of total sleep time				
16°C	−0.7 (−3.8 – 2.5)	0.678	−0.8 (−4.0 – 2.4)	0.634
20°C	0.4 (−2.8 – 3.6)	0.082	0.4 (−2.8 – 3.5)	0.812
Sleep stage 2 as a percentage of total sleep time				
16°C	−1.1 (−4.2 – 2.0)	0.478	−1.5 (−4.7 – 1.6)	0.336
20°C	−1.0 (−4.1 – 2.2)	0.532	−1.1 (−4.2 – 2.0)	0.497
Slow-wave sleep as a percentage of total sleep time				
16°C	0.6 (−1.4 – 2.6)	0.572	0.8 (−1.2 – 2.8)	0.419
20°C	−0.1 (−2.1 – 1.9)	0.937	0.0 (−2.0 – 1.9)	0.970
REM sleep as a percentage of total sleep time				
16°C	0.4 (−1.6 – 2.4)	0.679	0.5 (−1.5 – 2.5)	0.613
20°C	0.4 (−1.6 – 2.3)	0.724	0.4 (−1.6 – 2.3)	0.710
Karolinska Sleepiness Scale†				
16°C	−0.6 (−1.8 – −0.1)	0.028	−0.6 (−1.2 – −0.1)	0.027
20°C	−0.3 (−0.9 – 0.2)	0.246	−0.3 (−0.9 – 0.3)	0.303

*Adjusted for body mass index and time slept in supine position divided by total sleep time. †Adjusted for sleep stage before awakening, body mass index, and time slept in supine position divided by total sleep time. CI, confidence interval; REM, rapid eye movement.

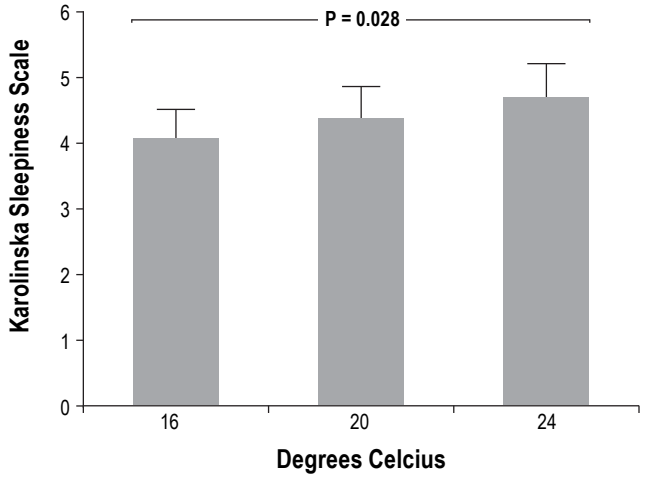

Figure 3—Mean Karolinska Sleepiness Scale at 16, 20, and 24°C (95% CI).

ronment. The effect on the apnea-hypopnea index was, however, counter to our hypothesis. A number of studies report an abnormal sensory response or sensory neuropathy in the upper airway in patients with obstructive sleep apnea from the vibration trauma of snoring,[13-16] which also persists after continuous positive airway pressure treatment of sleep apnea.[17] Neuropathy in the upper airway could explain why there was no decrease in the apnea-hypopnea index while sleeping in a cold room. However, the mechanism behind the increase in the apnea-hypopnea index while sleeping in a cold room remains unclear.

The effect of room temperature on sleep stages is mainly unknown because it has only been studied in a small number of trials comprising a few volunteers, from 6 to 17 subjects.[18-22] These studies investigated room temperatures from 20°C to 37°C. Three studies report an increased amount of wakefulness during a night in warm temperatures and a smaller amount of rapid eye movement and slow-wave sleep,[18-20] one reported the opposite results,[21] and one study found no difference.[22] We found no difference in the amount of sleep at different sleep stages, supporting the finding that room temperature does not affect the amount of sleep at different sleep stages.

Two previous studies observed that healthy volunteers slept longer in a colder versus a warmer ambient temperature. One study comprising 6 men reported shorter total sleep time at 35°C room temperature versus 20°C, whereas another study involving 10 healthy men reported a shorter total sleep time using a hot versus a normal blanket.[23,24] We also found that subjects slept longer in a cold environment due to improved sleep efficiency, but the mechanisms remain unknown. We assume that increased alertness after a night's sleep at a lower ambient temperature is due to the increase in total sleep time despite the increase in the apnea-hypopnea index.

One drawback with the current study is the lack of mechanistic insight, making it impossible to explain why subjects with sleep apnea sleep longer and why the severity of sleep apnea increases in a cold room. We encourage more studies of thermoregulation in patients with obstructive sleep apnea and also in normal subjects. Guilleminault et al. reported that patients with obstructive sleep apnea have an impairment in 2-point discrimination in the upper airway and that patients with upper airway resistance syndrome have a normal response.[13,25] A recent study by Sunnergren et al. observed that patients with obstructive sleep apnea have reduced sensitivity to cold in the soft palate compared with snorers, who in turn have less sensitivity than normal subjects.[16] We investigated patients with moderate to severe sleep apnea, and it is possible that the effect of ambient temperature on the apnea-hypopnea index is different in snorers, in patients with upper airway resistance syndrome, and in patients with mild sleep apnea because they have less neuropathy in the upper airway. Studies comparing the effect of different ambient temperatures in these subjects are therefore of real interest.

The apnea-hypopnea indices were generally lower in the baseline sleep apnea recordings than in the trial using polysomnography, with EEG scoring of total sleep time. The baseline study was conducted at home without an EEG and it is possible that sleep time was overestimated in the baseline recordings, leading to an underestimation of the apnea-hypopnea

index. It is possible that room humidity differed between the experimental nights. Unfortunately, we have no data on room humidity, which is a limitation of the study, as humidity could have an influence on the nasal and pharyngeal mucosa of the patients. Consistency in ambient temperature is essential when studying the effect of room temperatures during the night and a continuous recording of the room temperature would have been an even better control than measuring room temperature in the evening and in the morning. We did not count the number of arousals, which is another limitation. Objective measurements using the maintenance of wakefulness test or the multiple sleep latency test would have provided a better evaluation of daytime function than the Karolinska Sleepiness Scale used in the current trial.

We found that sleep time was longer, sleep efficiency was higher, and that patients with sleep apnea were more alert in the morning after sleeping in a cold room temperature, but the apnea-hypopnea index was somewhat higher in a cold temperature. It is therefore not possible to recommend a certain room temperature for untreated patients with sleep apnea. A low room temperature could, however, be suggested if residual daytime sleepiness occurs after the adequate treatment of sleep apnea.

In conclusion, untreated patients with obstructive sleep apnea sleep longer, have better sleep efficiency, and are more alert in the morning after a night's sleep at a room temperature of 16°C versus 24°C, but obstructive sleep apnea is more severe at 16°C and 20°C compared with 24°C.

Illustrating the opportunity to improve sleep, even in the presence of worsening obstructive sleep apnea, a lower ambient temperature improves sleep and alertness but increases obstructive sleep apnea. From a clinical point of view, it is suggested that patients with residual sleepiness after the successful reduction of obstructive apneas should reduce the ambient temperature during sleep.

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DISCLOSURE STATEMENT

This was not an industry supported study. The authors have indicated no financial conflicts of interest.

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