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Oxygen Consumption During Sleep: Influence of Sleep Stage and Time of Night

Thomas Ryan, Stanislaw Mlynczak, Tim Erickson, S. F. Paul Man, and Godfrey C. W. Man

Department of Medicine, University of Alberta, Edmonton, Alberta, Canada

Summary: We measured oxygen consumption ($\dot{V}O_2$) in eight normal male volunteers during sleep, using the ventilated-hood method. Data were collected over 28 subject-nights. There was an overnight trend of gradually decreasing $\dot{V}O_2$ in the first 4 h, followed by a rise toward the morning. The minimum $\dot{V}O_2$ was 7.9% lower than that in the first hour. To examine the influence of sleep stages on the $\dot{V}O_2$, we compared the $\dot{V}O_2$ of a sleep stage (an overnight average of all epochs in that stage) with that of other stages. The results show that $\dot{V}O_2$ values in stages awake and 1 are significantly higher than all other stages. Stage rapid eye movement (REM) is significantly lower than stage 2, but stages 3 and 4 are not different from each other or from stages REM and 2. We also compared $\dot{V}O_2$ of sleep stages that occurred close to each other (within the same hour). $\dot{V}O_2$ in awake stage is again significantly higher than in all other stages, and stage 2 is higher than stages 3 and 4. However, no difference is found between stage 1 and stages 2, 3 and REM, nor is there any difference between REM and stages 2 and 3. The discrepancy between close-stage comparison and overnight-average comparison can be accounted for by the variation in $\dot{V}O_2$ of an individual stage with the time of night. Although there is a variation in time distribution of the stages overnight, this factor influences the overnight trend of $\dot{V}O_2$ in a minor fashion only. **Key Words:** Oxygen consumption—Sleep stage.

It is well recognized that metabolic rate (MR) in humans falls during sleep. This is in keeping with the hypothesis that sleep serves an energy-conserving function. Both the body temperature and oxygen consumption ($\dot{V}O_2$) decreases gradually during the night, reaching a low point about 4 to 5 h after retiring, followed by a gradual rise toward the morning (1–3). This all-night pattern appears to coincide with the circadian cycle of neuroendocrine changes, but the exact interrelationship is not known.

It has also been suggested that the stage of sleep has an influence on MR. Several authors concluded that rapid-eye-movement sleep (REM) is characterized by a higher $\dot{V}O_2$ than non–rapid-eye-movement sleep (NREM); and during NREM sleep, $\dot{V}O_2$ is

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Address correspondence and reprint requests to Dr. G. C. W. Man at 2E4.44 Walter C. Mackenzie Health Sciences Centre, University of Alberta, Edmonton, Alberta, Canada T6G 2B7.

lower in stage 4 than in stage 1 or 2 (4–6). Thus, the time-dependent MR changes may be accounted for if the distribution of sleep stages is not uniform throughout the night. Indeed, this appears to be the case because stages 3 and 4 tend to be more prominent earlier in the night, and stage 2 and REM more dominant in the latter part of the night. This explanation, however, is not uniformly accepted because the stage-related difference in $\dot{V}O_2$ has not been consistently found (7). Furthermore, it is possible that the $\dot{V}O_2$ for a given sleep stage may vary depending on the time of night that the observation was made (7).

We performed these studies on healthy volunteers in an attempt to shed more light on the controversy. Specifically, our aims were: (a) to measure the $\dot{V}O_2$ during sleep at different times of the night; (b) to determine the distribution of sleep stages throughout the night; (c) to examine any difference in $\dot{V}O_2$ between sleep stages; and (d) to determine the relative influence of time of night and sleep stage on the $\dot{V}O_2$ during sleep. Finally, we calculated the night-to-night variation in overall $\dot{V}O_2$ and stage-specific $\dot{V}O_2$ for each individual. To collect sufficient data for such analysis, we repeated studies on each subject on multiple occasions. To measure $\dot{V}O_2$, we used the ventilated-hood method, which offered the least interference with the subject's respiration (4–6,8,9).

