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Effects of exercise modality on patterns of ventilation and respiratory timing

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Abstract. Ventilatory patterns and respiratory timing were measured in 14 subjects during cycling (CYC) and treadmill exercise (TM) at similar leg frequencies (f_{LEG}) to determine if mode of exercise affects patterns of ventilation and respiratory timing. Measurements of breathing frequency (f_R), tidal volume (VT), expired ventilation (\dot{V}_E), and inspiratory (Ti) and expiratory (TE) time were obtained at f_{LEG} of 50, 70, and 90 rev·min⁻¹ (rpm) for CYC and at similar incremental f_{LEG} (strides·min⁻¹; spm) during TM achieved by increasing belt speed at 0° grade. CYC exercise intensity was ~50% $\dot{V}_{O_2,max}$ at all f_{LEG} , whereas \dot{V}_{O_2} increased progressively with TM. f_R increased significantly ($P < 0.001$) with increasing f_{LEG} of TM (20.5 ± 4.6 , 25.4 ± 5.8 , and 36.3 ± 7.6 breaths·min⁻¹; $\bar{x} \pm SD$), but during CYC f_R changed significantly ($P < 0.05$) only between f_{LEG} of 70 and 90 rpm (25.0 ± 5.9 vs 28.5 ± 6.9 breaths·min⁻¹). Both average breath Ti and TE obtained by grouping into incremental ranges of f_R decreased significantly ($P < 0.05$) with increasing f_R up to 36 breaths·min⁻¹ and the relationships of Ti and TE to f_R , Ti to TE, and central inspiratory drive (VT/Ti) to \dot{V}_E were the same for CYC and TM. Group average f_R and f_{LEG} were synchronized during TM, but individual subjects did not exhibit a high degree of entrainment. This study shows respiratory timing patterns to be independent of mode of exercise over the range of f_R observed when describing patterns by grouping into incremental ranges of f_R .

Control of breathing, pattern, exercise; Exercise, mode, pattern of breathing; Mammals, humans; Pattern of breathing, exercise modes

Breathing patterns and respiratory timing variables have been investigated during various types of exercise in both animals and humans to determine whether neurogenic influences, originating in the exercising limbs, contribute to exercise hyperpnea. Several investigators have observed synchronization of breathing frequency to leg frequency during rhythmic exercise, suggesting that the ventilatory response to exercise can be accounted for by limb reflexes (Bannister *et al.*, 1954; Hey *et al.*, 1966; Asmusen, 1973; Bechbache and Duffin, 1977; Jasinskas *et al.*, 1980; Bramble, 1983; Bramble and Carrier, 1983). Others have concluded that afferent input from muscle receptors is not a component of exercise ventilation (Sipple and Gilbert, 1966; Kelman and Watson, 1973; Kay *et al.*, 1975a; Clark *et al.*, 1983).

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Measurements of tidal volume and durations of the inspiratory and expiratory phases of the ventilatory cycle correspond to variables that can be used to characterize the neural regulation of respiration. Specifically, the ratios of tidal volume to inspiratory time and of inspiratory time to total breath duration serve as indices of central inspiratory drive and respiratory timing, respectively (Milic-Emili and Grunstein, 1976). Evidence of whether these variables are affected by different modes of exercise is limited (Kay *et al.*, 1975b; Clark *et al.*, 1983). Furthermore, in order to determine if differences in breathing patterns occur between exercise modes, ventilatory patterns should be measured under the same conditions (*i.e.* environment, leg frequency) for each mode. However, these considerations have often been overlooked.

Therefore, the present study was undertaken to determine (1) the effects of three progressively increasing leg frequencies on ventilatory patterns and respiratory timing; and (2) the effects of two modes of exercise, cycle ergometry and treadmill exercise, on these variables.

