

## Breathing During Sleep in Normal Middle-Aged Subjects

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**Summary:** Although ventilation during sleep has been studied in normal young and elderly subjects, little data are available concerning possible quantitative changes in ventilatory parameters in normal middle-aged subjects. We studied the occurrence of respiratory events and the changes in minute ventilation, tidal volume, and respiratory rate during rapid-eye-movement (REM) and non-REM (NREM) sleep in 40 normal (20 men and 20 women) middle-aged subjects, using polysomnography with pneumotachography and oximetry. Apnea indices greater than 5, with apneas predominantly of the obstructive type, were found in 17.5% of the subjects (30% of the men and 5% of the women). These "apneic" subjects differed from the "nonapneic" subjects only in that they had a higher body mass index. Minute ventilation decreased from wakefulness to sleep by 14% to 19%, owing to a decrease in tidal volume without a significant change in respiratory rate. This decrease was not greater in slow wave (stage 3-4 NREM) or in REM sleep than in stage 2 NREM sleep, nor was it greater in men than in women. It correlated with the minute ventilation during wakefulness: the higher the minute ventilation during wakefulness, the greater the decrease during sleep. The occurrence of respiratory events was not related to the degree of the decrease in minute ventilation from wakefulness to apnea-free sleep. **Key Words:** Breathing—Sleep—Apnea—Middle age.

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Breathing during sleep has been the subject of numerous studies during the past decades, centering mainly on obstructive sleep apnea syndromes (see recent review) (1) and hypoxemia during sleep in patients with chronic respiratory diseases, mostly chronic obstructive pulmonary disease (see recent review) (2).

By contrast, ventilation during sleep in normal subjects has been investigated to a far less extent. After the recognition of numerous respiratory arrests during sleep in about 30% of healthy elderly subjects (3), several studies have investigated the frequency of respiratory arrests in the elderly (4-7), but only a few of the studies have analyzed respiratory parameters quantitatively (6,7). More quantitative studies of ventilatory parameters during sleep have been performed in younger subjects (6-15) (see Tables 1

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**TABLE 1.** Summary of changes in quantitative ventilatory parameters during NREM sleep as compared with wakefulness (data from the literature and the present study)

Authors (References)	No. of subjects	Age range (yr)	Technique	Sleep stage	Minute ventilation		Tidal volume		Respiratory rate	
					Awake (L)	% change from awake*	Awake (ml)	% change from awake*	Awake (b/min)	% change from awake*
Tabachnik et al (8)	5M, 4F	12-17	IP	2	6.14	-8.0	354	2.3	17.4	-9.8
				4		-9.1		3.7		-12.1
Skatrud et al (9)	2M	21-26	IP	2-4	6.50	-0.3	580	-12.1	11.9	3.4
Douglas et al (10)	8M, 11F	m = 29	A	2	7.66	-5.5	560	-16.1	14.1	9.9
				4		-7.5		-26.8		12.1
Iber et al (11)	6M	19-26	P	2-4	9.60	-4.2	660	-7.6	14.5	4.1
Krieger et al (6)	10M, 10F	20-30	P	2	7.66	-15.8	482	-15.6	16.2	-2.5
				3-4		-19.8		-19.1		-3.1
Lopes et al (12)	4M, 1F	23-31	IP	3-4	5.44	-7.2	341	-4.4	16.3	-3.7
Hudgel et al (13)	6M	18-40	P	2	10.97	-13.9	770	-16.9	14.4	3.1
Shore et al (7)	10	19-29	IP	1-2	5.03	-11.9	307	-3.3	16.4	-9.1
				3-4		-21.5		-15.3		-7.3
Stradling et al (14)	6M	18-32	IP	3-4	6.30	-9.7	420	-11.2	15.0	0.1
Gould et al (15)	10M	24-36	P	2	7.18	-9.9	530	-11.3	14.4	-2.8
				3-4		-10.1		-13.2		-0.7
Present study	20M	30-55	P	2	8.24	-13.7	596	-23.2	14.6	3.4
				3-4		-15.3		-24.0		8.2
	20F	30-55	P	2	6.57	-19.0	444	-21.4	15.6	0.3
				3-4		-18.1		-22.7		1.0

M, male; F, female; IP, inductive plethysmography; A, anamometer; P, pneumotachography; m, mean.

\* Negative values indicate a decrease.

and 2 for a recapitulation of the results of these studies). The studies involved subjects under 30 years of age, except for one study (13) that investigated only six subjects.

Because of this gap in our knowledge of quantitative ventilatory parameters during sleep in middle-aged subjects, we investigated ventilation during sleep in 40 healthy subjects aged 30 to 55 years.