METHODS

Eight subjects were studied on 3 nonconsecutive nights and four of them on an additional fourth night, for a total of 28 subject-nights. The subjects reported to the sleep laboratory between 9:30 and 10:00 p.m. They were asked not to have any meals for at least 6 hours before the study. They also agreed not to take any medication and to avoid strenuous exercise on the day of the study. All of them were healthy men (ages 20–40) without any history or signs of pulmonary, cardiac, or metabolic disease. Pulmonary function tests were performed and showed normal lung mechanics in all eight subjects.

Sleep studies

The subjects slept in a sound-shielded laboratory that was maintained at 21–22°C. Standard electrode placements were used for electroencephalogram recording: central electrodes C3-A2 and C4-A1, occipital electrodes O2-A1 and O1-A2, chin electromyogram, and two electrooculograms. The signals were amplified and recorded on a Model 78D Grass Polygraph set to a chart speed of 15 mm/s. Sleep records were scored in 40-s epochs according to standardized criteria set forth in Rechtschaffen and Kales (10). Scoring was done by one of us without prior knowledge of the $\dot{V}O_2$ results of the individual subjects.

For determination of $\dot{V}O_2$ as a function of time of night, all sleep stages lasting for at least one epoch were used. To compare $\dot{V}O_2$ in one stage with that of another, only sleep stages lasting for 5 min or more were used in the analysis. It was thought that the 5-min restriction would help reduce the carryover effect that an individual sleep stage would have on another stage immediately following. Also, any inertia in the flow system would be at least partially compensated for. The response time of the system for measurement of $\dot{V}O_2$ was determined to be 2 min, with an additional rise time of 1 min. To examine the effect of response time on the $\dot{V}O_2$ values for various stages, $\dot{V}O_2$ response times of 3 min and 0 min were compared. The differences were $<2\%$ and had no effect on the statistical analysis.

Oxygen consumption

The apparatus used to measure oxygen uptake during sleep is shown in Fig. 1. Oxygen concentration and air flow were measured continuously using a sensitive oxygen analyzer (Applied Electrochemistry Model 3A) and a pneumotachograph (Hans Rudolph Model 3800) connected to a Validyne amplifier (Model CD19). To accurately measure small changes in oxygen concentration, a second stage of amplification and zero suppression was applied to the output signal of the oxygen analyzer. The analog to digital conversion of the oxygen analyzer and flow signal voltages was performed using a Data Translation circuit board (Model DT2801), mounted in an IBM XT computer. The respiratory quotient (R) was determined in the morning by having the subject breathe into a bag with subsequent measurement of the expired oxygen concentration (as described above) and expired CO_2 concentration with a capnograph (Godart Model 17070). This R value was used to correct the $\dot{V}O_2$ data for each epoch during the night.

The computer acquired data continuously (40-s epochs) while the subject slept under the hood. Room air was drawn through the system by an electric pump, located downstream of the pneumotachograph, at the rate of 80 L/min. The hood covered the subject from the neck up and a plastic collar was attached to the front of the hood and around the subject's neck to reduce air leak. The main room air leak into the hood was through a hole near the top of the hood. This arrangement, plus a flow rate of 80 L/min through the system, prevented expired air from escaping from the hood by any means other than through the mixing chamber and pneumotachograph. The value of $\dot{V}O_2$ and flow rate were calculated in real time and stored in the subject's data file. At the end of each 40-s epoch, a signal was sent from the computer to the marker channel on the Grass Recorder to indicate the beginning of a new epoch. In this way, epochs in the computer record could be matched with epochs on the chart recorder paper.

Flow calibrations were performed by attaching a dry gas meter to the input of the mixing chamber. Air was pumped through the system, at a constant flow rate, for a period measured with a stopwatch. The volume reading on the dry gas meter allowed the exact flow rate to be calculated. The calculated flows were then plotted against output voltages from the Validyne amplifier to obtain the slope and intercept to be used in the computer program. The accuracy of the flow rate and O_2 concentration measurements were confirmed by injecting nitrogen into the hood at a known rate. The simulated oxygen uptake values, calculated by the computer, agreed with those predicted to within ±2%.

Statistical analysis

Paired samples were compared using Student's *t* test. Analysis of variance (two-way) was used where appropriate. Values are expressed as mean ± SD.