Methods

Fourteen healthy male subjects (age 28.4 ± 7.1 years; $\bar{x} \pm SD$) volunteered for this study. The study was approved by the U.S. Army Research Institute of Environmental Medicine in accordance with Army Regulation 70-25 for the use of human volunteers. After informed consent was obtained, subjects completed a health and physical activity questionnaire and measurements of height and body weight were taken. One day before testing each subject performed a maximal oxygen consumption ($\dot{V}_{O_{2,max}}$) test on a cycle ergometer. Briefly, subjects pedaled continuously at $60 \text{ rev} \cdot \text{min}^{-1}$ (rpm) while workload was increased 50 Watts every 3 min until exhaustion or until pedal frequency could not be maintained. Following a 5-min rest period, subjects exercised again starting at a workload 50 Watts lower than the highest workload that they had obtained. After 3 min, intensity was increased by 50 Watts and subjects continued to exercise to exhaustion. It was determined that $\dot{V}_{O_{2,max}}$ had been obtained if oxygen consumption (\dot{V}_{O_2}) during this second maximal exercise bout did not exceed peak values from the first exhaustive test. $\dot{V}_{O_{2,max}}$ values were used for determination of relative oxygen consumption during subsequent testing. Subjects had relatively wide ranges of body weights (57.97–110.52 kg) and physical fitness levels ($\dot{V}_{O_{2,max}}$: 38.77–61.60 $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$).

This investigation involved 4 separate days of testing. Subjects randomly performed one exercise session on a cycle ergometer (Collins Pedalmate) and a treadmill on either of the first 2 testing days. During cycle ergometry, subjects exercised continuously at an estimated intensity of 50% $\dot{V}_{O_{2,max}}$ at leg frequencies (f_{LEG}) of 50, 70, and 90 rpm for 15 min each. Subjects maintained leg frequencies by watching a speedometer and were individually monitored by technical personnel to assure sustainment of the respective frequency. Also, f_{LEG} were measured in conjunction with sequential breath measurements during the last 5 min of exercise at each frequency interval by counting the number of pedal revolutions for a given amount of time.

During treadmill trials, subjects walked, or jogged, at zero percent grade at three treadmill speeds adjusted to elicit f_{LEG} of 50, 70, and 90 strides \cdot min⁻¹ (spm), similar to the frequencies of cycling. Leg frequencies were measured as during cycling but by counting the number of strides for a given amount of time. For both modes of exercise subjects were unaware that these measurements were being taken. Each f_{LEG} involved 15 min of total exercise. Six days later subjects repeated both the cycling and treadmill regimens on 2 separate days. Speeds selected on each subject's initial treadmill exercise session were duplicated for the final bout of treadmill exercise.

Heart rate (HR), f_{LEG} , breathing patterns, and expired gases were monitored using the same procedures for both cycling and treadmill trials. Heart rate was monitored continuously from 3-channel ECG leads using a Hewlett-Packard telemetry system. A semi-automated system consisting of a Hewlett-Packard 85B computer and digital voltmeter interfaced with a gas meter (Parkinson-Cowan), oxygen analyzer (Applied Electrochemistry S3A), and carbon dioxide analyzer (Beckman LB2) was used to collect and analyze expired gases from the expiratory side of a Collins J-valve. Expired gases were collected on-line during the last 5 min of exercise at each f_{LEG} . Sustained levels of \dot{V}_{O_2} for 4–5 min signified that a steady-state of exercise had been obtained.

Patterns of ventilation and respiratory timing were measured concurrently with expired gases. A pneumotachometer (Hans Rudolph), connected to a pressure transducer (Validyne MP45), carrier demodulator (Validyne CD15), and a polygraph (Western Graphtech), was affixed to the inspiratory side of a Collins J-valve to measure inspiratory air flow. After subjects inserted the mouthpiece connected to the Collins J-valve into their mouth, a noseclip was put in place and recordings of ventilatory flow were monitored on the polygraph. Once the subject felt comfortable with the mouthpiece and breathing apparatus, based on steady polygraph readings and visual observation, measurements of expired gases and breathing patterns began. Measurements of breathing frequency (f_R), tidal volume (V_T), expired ventilation (\dot{V}_E), and inspiratory (TI) and expiratory (TE) time were obtained on 3 separate occasions during the last 5 min of each f_{LEG} interval. Measurements were averaged for each incremental leg frequency. Average ratios of pedaling or stepping frequencies to breathing frequency were calculated to test for synchronization of breathing frequency to leg frequency.