## SUBJECTS AND METHODS

### Subjects

Forty subjects (20 men, 20 women) were recruited in the order in which they replied to a notice in a local newspaper requesting healthy volunteers for sleep studies. Before

**TABLE 2.** Summary of changes in quantitative ventilatory parameters during REM sleep as compared with wakefulness and with NREM sleep (data from the literature and the present study)

Authors (References)	Minute ventilation		Tidal volume		Respiratory rate	
	% change from awake	from NREM	% change from awake	from NREM	% change from awake	from NREM
Tabachnik et al (8)	-4.9	3.4	2.3	0.0	-5.7	4.5
Douglas et al (10)	-15.7	-10.8	-42.5	-31.9	22.0	11.0
Krieger et al (6)	-18.7	-3.4	-36.7	-25.1	-1.9	0.6
Lopes et al (12)	-0.6	7.1	0.3	4.9	-14.1	-10.8
Hudgel et al (13)	-14.8	-1.1	-18.2	-1.6	11.5	8.2
Stradling et al (14)	-13.4	-4.1	-12.6	-1.6	-1.3	-2.0
Gould et al (15)	-8.7	1.2	-17.0	-6.4	5.6	8.6
Present study	-17.0	-3.8	-50.3	-35.4	18.6	14.6
	-18.3	0.9	-46.4	-31.8	10.6	10.2

\* Negative values indicate a decrease.

being allowed to apply, the subjects were informed of the conditions and constraints of the study and reminded of the need for them to be in good health. Particular attention was focused on *insomnia*, *daytime somnolence*, and *habitual snoring*; the applicants then underwent a clinical interview and examination. The criteria for exclusion, in addition to signs or symptoms of sleep disorders, were the presence of any major organic or psychiatric disease and the use of hypnotics. No subject complained of daytime somnolence or habitual snoring; seven of the men (35%) and four of the women (20%) admitted occasional snoring. Only one subject, who had a major psychiatric disorder treated with neuroleptics, was excluded. All subjects gave written consent.

### Methods

Each recording night was preceded by an unrecorded adaptation night during which the subjects slept in the sleep laboratory with part of the recording electrodes attached. On the recording night, the electrodes were attached between 5 and 6 p.m. The subjects then remained free until 10 p.m., when the recording was begun. They decided themselves when the lights would be turned off. The recording ended at the subjects' request after 6 a.m.

### Polysomnography

The recordings included eight electroencephalography (EEG) leads ( $F_2-T_4$ ,  $T_4-O_2$ ,  $F_2-C_4$ ,  $C_4-O_2$ ,  $T_4-C_4$ ,  $C_4-C_z$ ,  $C_z-C_3$ ,  $C_3-T_3$ ,  $F_{p_1}-C_3$ ,  $C_3-O_1$ ,  $F_{p_1}-T_3$ ,  $T_3-O_1$ ), an electro-oculogram, and an electromyogram of submental muscles. These parameters were recorded on a 16-channel recorder (Alvar REEGA XVI Tr) at a paper speed of 15 mm/s.

Ventilation was analyzed with a Fleisch No. 2 pneumotachograph yielding flow rates and ventilatory volumes by means of an electronic integrator (Gould Godart), and with thoracic and abdominal mercury-filled Silastic strain gauges. The pneumotachograph was attached to a soft Silastic mask (Bird 3433) covering the nose and the mouth. No valve was used; both inspiratory and expiratory flows and volumes were recorded. The added resistance was that of the pneumotachograph (less than 0.5 cm  $H_2O/L/s$ ). The added dead space due to the pneumotachograph was 40 ml; that due to the face mask varied with the subject's facial features, ranging between 20 and 40 ml. No leak detector was used. Leaks were searched for manually at half-hour intervals, after each body position change, and whenever the flows and volumes changed abruptly. All measurements were made on inspiratory flows and volumes, because the minor leaks that may have occurred during expiration were eliminated during inspiration, given the soft structure of the facial mask. Finally, oxyhemoglobin saturation ( $SaO_2$ ) was measured by transcutaneous ear oximetry (Hewlett-Packard 47201 A).

These parameters were recorded on an eight-channel recorder (Dynograph Beckman R411) running at a paper speed of 1 mm/s. One-minute interval synchronous time markers and one respiratory signal common to both recordings made it possible to identify simultaneous events.

### Data Analysis

Sleep stages were scored according to standard criteria (16). Stages 3 and 4 were considered together and termed slow-wave sleep (SWS); in some instances, stages 1 and 2 were considered together and termed light non-rapid-eye-movement (NREM) sleep.