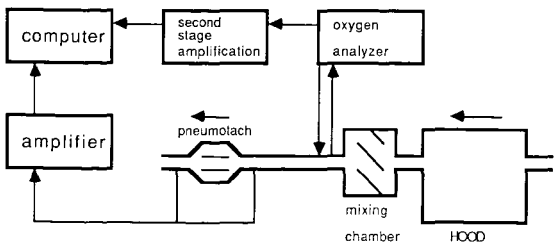

FIG. 1. Schematic diagram of experimental setup for measurement of oxygen consumption.

RESULTS

Subjects slept for at least 5 hours each night. The percentage of time spent in the various sleep stages is shown in Table 1, along with values obtained by other workers. Results are presented for each of the first 3 nights and for all of the data together. There is little indication of significant variation between the first 3 nights. The percentage of time spent in stage 2 is higher than that found in the two works cited (9,11). Also, REM and stage 4 are not so prominent as previously reported. The reported normal values for this age group are: mean (range); awake, 0.86 (2.81); stage 1, 5.39 (16.41); stage 2, 48.73 (15.54); stage 3, 7.72 (11.95); stage 4, 13.18 (19.06); stage REM, 24.11 (15.48) (12). As seen from Table 1, the stage distribution found here is within the normal range.

OXYGEN UPTAKE AS A FUNCTION OF TIME OF NIGHT

Oxygen uptake as a function of time of night was examined to determine whether there were any systematic changes in oxygen consumption as the night progressed. Table 2 and Fig. 2 show the average values of oxygen uptake for each sleep hour. These numbers were obtained by taking data for each night and calculating an average value for each hour. Average values for each subject were then obtained for each hour and the overall averages, shown in Table 2, were obtained by averaging over eight subjects. An analysis of variance (repeated measures two-way) on hours 1 to 5 gave a p of 0.025. Paired t tests showed that only hours 1 and 4 were significantly different ($p = 0.018$).

To acquire additional insight into the factors that cause changes in oxygen consumption during the night, the night was divided into three equal parts. Values of $\dot{V}O_2$ for each subject and each stage were extracted from the data for each third of the night. In this case all stage data were used even if the patient remained in a stage for only one epoch. The overall average $\dot{V}O_2$ for each subject was obtained by averaging over all stages for each third of the night and these were averaged over all subjects. Average $\dot{V}O_2$ values were (mean ± SD) 4.16 ± 0.42, 3.97 ± 0.28, and 3.83 ± 0.31 $ml \cdot min^{-1} \cdot kg$ for the first, second, and third parts of the night, respectively. Two-way analysis of variance across the three parts of the night gave $p = 0.002$ and t tests showed that the first and third parts of the night were significantly different ($p = 0.004$) as well as the second and third ($p = 0.0498$). When only stage 2 data is used, the values for the three parts of the night are 4.09 ± 0.40, 3.98 ± 0.32, and 3.72 ± 0.33 $ml \cdot min^{-1} \cdot kg$, respectively. Analysis of variance (two-way) gave $p = 0.0004$ and

TABLE 1. *Profile of sleep stages*

Sleep stage	Williams (11)	Shapiro (9) 2nd night n = 4	1st night n = 8	Present study (ages 20–40) 2nd night n = 8	3rd night n = 8	All data n = 28
Awake	1.3 ± 1.1	3.3 ± 3.0	18.4 ± 6.5	10.3 ± 1.9	10.0 ± 2.1	12.0 ± 2.2
Stage 1	4.4 ± 1.6	8.4 ± 3.7	10.2 ± 2.3	6.1 ± 1.7	4.7 ± 1.1	6.5 ± 1.0
Stage 2	45.5 ± 5.2	40.5 ± 11.1	53.4 ± 5.8	60.2 ± 3.9	61.2 ± 3.6	59.3 ± 2.5
Stage 3	6.2 ± 1.4	9.8 ± 3.9	6.6 ± 1.3	8.8 ± 2.2	7.5 ± 1.7	7.4 ± 1.0
Stage 4	14.6 ± 4.4	20.1 ± 9.7	2.1 ± 1.1	3.9 ± 1.6	2.6 ± 1.7	3.2 ± 0.9
REM	28.0 ± 5.7	17.9 ± 1.7	9.3 ± 2.3	10.7 ± 1.4	13.9 ± 2.6	11.6 ± 1.1

Values are expressed as percentage of sleep time, mean ± SD.