Breath-by-breath analyses of respiratory timing were taken from the 3 data collection periods during the last 5 min of exercise for each f_{LEG} . Up to ten sequential breaths (maximum of 30 breaths from each steady-state) were analyzed for TI, TE, and total breath duration (TTOT). Instantaneous breath frequency (f_R) ($60/TTOT$) and respiratory timing (TI and TE) were calculated. For analysis, individual breath data for each mode of exercise were grouped into incremental ranges of breath frequency (3 breaths \cdot min⁻¹ intervals).

With a Complete Statistical System (CSS) software package (StatSoft 1987), data were analyzed within and between exercise modes using ANOVA and Scheffe's *post-hoc* analyses. The null hypothesis was rejected at the $P < 0.05$ level. All values represent mean \pm SD.

Results

No differences existed between each cycling and each treadmill trial. Therefore, data from both cycling trials were pooled and analyzed as one data set vs the pooled treadmill data.

Exercise intensity

Expressed as percent $\dot{V}_{O_{2,max}}$, the average intensity of exercise during cycling was not significantly different at the three different pedal frequencies (Table 1). For treadmill exercise, subjects utilized a significantly ($P < 0.001$) greater percentage of $\dot{V}_{O_{2,max}}$ with each increase in stride frequency. The \dot{V}_{O_2} during cycling was significantly ($P < 0.05$) different from treadmill exercise at all leg frequencies. Heart rate responses differed significantly ($P < 0.001$) between modes at the lowest and highest f_{LEG} , and increased significantly ($P < 0.001$) with progressively increasing f_{LEG} during treadmill exercise (Table 1).

Ventilatory and respiratory timing patterns

Average values of f_R , V_T , \dot{V}_E , and T_I and T_E at each f_{LEG} are presented in Table 2. No significant changes in V_T or \dot{V}_E occurred with increasing f_{LEG} during cycling. Treadmill exercise elicited a significant ($P < 0.001$) increase in V_T when stride frequency increased from 70 to 90 spm, and \dot{V}_E increased significantly ($P < 0.005$) with each f_{LEG} increase.

For both modes, as f_{LEG} increased, f_R increased progressively. With incremental f_{LEG} , elevations in f_R during cycling were less than the corresponding increases during treadmill exercise. Increases in f_R at each incremental f_{LEG} were significant ($P < 0.001$) during treadmill exercise, but during cycling increases in f_R were significant ($P < 0.05$) only when subjects progressed from 70 to 90 rpm. At the highest f_{LEG} , f_R was significantly ($P < 0.001$) greater for treadmill vs cycling exercise. As f_R increased with

TABLE 1
Average exercise intensity and heart rate responses

Measure	Cycling (rpm)			Treadmill (spm)		
	50	70	90	50	70	90
% $\dot{V}_{O_{2,max}}$	46.4 (10.6)	47.1 (13.1)	53.3 (14.5)	20.7 ^a (7.2)	35.8 ^{a,b} (12.8)	68.0 ^{a,b} (11.7)
HR	114.7 (17.0)	118.4 (17.6)	123.1 (22.5)	86.8 ^a (11.7)	112.6 ^b (26.7)	156.7 ^{a,b} (18.0)

Values are means (\pm SD) of measures taken at each leg frequency interval ($n = 28$). % $\dot{V}_{O_{2,max}}$ = percent of maximal oxygen consumption; HR = heart rate ($\text{beats} \cdot \text{min}^{-1}$).

^a Significant difference between modes of exercise.

^b Significant difference between sequential leg frequency intervals.

TABLE 2
Average ventilatory and respiratory timing patterns

Measure	Cycling (rpm)			Treadmill (spm)		
	50	70	90	50	70	90
V _T	1.67 (0.49)	1.64 (0.41)	1.72 (0.39)	0.95 ^a (0.35)	1.18 ^a (0.41)	1.83 ^b (0.46)
\dot{V}_E	37.9 (7.9)	39.5 (7.6)	44.6 (9.5)	18.4 ^a (5.3)	28.7 ^{a,b} (9.6)	63.7 ^{a,b} (16.8)
f _R	23.2 (5.6)	25.0 (5.9)	28.5 ^b (6.9)	20.5 (4.6)	25.4 ^b (5.8)	36.3 ^{a,b} (7.6)
T _I	1.17 (0.36)	1.11 (0.32)	1.07 (0.40)	1.25 (0.47)	1.07 ^b (0.32)	0.82 ^{a,b} (0.21)
T _E	1.57 (0.48)	1.44 (0.34)	1.33 (0.37)	1.99 ^a (0.52)	1.50 ^b (0.40)	0.95 ^{a,b} (0.32)

Values are means (\pm SD) of measures taken at each leg frequency interval ($n = 28$). V_T = tidal volume (L); \dot{V}_E = expired ventilation (L·min⁻¹); f_R = breathing frequency (breaths·min⁻¹); T_I = inspiratory time (sec); T_E = expiratory time (sec).