For each recording, the sleep period (time duration from sleep onset to final awak-

ening), the total sleep time (sleep period minus wake time after sleep onset), the sleep onset latency (from lights out to onset of stage 1), and the latencies from stage 1 to stage 2, to stage 3, and to rapid-eye-movement (REM) sleep were computed, as well as the percentage of total sleep time spent in each sleep stage and the cumulative duration of intrasleep awakenings.

The respiratory events were counted and their cumulative duration was calculated. Respiratory events were identified as hypopneas and apneas. Hypopneas were defined as a decrease in tidal volume below 50% of its value during quiet wakefulness before sleep onset, without a major change in respiratory rate. Central apneas were defined as a simultaneous interruption of respiratory flow and thoracic and abdominal movements, whereas thoracic or abdominal movements (or both) persisted during obstructive apneas. Mixed apneas consisted of a central apnea followed by an obstructive apnea during the same apneic episode. Only events lasting at least 10 s were considered.

Blood oxygenation was evaluated by the mean  $\text{SaO}_2$ , as well as the time spent below 98, 96, 94, 92, 90, and 88%  $\text{SaO}_2$ . The amount of desaturation was evaluated by measuring the area of the saturation curve lying below the desaturation threshold; the desaturation threshold was defined as the awake  $\text{SaO}_2$  minus 4%. The amount of desaturation was expressed in seconds (s)  $\times$  %  $\text{SaO}_2$ .

Ventilatory parameters (i.e., minute ventilation, tidal volume, and respiratory rate) were determined during the first, second, fourth, sixth, eighth, and tenth minutes of stage 1, stage 2, and stage 3–4 NREM sleep, REM sleep, and intrasleep wakefulness. These parameters were determined upon the first occurrence of each sleep state lasting at least 10 min and free of apneas. Such episodes were found in wakefulness in 20 subjects, in stage 2 NREM in 29 subjects, in slow wave sleep in 30 subjects, and in REM sleep in 23 subjects. When no 10-min uninterrupted apnea-free sleep periods could be found, the longest apnea-free period was considered.

### Statistical Analysis

Sleep and respiratory events were compared between the sexes by means of a Student's *t* test. The ventilatory parameters were submitted to a three-factor analysis of variance (ANOVA) [the factors considered being sex, sleep state, and the chronological situation of the analyzed period (from the first to the tenth minute)], with repeated measures on two factors (sleep state and chronological situation), followed by a Scheffe test for the localization of differences (17). Correlations between parameters were tested by means of Pearson's correlation coefficient. A value of  $p = 0.05$  was accepted as the level of statistical significance. Results are given as means  $\pm$  standard error of the mean (SEM).

## RESULTS

### Anthropometric Data

The main anthropometric data of the populations studied are given in Table 3. The men did not differ from the women in age, but they had a higher body mass index (BMI) (the range in men was 18.7 to 32.8  $\text{kg/m}^2$ , two men having a BMI greater than 30; the range in women was 17.3 to 28.9  $\text{kg/m}^2$ ) and higher systolic and diastolic blood pressures.

TABLE 3. Anthropometric data

		Age (yr)	Body mass index (kg/m <sup>2</sup> )	Systolic blood pressure (mm Hg)	Diastolic blood pressure (mm Hg)
Men	Mean	39.3	24.8	135.0	89.2
	SEM	1.4	0.8	2.9	2.6
Women	Mean	38.4	22.0	124.3	78.8
	SEM	1.6	0.6	2.3	2.0
Total	p	ns	<0.01	<0.01	<.005
	Mean	38.9	23.4	129.5	84.3
	SEM	1.1	0.6	2.0	1.9

SEM, standard error of the mean; ns, not significant.

### Sleep Data

Women tended to have better sleep than men, as indicated by a lower amount of stage 1 and a tendency for more slow wave sleep (SWS, Table 4). However, in both sexes the amounts of SWS and REM sleep were low, and the latencies for these sleep stages were long (Table 4).

### Respiratory Events

*Hypopneas* were observed in all but one of the men and in all women. However, the number of hypopneas per hour of sleep was greater in men than in women (Table 5). The mean duration of hypopneas did not differ between the sexes (Table 5).

*Central apneas* were observed in 14 men (70%) and in seven women (35%). They were infrequent (fewer than two per hour of sleep) in all women and in most men; however, two men had a higher number of central apneas (5.4 and 9.3 central apneas per hour of sleep, respectively). On the whole, the central apnea index was slightly, but not significantly, greater in men than in women (Table 5). The mean duration of central apneas was also slightly greater in men than in women ( $15.0 \pm 0.8$  versus  $11.7 \pm 1.3$  s,  $p < 0.05$ ).