TABLE 2. *Variation of oxygen uptake with time of night*

Sleep hour	Oxygen uptake (ml · min^{-1} · kg)
Awake	4.60 ± 0.51
1	4.20 ± 0.49
2	4.08 ± 0.38
3	3.98 ± 0.29
4	3.87 ± 0.30
5	3.99 ± 0.46
6	3.97 ± 0.29
Awake	4.26 ± 0.35

Values are averages over 28 subject-nights, ml · min^{-1} · kg, mean ± SD. Analysis of variance (two-way) hours 1–5 ($p = 0.025$). Paired t test showed that only hours 1 and 4 are significantly different ($p = 0.018$).

subsequent t tests showed that parts 1 and 3 ($p = 0.004$) and parts 2 and 3 ($p = 0.003$) are significantly different.

The data demonstrate again that there is a downward trend in $\dot{V}O_2$ as the night progresses. Table 3 shows the percent time (averaged for all subjects) spent in the various sleep stages for each third of the night. The percentages of time spent awake are: 16% (first third of the night), 7% (second third), and 13% (final third). These values seem reasonable because the subjects are awake at the start and end of the study. Stage 1 does not vary much, going from 9% to 7% and to 6% as the night progresses. The stage 2 percentages are 53%, 68%, and 57%. Stage 3 and stage 4 percentages decrease (from 13% to 6% and 4% for stage 3; 7% to 1% and 0.6% for stage 4), whereas REM increases from 3% to 12% and 19%. These trends have important implications for the sleep stage $\dot{V}O_2$ comparisons described below.

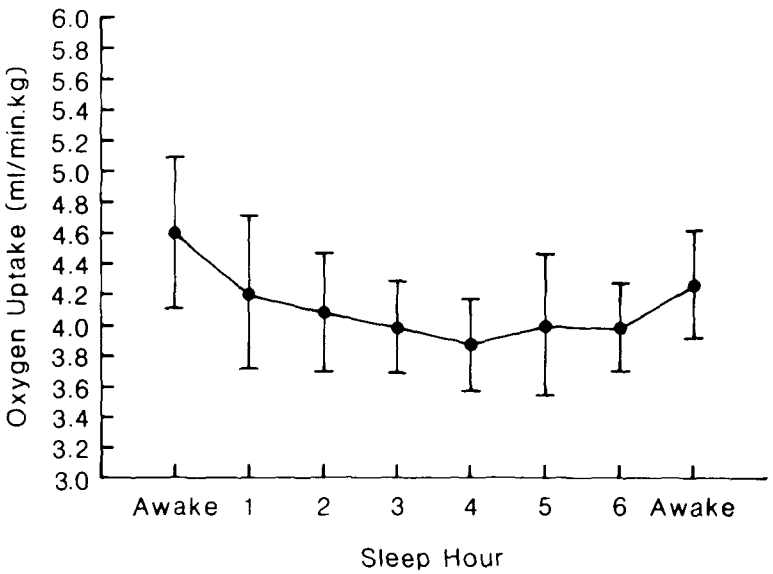

FIG. 2. Plot of Table 2 data: $\dot{V}O_2$ versus time of night.

TABLE 3. *Distribution of sleep stages over each third of the night*

Part of night	Awake	Stage 1	Stage 2	Stage 3	Stage 4	Stage REM
First part	16.3	8.8	52.8	12.6	6.9	2.9
Second part	7.1	6.8	67.9	5.9	1.1	11.6
Third part	13.4	5.5	57.3	3.9	0.6	18.9

Values are percentages of time, averaged over 28 subject-nights.