^a Significant difference between modes of exercise.

^b Significant difference between sequential leg frequency intervals.

progressively increasing leg frequencies during treadmill exercise, both average breath T_I and T_E decreased significantly ($P < 0.05$). Average breath T_I and T_E decreased with increasing f_{LEG} during cycling, but changes were not significant. In addition, average breath T_E was greater than T_I at all three leg frequencies. This relationship was not different between modes of exercise.

Average group values of the breath-by-breath relationship of T_I and T_E to f_R obtained by binning into incremental ranges for both modes of exercise can be seen in Fig. 1. For the 14 subjects a total of 3744 breaths, 1538 during cycling and 2206 during treadmill exercise, were measured. The relationships of T_I and T_E to f_R were similar between modes of exercise. Average T_I and T_E decreased significantly ($P < 0.05$) with increasing f_R up to approximately 36 breaths·min⁻¹ and the absolute change in T_E was greater than that for T_I. At f_R greater than 36 breaths·min⁻¹ average T_I did not change significantly, whereas T_E continued to decrease significantly. Only between f_R of 36–39 breaths·min⁻¹ during cycling was the change in T_E not significant. Average duration of T_I was significantly ($P < 0.05$) less than T_E at all f_R below 39 breaths·min⁻¹.

The relationships of T_I and T_E to f_R were quantitatively similar between cycling and treadmill modes of exercise at f_R above 12 breaths·min⁻¹. However, at the single f_R bin below 12 breaths·min⁻¹ average T_E during treadmill exercise was significantly greater compared to cycling.

Average durations of T_E vs T_I obtained from the same binned incremental f_R are plotted in Fig. 2 against isolines of the proportion of total breath duration spent in inspiration (T_I/T_{TOT}) for both modes of exercise. As breath T_I and T_E decreased with

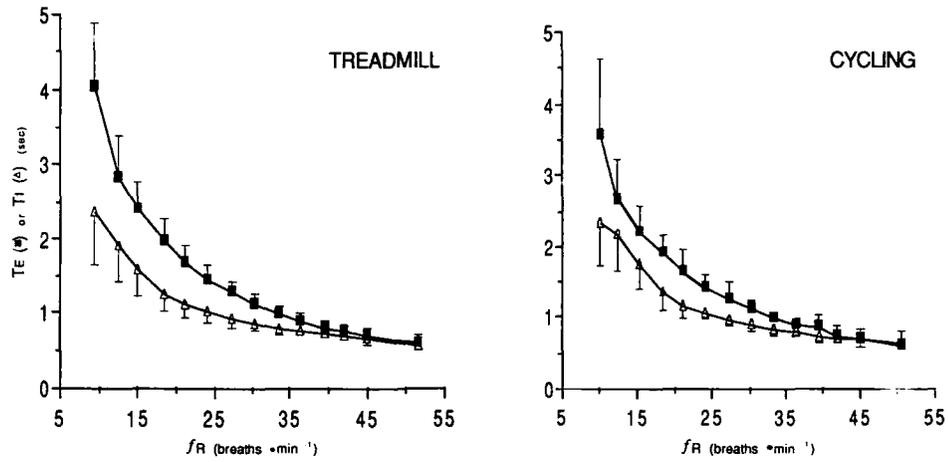


Fig. 1. Relationship of average T_l (Δ) and T_E (\blacksquare) binned by sequential ranges of f_R for both modes of exercise. Data represent mean \pm SD for the subject group. Number of breaths analyzed for treadmill exercise was 2206 ($n = 15, 50, 104, 150, 193, 242, 234, 221, 166, 130, 251, 204, 138,$ and 108 for bins 1–14, respectively). 1538 breaths were analyzed for cycling ($n = 12, 27, 110, 110, 231, 276, 271, 185, 134, 89, 37, 33, 19,$ and 4 for bins 1–14).

increasing f_R , T_l/T_{TOT} was reduced and the ratio approached 0.50. This relationship was the same for both modes of exercise.