*Obstructive apneas* were observed in 19 men (95%) and in 16 women (80%), with overall small apnea indices in men and in women (Table 5). However, two men had obstructive apnea indices greater than 5 (7.0 and 32.6, respectively). The mean duration of obstructive apneas was not different in men and women ( $16.3 \pm 0.9$  versus  $15.2 \pm 1.5$  s).

*Mixed apneas* were rare, being present in small amounts in only five men (25%) and

TABLE 4. Sleep parameters

		Sleep onset latency (min)	Latency to st 2 (min)	Latency to SWS (min)	Latency to REM (min)	WASO (min)	Total sleep time (min)	St 1%	St 2%	SWS %	REM %	Sleep effi- ciency
Men	Mean	13.6	13.0	79.2	214.7	130.1	307.8	14.1%	60.4%	12.6%	12.9%	70.6%
	SEM	1.8	3.3	17.3	23.0	13.2	13.3	1.9%	2.6%	2.0%	1.1%	2.6%
Women	Mean	15.3	7.5	54.4	202.8	108.8	326.7	8.8%	60.2%	17.1%	13.9%	75.0%
	SEM	1.6	1.8	12.9	25.2	14.0	17.3	1.1%	2.1%	2.0%	1.7%	3.0%
Total	p	ns	ns	ns	ns	ns	ns	<.025	ns	ns	ns	ns
	Mean	14.4	10.2	66.1	208.9	119.4	317.3	11.4%	60.3%	14.9%	13.4%	72.8%
	SEM	1.2	1.9	10.7	16.8	9.6	10.9	1.2%	1.7%	1.4%	1.0%	2.0%

St 2, stage 2; SWS, slow wave sleep; REM, rapid eye movement; WASO, wake time after sleep onset; st 1, stage 1; SEM, standard error of the mean; ns, not significant.

TABLE 5. Respiratory events

		Hypopnea index (n/h)	Mean hypopnea duration (s)	Apnea index (n/h)	Mean apnea duration (s)	Central apnea index (n/h)	Obstructive apnea index (n/h)	Apnea index in st 1-2 (n/h)	Apnea index in SWS (n/h)	Apnea index in REM (n/h)
Men	Mean	9.4	18.1	5.2	16.1	1.3	3.8	4.7	0.3	13.6
	SEM	1.6	1.3	1.8	0.8	0.5	1.7	1.7	0.2	4.7
Women	Mean	5.0	15.1	1.8	14.8	0.2	1.5	2.0	0.0	3.0
	SEM	1.0	0.8	1.0	1.5	0.1	0.9	1.3	0.0	1.0
Total	p	<0.05	<0.05	ns	ns	ns	ns	ns	ns	<0.05
	Mean	7.1	16.6	3.5	15.5	0.8	2.6	3.3	0.1	8.3
	SEM	1.0	0.8	1.0	0.8	0.3	0.9	1.1	0.1	2.5

SWS, slow wave sleep; REM, rapid eye movement; SEM, standard error of the mean; NS, not significant.

two women (10%); mixed apnea indices were below 1 in all instances. Their mean duration was again similar in men and in women ( $15.5 \pm 2.5$  versus  $14.4 \pm 4.6$  s).

When all types of apneas were considered together, the overall apnea index was not significantly different in men and in women (Table 5). Six men (30%) and one woman (5%) had an apnea index greater than 5. In four men and in the woman, obstructive apneas represented more than 80% of all apneas. In one man, central and obstructive apneas were equally numerous, and in the remaining man central apneas accounted for more than 80% of all apneas.

Overall, the incidence of apneas was higher in REM sleep than in stage 2 NREM sleep, mainly because men had higher apnea indices in REM sleep (Table 5). Apneas were rare in SWS.

When compared with the subjects who had an apnea index less than 5, the seven subjects with an apnea index greater than 5 had a greater BMI [ $25.9 \pm 0.9$  kg/m<sup>2</sup> (range, 23.1 to 29.0) versus  $22.8 \pm 0.6$  kg/m<sup>2</sup> (range, 17.3 to 32.8,  $p < 0.05$ )]; however, the two subjects with a BMI greater than 30 kg/m<sup>2</sup> belonged to the "nonapneic group." The central apnea index was correlated with BMI ( $r = 0.32$ ,  $p < 0.05$ ), whereas the obstructive apnea index was not. Except for this, no significant correlation could be demonstrated between the apnea indices and any of the anthropometric parameters.