Results shown in Table 3 suggest that the percent time spent in various stages does not vary enough to account for the change in overall $\dot{V}O_2$ during the night. To demonstrate this, close stage data were weighted by using the percentages in Table 3. Each of the sleep stages was normalized to awake by using close stage comparisons involving awake stage. Only 0.6% of the observed 8% decrease in $\dot{V}O_2$ between the first and third parts of the night, and 0.5% of the 4.4% drop between the first and second parts, could be accounted for by incorporating the effect of stage time distribution. To clarify this further, the night was divided into 10 equal parts and the average $\dot{V}O_2$ value (averaged over 28 nights) was calculated for each of these fractions. The percentage of time spent in individual stages was also calculated for each part of the night.

A multiple regression analysis (on the first nine parts of the night) was performed using $\dot{V}O_2$ as the dependent variable and using time (as a fraction of the night) and percent time in each of the sleep stages as the independent variables. The values obtained for the standard regression coefficients (SRC) and two-tail probabilities (p) are: time [SRC = −1.19, p = 0.09], time% (stage 1) [SRC = 0.24, p = 0.51], time% (stage 2) [SRC = 0.08, p = 0.74], time% (REM) [SRC = 0.29, p = 0.63], time% (stage 3) [SRC = 0.41, p = 0.53], and time% (stage 4) [SRC = −0.45, p = 0.39]. The analysis does not prove conclusively that time of night has a larger effect on $\dot{V}O_2$ than does stage distribution, but it certainly indicates that this is the case.

COMPARISON OF SLEEP STAGES

Two types of sleep stage comparisons were made. The first type involved the comparison of average values from all of the data for each individual. For example, to obtain an average value for stage 2 for a subject, all of the stage 2 data (for that subject), from stage 2 sequences lasting at least 5 uninterrupted min, were averaged. A two-way analysis of variance over stages 0, 1, 2, 3, and REM, using these average values, gave $p < 0.0001$. Stage 4 was left out because two subjects did not have any stage 4. One stage was compared with another using a paired *t* test.

Table 4 shows that awake and 1 are significantly different (at the 1% level) from all other stages. Also, stage REM is significantly different from stage 2 but stages 3 and 4 are not significantly different from each other or from stages REM and 2.

As mentioned above, the percentage of time spent in REM sleep increases as the night progresses from the first third to the final third. Stage 3 and 4 show the opposite trend. This may bias the mean $\dot{V}O_2$ comparison between REM and stage 3 or 4 because stages occurring later in the night will tend to have lower $\dot{V}O_2$ because of the time-dependence described above.

Close stage comparisons were made by taking data from legitimate stages (stages lasting for 5 uninterrupted min) with other legitimate stages occurring within the same sleep hour. In this way, paired data was generated that allowed for *t* test comparison of stages that were close together in time. Table 5 shows the results obtained from all of

TABLE 4. *Comparison of $\dot{V}O_2$ between sleep stages (data taken from complete nights)*

	Awake 4.01 ± 0.37	Stage 1 3.86 ± 0.37	Stage 2 3.66 ± 0.34	Stage 3 3.55 ± 0.37	Stage 4 3.62 ± 0.42	Stage REM 3.58 ± 0.34
Awake 4.01 ± 0.37	—	(n = 8) s	(n = 8) s	(n = 8) s	(n = 6) s	(n = 8) s
Stage 1 3.86 ± 0.37	—	—	(n = 8) s	(n = 8) s	(n = 6) s	(n = 8) s
Stage 2 3.66 ± 0.34	—	—	—	(n = 8) ns	(n = 6) ns	(n = 8) s
Stage 3 3.55 ± 0.37	—	—	—	—	(n = 6) ns	(n = 8) ns
Stage 4 3.62 ± 0.42	—	—	—	—	—	(n = 6) ns

Values are ml · min^{-1} · kg, mean ± SD. A p value <0.01 is considered significant (s). ns, not significant. Two-way analysis of variance over stages Awake, 1, 2, 3, and REM gave $p < 0.0001$.

the close stages that could be identified in the data. Awake stage is again significantly different from all other stages and stage 2 is significantly different from stages 3 and 4. Stage 1 does not show a significant difference from stages 2, 3, and REM. This result is probably due to the fact that stage 1 accounts for only 6.5% of the sleep time and it was difficult to find stage 1 data within the same sleep hour as some of the other stages.