Respiratory drive

Central inspiratory drive (\dot{V}_T/T_l), an index of inspiratory motor input, was plotted against \dot{V}_E in Fig. 3 for both modes of exercise. During both cycling ($r = 0.97$; $P < 0.001$)

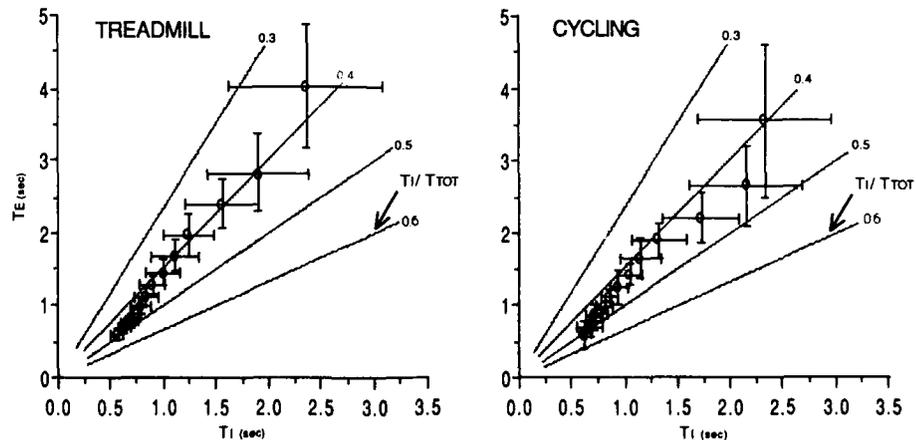


Fig. 2. Average values \pm SD of T_E versus T_l obtained from the same sequential ranges of f_R for both exercise modes. The proportion of time spent in inspiration during the total breath cycle is represented by the superimposed isolines of T_i/T_{TOT} .

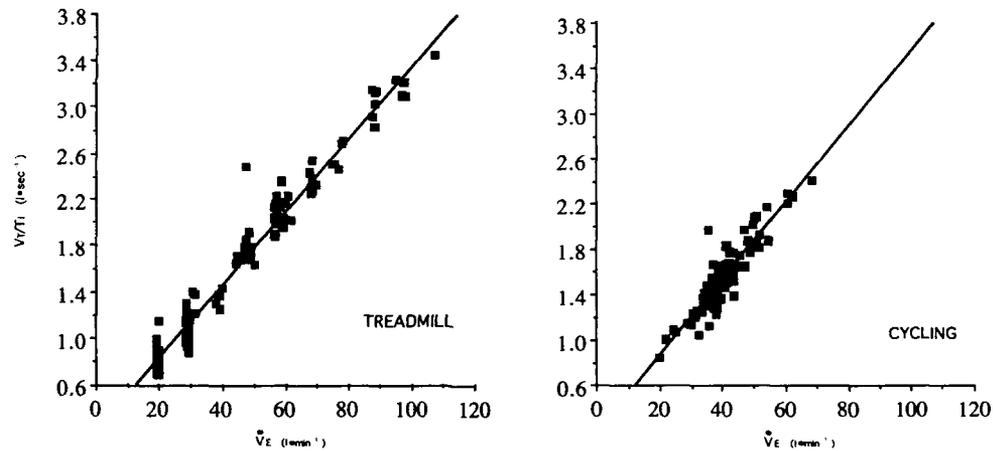


Fig. 3. Central inspiratory drive (V_T/T_i) plotted against \dot{V}_E for both modes of exercise. Data represent average values of V_T/T_i and \dot{V}_E obtained during each of the 3 leg frequency intervals.

and treadmill exercise ($r = 0.98$; $P < 0.001$) central inspiratory drive was positively correlated to \dot{V}_E , and no differences were found between exercise modes.