The seven subjects with an apnea index greater than 5 also had a greater number of intrasleep awakenings ( $257 \pm 51$  versus  $135 \pm 11$ ,  $p < 0.001$ ) and longer wake time after sleep onset ( $154.7 \pm 32.4$  versus  $102.9 \pm 18.5$  min, not significant). The total sleep time was not significantly different, but the sleep period was longer ( $481.5 \pm 17.9$  versus  $427.2 \pm 10.4$  min). They also had a greater percentage of stage 2 sleep ( $67.9 \pm 4.6$  % versus  $58.7 \pm 1.7$ %,  $p < 0.05$ ) and a smaller percentage of slow wave sleep ( $8.3 \pm 2.3$  % versus  $16.2 \pm 1.6$ %,  $p < 0.05$ ). The respiratory event indices were correlated with the number of awakenings (hypopnea index:  $r = 0.32$ ,  $p < 0.05$ ; central apnea index:  $r = 0.44$ ,  $p < 0.005$ ; obstructive apnea index:  $r = 0.31$ ,  $p < 0.05$ ; total apnea index:  $r = 0.40$ ,  $p < 0.01$ , hypopnea + apnea index:  $r = 0.43$ ,  $p < 0.01$ ).

The consequences of respiratory events on SaO<sub>2</sub> were mild: the mean SaO<sub>2</sub> for the whole night was lower in the seven subjects with an apnea index greater than 5 ( $95.9 \pm 0.7$  % versus  $97.2 \pm 0.2$ %,  $p < 0.05$ ), but the amount of desaturation was below 60 s × % in all subjects but one, who had an amount of desaturation of 679 s × %. Still, the seven subjects with an apnea index greater than 5 spent a greater percentage of their sleep time at lower SaO<sub>2</sub> levels; for instance, they spent  $19.9 \pm 10.5$  % of their sleep time at a SaO<sub>2</sub> below 94% versus  $0.5 \pm 0.2$  % for the subjects with an apnea index below 5.

## Ventilatory Parameters

No episode of stage 1 sleep lasting more than 10 min could be found in any of the subjects. Therefore, stage 1 was left out of the study of ventilatory parameters. The ANOVA showed that in no sleep state (wakefulness, stage 2, SWS, or REM sleep) did the respiratory parameters change significantly between the first and the tenth minute of sleep (Fig. 1A and B). Therefore, only the mean value from the first to the tenth minute was considered; as illustrated in Fig. 2, only two factors in the ANOVA played a significant role: sleep state and gender.

*Effects of Gender.* Minute ventilation was greater in men than in women ( $p < 0.001$ ), regardless of the sleep state (Fig. 2). This difference in minute ventilation was due to a greater tidal volume regardless of the sleep state ( $p < 0.02$ ), despite a smaller respiratory rate (not significant) in men.

Despite these differences in minute ventilation, no gender-related difference in  $\text{SaO}_2$  was demonstrated in any sleep state (Fig. 2).

*Effects of Sleep State.* Minute ventilation varied between sleep states ( $p < 0.0001$ ). Minute ventilation during wakefulness was higher than during any sleep stage ( $p < 0.01$  for the comparisons between wakefulness and each sleep stage) but did not differ among sleep stages (Fig. 2). The difference in minute ventilation was due to a difference in tidal volume among sleep states ( $p < 0.001$ ). Again tidal volume was greater in wakefulness than in each sleep stage ( $p < 0.01$  for each comparison) but did not differ among sleep stages. The respiratory rate varied significantly among sleep states ( $p < 0.001$ ). It was higher in REM sleep than in any other state ( $p < 0.01$ ) and lower in wakefulness than in any other state ( $p < 0.05$ , Fig. 2).

Finally,  $\text{SaO}_2$  varied between sleep states ( $p < 0.05$ ), being higher during wakefulness than in any other state ( $p < 0.05$  for each comparison) but not differing among sleep stages (Fig. 2).

*Interactions.* No interaction (gender  $\times$  sleep state, gender  $\times$  chronological situation within a sleep state, or sleep state  $\times$  chronological situation within a sleep state) could be demonstrated.

*Correlations.* To analyze the factors related to the decrease in minute ventilation from wakefulness to sleep, correlations with the decrease in minute ventilation from wakefulness to sleep were tested; because minute ventilation did not differ among sleep stages, only the difference in minute ventilation from wakefulness to stage 2, which was present in all subjects, was considered.