The fact that a significant difference is not observed between REM and stages 2 and 3 indicates again that REM sleep is not characterized by higher $\dot{V}O_2$ than NREM sleep.

INTRAINDIVIDUAL VARIATION OF $\dot{V}O_2$ BETWEEN NIGHTS

For each individual subject, we calculated the variability of measurement of $\dot{V}O_2$ by this method from night to night. An overall mean $\dot{V}O_2$ was obtained for each study night from all data collected on that night. A coefficient of variation over the 3 or 4 nights was then calculated from the mean value and standard deviation. Table 6 shows the coefficient of variation for each individual. This ranges from 0.8% to 10.7%, with the

TABLE 5. *Comparison of $\dot{V}O_2$ between close stages (see text for explanation)*

Number of subjects	Stage	$\dot{V}O_2$	Stage	$\dot{V}O_2$	n	p
6	Awake	4.23 ± 0.59	1	3.96 ± 0.53	10	<0.005
8	Awake	4.19 ± 0.47	2	3.69 ± 0.45	42	<0.00001
5	Awake	4.45 ± 0.55	3	3.65 ± 0.25	6	<0.01
5	Awake	4.67 ± 0.69	4	3.76 ± 0.39	7	<0.005
7	Awake	4.05 ± 0.34	REM	3.46 ± 0.41	15	<0.00002
5	1	3.94 ± 0.44	2	3.83 ± 0.31	13	ns
4	1	4.29 ± 0.24	3	3.90 ± 0.30	5	ns
3	1	3.51 ± 0.48	REM	3.42 ± 0.34	5	ns
8	2	3.70 ± 0.46	3	3.61 ± 0.44	49	0.001
4	2	3.82 ± 0.42	4	3.62 ± 0.38	21	<0.0005
8	2	3.71 ± 0.41	REM	3.68 ± 0.36	60	ns
3	3	3.69 ± 0.37	4	3.66 ± 0.37	8	ns
4	REM	3.62 ± 0.30	3	3.50 ± 0.36	6	ns

Values are ml · min^{-1} · kg, mean ± SD. A p value <0.01 is considered significant. ns, not significant.

TABLE 6. *Mean $\dot{V}O_2$ for each subject for the individual nights and the coefficient of variation*

Subject	First night	Second night	Third night	Fourth night	Mean ± SD	CV
1	4.40	3.82	3.92	3.53	3.92 ± 0.31	0.080
2	4.18	4.27	3.66	3.25	3.84 ± 0.41	0.107
3	3.18	3.77	3.96	3.52	3.61 ± 0.29	0.081
4	3.72	3.60	3.78	3.90	3.75 ± 0.11	0.029
5	3.56	3.36	3.42	—	3.45 ± 0.08	0.024
6	4.58	4.14	4.37	—	4.36 ± 0.18	0.041
7	3.61	4.09	3.17	—	3.62 ± 0.38	0.104
8	3.47	3.40	3.43	—	3.43 ± 0.03	0.008

$\dot{V}O_2$ values are expressed as ml · min^{-1} · kg. CV, coefficient of variation (SD/mean).

average for the group being 5.9%. Stage-specific $\dot{V}O_2$ was also calculated for each night and the coefficient of variation over the several nights was obtained for each subject. The average value for the group is ~6% (awake 5.4%; stage 1 7.0%; stage 2 6.2%; stage 3 6.7%; stage 4 7.0%; stage REM 7.1%). Thus, the determination of $\dot{V}O_2$ appears to be quite reproducible from night to night in this group of subjects.

DISCUSSION

Several studies have been carried out showing that oxygen consumption varies with sleep stage and time of night (4–9,13). In most of these studies [except (7) and (13)], an open-circuit ventilated hood system similar to that described here was used. There is general agreement among these authors that $\dot{V}O_2$ decreases during the first part of the night, reaches a minimum, and starts to rise towards morning. The magnitude of the decline in $\dot{V}O_2$ from awake to the minimum value during sleep was found to be between 13 and 16% (8,13). In the present study, comparing the minimum $\dot{V}O_2$ from the data in Table 2 with the awake value obtained from the first part of the night, there is a 14% decrease. Our study population is similar to that of Brebbia and Altshuler (5) whereas White et al. studied both men and women between the ages of 21 to 77 years (13). Thus, it would appear that the typical change in $\dot{V}O_2$ in healthy adults, from the awake state to the minimum level of metabolism in sleep, is on the order of 13–17%.