Influence of limb movement on breathing frequency

To evaluate the possibility of synchronization of f_R to leg frequency (f_{LEG}), or entrainment, calculations of the ratio of f_{LEG} to f_R (f_{LEG}/f_R) were made. Ratios of f_{LEG}/f_R were identical for the subject group at each leg frequency (2.6 ± 0.8 , 2.7 ± 0.6 , and 2.6 ± 0.7) during treadmill exercise. Average group ratios of f_{LEG}/f_R increased significantly ($P < 0.001$) for the group with increasing leg frequencies during cycling (2.3 ± 0.7 , 2.9 ± 0.6 , and 3.4 ± 0.9).

Discussion

Ventilatory patterns and respiratory timing and drive

Changes in f_R have generally been attributed to changes in T_E rather than T_i , in both resting animals and humans (Newsom-Davis and Stagg, 1975; Sullivan *et al.*, 1978). Kay *et al.* (1975b) and Clark *et al.* (1983) also reported this relationship during exercise in man. However, Iscoe *et al.* (1983) and Jennings and Szlyk (1985) reported that both T_i and T_E change as f_R spontaneously changes for dogs and cats, respectively, while breathing room air. Rather than using consecutive breaths with varying f_R to average timing, these latter investigators grouped T_i and T_E by individual breath f_R . This unique approach enabled comparisons of T_i and T_E at a given f_R in response to a stimulus with timing at the same f_R under control conditions. By averaging timing from consecutive breaths with variable f_R , previous investigators masked not only the differences in timing related to f_R but also the considerable amount of variability found

in breathing patterns (Kay *et al.*, 1975b; Newsom-Davis and Stagg, 1975; Sullivan *et al.*, 1978; Clark *et al.*, 1983). Kay *et al.* (1975b) further restricted interpretation of their data by eliminating any breath if V_T was greater than one and a half times the mean or if T_I was two times greater than the mean, and by eliminating the two breaths immediately following any mis-recorded breath. Clark *et al.* (1983) averaged timing patterns for each minute of an exercise session rather than for f_R , thus failing to actually compare timing at a given breath f_R .

In our data analysis we employed the technique of grouping T_I and T_E by individual f_R and found that the relationship of respiratory timing and f_R during submaximal exercise in man was qualitatively similar to that of resting, awake cats and dogs (Iscoe *et al.*, 1983; Jennings and Szlyk, 1985). As f_R increased up to approximately 36 breaths·min⁻¹, both T_I and T_E decreased significantly (Fig. 1). Above this f_R , average T_I was relatively fixed, whereas T_E continued to decrease significantly. Average T_I was less than T_E at f_R below 39 breaths·min⁻¹, but as f_R increased above this frequency the durations of T_I and T_E became equal. This relationship of T_I and T_E to f_R was similar for both treadmill exercise and cycling, and for a given f_R there was a predictable T_I and T_E .

At a given f_R above 12 breaths·min⁻¹, the T_I and T_E for treadmill exercise were indistinguishable from the T_I and T_E for cycling (Fig. 1). Significantly longer average T_E was observed at f_R less than 12 breaths·min⁻¹ during treadmill compared to cycling exercise. This difference resulted from the greater variability of T_E measured at the lowest f_R interval during cycling (3.55 ± 1.06 sec; $n = 12$) compared to treadmill exercise (4.02 ± 0.85 sec; $n = 15$). Sequential breath measurements also showed a large degree of variability in T_I and T_E below f_R of 18 breaths·min⁻¹. As breath f_R increased above 18 breaths·min⁻¹, respiratory timing decreased and varied less at a given f_R .

It has been reported that during maximal exercise average T_E becomes slightly less than T_I at an average f_R of 62 breaths·min⁻¹ (Clark *et al.*, 1983). In the present study, with the greater decrease in T_E than T_I with increasing f_R , the amount of time spent in inspiration ($T_I/TTOT$) increased from approximately 0.40 to 0.50 for both exercise modes. At the highest recorded f_R during cycling and treadmill exercise, average durations of T_I essentially equalled those of T_E . However, during cycling the duration of T_I was longer (not significantly) than T_E , and a slight 'cross-over' of T_E and T_I was observed at a f_R of approximately 45–50 breaths·min⁻¹. Our inability to see a sustained 'cross-over' of T_E and T_I during exercise probably is due to the lower f_R of our subjects compared to those reported during maximal exercise. Numerous reports suggest that central hypothalamic mechanisms probably regulate breathing when $T_I/TTOT$ exceeds 0.50 (Jennings and Szlyk, 1985; Szlyk and Jennings, 1987).