The difference in minute ventilation from wakefulness to stage 2 was negatively correlated with the minute ventilation ( $r = -0.60$ ,  $p < 0.0001$ ) and with the tidal volume ( $r = -0.41$ ,  $p < 0.01$ ) during wakefulness, indicating that the higher the minute ventilation and the tidal volume during wakefulness, the greater the decrease in minute ventilation with sleep. Similarly, the decrease in tidal volume from wakefulness to stage 2 was negatively correlated with the tidal volume during wakefulness ( $r = -0.77$ ,  $p < 0.0001$ ), and the difference in respiratory rate from wakefulness to stage 2 was negatively correlated with the respiratory rate ( $r = -0.71$ ,  $p < 0.0001$ ) and with the minute ventilation ( $r = -0.32$ ,  $p < 0.05$ ) during wakefulness. The difference in minute ventilation was correlated with the difference in tidal volume from wakefulness to sleep ( $r = 0.51$ ,  $p < 0.001$ ). Finally, the difference in  $\text{SaO}_2$  from wakefulness to sleep was negatively correlated with the  $\text{SaO}_2$  during wakefulness ( $r = -0.34$ ,  $p < 0.05$ ).

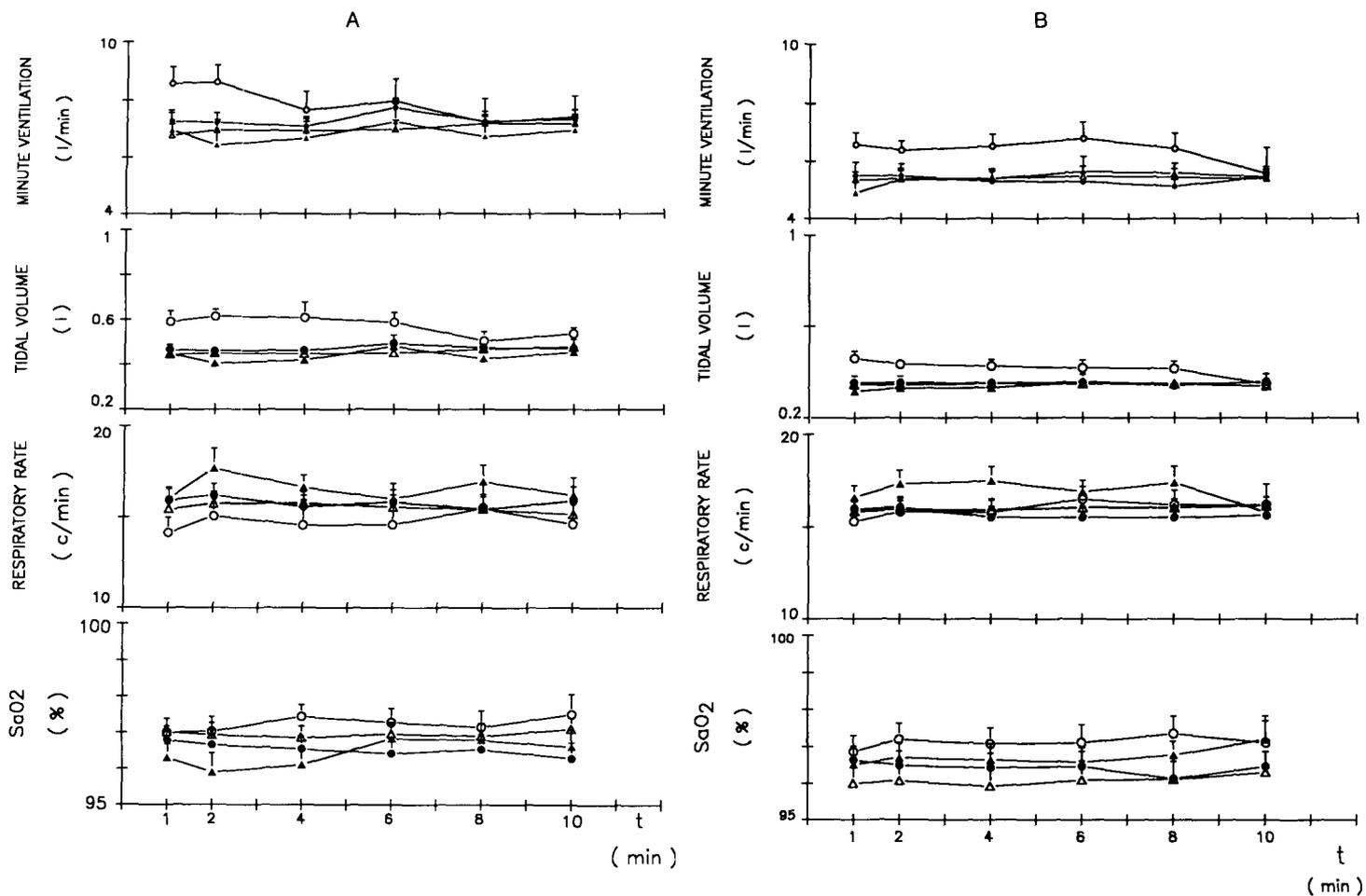


FIG. 1. Evolution of ventilatory parameters (minute ventilation, tidal volume, respiratory rate, and SaO<sub>2</sub>) from the first to the tenth minute during wakefulness (○—○), stage 2 (●—●) and stage 3-4 NREM (△—△), and REM sleep (▲—▲) in 20 men (A) and in 20 women (B); means + 1 SEM.