White et al. found that the R for the whole group changed from 0.85 (wake) to 0.82 (sleep). This would produce a change, in the $\dot{V}O_2$ correction for R, of 0.7%. We only measured R in the morning but it would appear that changes in R during the night will not significantly affect our group $\dot{V}O_2$ values.

COMPARISON OF SLEEP STAGES

The fact that oxygen uptake varies with time of night complicates comparisons of $\dot{V}O_2$ values for individual sleep stages. It has been recognized by several authors (7,8,14) that comparisons of sleep stage $\dot{V}O_2$ using data averaged over complete nights are suspect because changes in $\dot{V}O_2$ with time of night are not considered. This can be clearly seen in Table 3 where the percentage of sleep time spent in REM is increasing as the night progresses. Because $\dot{V}O_2$ values tend to be lower in the second and last third of the night as compared with the first, this creates the impression that stage REM $\dot{V}O_2$ values are lower, as compared with other stages, than may actually be the case. A better comparison would be between sleep stages that are close to each other in time

(4). As mentioned above, when close stage comparisons are made, REM sleep yields the lowest mean value of all the stages but the differences between REM and stages 2 and 3 are not statistically significant (Table 5). The data in Table 5 also demonstrates that stage 2 $\dot{V}O_2$ is significantly higher than that for stages 3 or 4. One cannot state conclusively that REM sleep is characterized by higher or lower $\dot{V}O_2$ than stages 2 or 3, but it is very unlikely that REM sleep exhibits higher O_2 consumption than NREM sleep.

TIME DEPENDENCE OF $\dot{V}O_2$

The decrease in $\dot{V}O_2$ from the first to fourth hour (minimum value) is 7.9% (Table 2). This decrease compares favorably with that found by Kreider et al. (2), who observed a 7% decrease in $\dot{V}O_2$ between the first hour and the fifth.

The drop in $\dot{V}O_2$ from the early sleep hours to the middle portion of the night could be caused by a change in the time distribution of sleep stages. The subject might spend a larger fraction of time in sleep stages with lower $\dot{V}O_2$ in the middle of the night than earlier on. Another possibility is that the O_2 consumption decreases for all sleep stages as the night progresses towards the a.m. hours and the time distribution of sleep stages is not significantly changed. Our results are in agreement with Webb and Hiestand (7), who concluded that the reduction in $\dot{V}O_2$ during the night is mainly caused by decreasing $\dot{V}O_2$ in individual sleep stages and is not due to changes in the time distribution of these stages.

VARIATION IN $\dot{V}O_2$ BETWEEN NIGHTS

Despite all the above reservations and other possible influences of dietary, exercise, and activity changes over the several study days, it is perhaps remarkable to find that the $\dot{V}O_2$ measurement for this group is reproducible from night to night. Studies of basal metabolic rate using data from one night may be acceptable as being representative of the usual metabolic rate. However, for any one individual, the range of variation is large enough that repeated studies would be preferable.

CONCLUSION

Results from the present study indicate that comparisons of $\dot{V}O_2$ values between sleep stages have to be done with care. The fact that $\dot{V}O_2$ is time dependent during sleep introduces a complicating factor that makes suspect any stage comparisons using pooled overnight data.

The variation of $\dot{V}O_2$ with sleep time was examined in detail. Others have speculated that the decrease in $\dot{V}O_2$, from the start of the night to the middle, is caused by lower $\dot{V}O_2$ in sleep stages occurring in the middle period than in stages occurring earlier. Our analysis indicates that this is indeed the case and that changes in the time distribution of the sleep stages plays a minor role. In summary, we conclude that $\dot{V}O_2$ is dependent on the stage of sleep but is also dependent on when that stage occurs during the night.

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