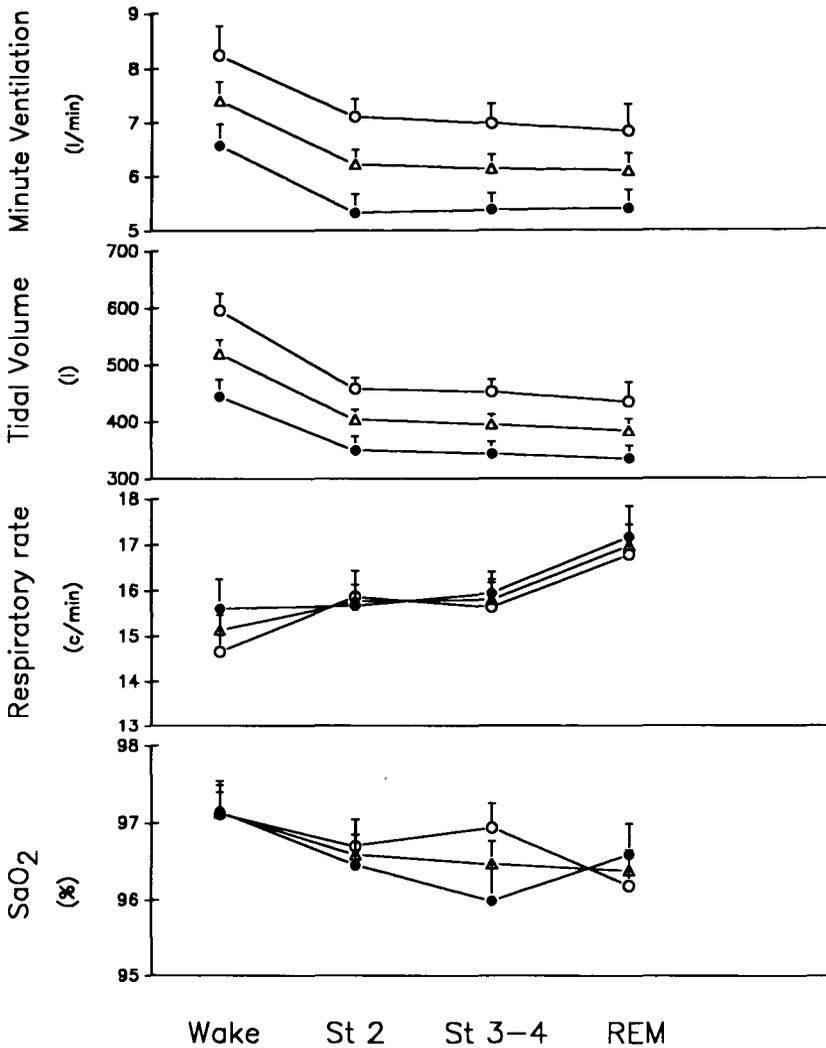


FIG. 2. Changes in ventilatory parameters from wakefulness to stage 2 and stage 3-4 NREM and to REM sleep in 20 men (○—○), in 20 women (●—●), and in the total population (△—△); means + 1 SEM.

### DISCUSSION

Although respiration during sleep has been investigated previously in normal young and elderly subjects, this study is the first specifically focused on normal middle-aged subjects.

The subjects studied were recruited on the basis of their good health; nevertheless, subjects concerned about their sleep could have been more likely to apply for a sleep study, thus resulting in a self-selection bias. This was not the case in the sample selected for this study, as subjects with insomnia, daytime somnolence, or habitual snoring were not included. The percentage of occasional snorers was in the range of that found in the same age group in a survey of the general population [8% at age 30,

24% at age 55 in women; 18% at age 30, 48% at age 55 in men (18)], indicating that snorers were not overrepresented in the sample studied.

Similarly, the BMI was in the normal range, both in men and in women (19); the difference in BMI that we observed between men and women also agrees with data found in the general population (20).

These subjects had a poorer sleep quality than normal subjects in the same age range (21), which may be due to the polygraphic setting, especially the face mask used for the recording of respiratory flows with a pneumotachograph. However, the degree of the alterations in the sleep pattern was in the range of what we had previously observed when comparing younger subjects recorded either with or without a face mask on two different nights (22). In these younger subjects, the respiratory frequency and the occurrence of apneas were not different with and without the face mask. Therefore, we believe that the recording setting, although it may have altered sleep, probably did not introduce major changes in the respiratory pattern.

Our data demonstrate, among healthy subjects without complaints evocative of obstructive sleep apnea syndrome (OSA), a significant percentage (17.5%) of subjects with an apnea index greater than 5, mostly of the obstructive type, which is often accepted as a criterion for the diagnosis of OSA in patients with clinical symptoms of OSA (23), although this criterion has been a matter of debate (24). Given the high frequency of obesity in OSA, the higher BMI in the apneic subgroup than in the nonapneic subgroup suggests that the presence of apneas in noncomplaining subjects may correspond to a premorbid state; however, obesity as reflected by the BMI does not seem to be an accurate predictor of apneas in a healthy population, because the only two subjects with a BMI greater than 30 kg/m<sup>2</sup> belonged to the nonapneic group. The long-term evolution of these cases would be of interest.

The percentage of subjects (17.5%) with an apnea index greater than 5 is intermediate between that found in younger subjects [in whom apneas are absent or rare (6–15)] and in older subjects, in whom it has been found to approximate 30% (3–7). Since the apneas were predominantly of the obstructive type, this suggests that aging compromises upper airway stability during sleep, a fact in agreement with the increasing frequency of OSA with increasing age. This increased upper airway collapsibility with increasing age seems to be independent of increasing body weight, because in the studies performed by our group applying the same methodologies to various age groups, the younger (below age 30) and older (over age 55) subjects did not differ from the subjects in the present study with respect to BMI [recalculated from Krieger and co-workers (6)].

Our results also show, in middle-aged subjects, a decrease in ventilation during sleep that is independent of the occurrence of apneas and similar to that described in younger (6–15) or older subjects (6,7). This decrease in minute ventilation, of an average of 1.2 L/min from wakefulness to NREM sleep, is similar in men and women and is similar in magnitude to that observed in younger subjects [1.2 L/min (6), 1.5 L/min (15)] when equivalent techniques for the measurement of ventilation are used. Indeed, it seems that the decrease in ventilation from wakefulness to sleep depends on the invasiveness of the technique used to measure ventilation. This is evident from the published data (see Table 1), which appears to show that the decrease in minute ventilation is smaller when inductance plethysmography or an anemometer is used instead of a pneumotachograph attached to an airtight face mask (25). This is also evidenced by our data showing that the decrease in minute ventilation was correlated with the level of ven-

tilation during wakefulness. This agrees with the hypothesis that the decrease in ventilation is due to the elimination of the contribution of the behavioral system to the baseline ventilation, independent of the requirements of the metabolic control system (26). The absence of a significant change in  $\text{SaO}_2$  further suggests that the decrease in ventilation corresponds to the elimination of an excess ventilation independent of metabolic needs, although the position of the subjects on the flat part of the oxyhemoglobin dissociation curve could explain why the  $\text{SaO}_2$  changed little despite a significant decrease in ventilation. The question may be raised whether the wakefulness-related extraveilation is not entirely artifactual, a hypothesis suggested by Duron and co-workers 20 years ago (27). To address this question would require an entirely noninvasive investigation in subjects unaware that they were being investigated.

Our data also demonstrate that the ventilation is stable within a given sleep state from the onset of the sleep state to the tenth minute. They also failed to demonstrate a difference between sleep stages, and more specifically, between NREM and REM sleep. In young subjects, differences between NREM and REM sleep have been reported (Table 2); they seem to be dependent mainly on the way in which the periods of REM sleep were selected for analysis, as the greatest decrease in ventilation has been observed during phasic REM sleep, contemporary with the occurrence of bursts of REMs (15,28).

Finally, our data do not demonstrate a relationship between the occurrence of apneas during sleep and the degree of the decrease in ventilation from wakefulness to apnea-free sleep; this observation is similar to the one we made in elderly subjects (6). If it is accepted that the repetitive apneas observed during sleep in normal subjects are an extension of what has been termed "periodic breathing" at sleep onset (29), this lack of correlation contradicts the hypothesis that ventilatory instability at sleep onset is due to the sleep-related decrease in ventilation (26).

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