When respiratory timing data was analyzed by averaging timing from sequential breaths of different frequencies we found that average duration of T_E was longer than T_I at each of the three leg frequency intervals (Table 2). This was true for both modes of exercise. However, this analysis suggests that changes in T_I and T_E did not contribute significantly to increasing f_R during cycling. In contrast, grouping T_I and T_E by individual f_R showed that both T_I and T_E decreased significantly with increasing

f_R during cycling. This analysis supports the concept that averaging timing from sequential breaths obscures the differences of timing related to individual f_R . Furthermore, averaging sequential f_R at each f_{LEG} also obscured measures of individual f_R . Averaging timing from sequential breaths showed that T_I and T_E between exercise modes were significantly shorter during treadmill exercise at the highest leg frequency. The higher f_R exhibited at this leg frequency level during treadmill exercise would account for these observed differences. This greater f_R , in turn, probably resulted from the greater oxygen consumption observed between treadmill vs cycling modes at the highest leg frequencies.

Clark *et al.* (1983) reported two linear relationships of T_E to T_I , one during walking and the second while running. One relationship had a shallow slope that included all values of respiratory timing obtained during exercise and T_I/T_{TOT} was approximately 0.50. The second, obtained during walking and when at rest, displayed a steeper slope, and T_E was longer than T_I . We did not observe two distinct linear relationships when comparing breath-by-breath durations of T_E and T_I during either cycling or treadmill exercise at the three different leg frequencies. However, no rest or recovery data were included in our analysis.

As shown in Fig. 3, mean inspiratory flow rate (V_T/T_I) increased linearly as \dot{V}_E increased during cycling and treadmill exercise. Thus, V_T/T_I appeared to be an index of central inspiratory drive as previously reported (Milic-Emili and Grunstein, 1976). Also, Milic-Emili and Grunstein (1976) and Clark *et al.* (1983) have stated that the relationship of V_T/T_I to \dot{V}_E will be linear as long as T_I/T_{TOT} remains constant. In our experiments T_I/T_{TOT} varied from approximately 0.40 to 0.53 during cycling and from 0.38 to 0.53 during treadmill exercise as \dot{V}_E increased. This finding indicates that central inspiratory drive is linearly related to \dot{V}_E independent of respiratory timing or modes of exercise. Similar results have been observed for air and CO_2 inhalation in cats (Jennings and Szlyk, 1985; Szlyk and Jennings, 1987).

The relationships of T_E and T_I (Fig. 2) and V_T/T_I and \dot{V}_E (Fig. 3) were indistinguishable between cycling and treadmill exercise. The drive for ventilation, therefore, was the same for the three leg frequency levels during both modes of exercise. This observation indicates that these relationships are not influenced by exercise mode.

Entrainment

The possibility of entrainment, or synchronization of breathing frequency to exercise rhythm, has long been recognized, but has been difficult to detect (Bannister *et al.*, 1954; Hey *et al.*, 1966; Kay *et al.*, 1975a; Bechbache and Duffin, 1977; Jasinskas *et al.*, 1980; Bramble and Carrier, 1983; Clark *et al.*, 1983). The results of the present study showed average ratios of f_{LEG}/f_R to be constant with progressive increases in leg frequency during treadmill exercise, but not during cycling. However, based on average f_{LEG}/f_R ratios for each individual subject, only 64% of the subjects had constant ratios at all leg frequencies during treadmill exercise.

It has been suggested that exercise intensity may influence entrainment (Bechbache and Duffin, 1977; Jasinskas *et al.*, 1980; McMurray and Ahlborn, 1982). In the present

study, no entrainment was observed when exercise intensity remained unchanged while cycling. During treadmill exercise, intensity increased significantly with increasing f_{LEG} and 64% of the subjects appeared to entrain f_R to f_{LEG} . These findings tend to support that metabolic rate may determine the degree of subject entrainment. Also, since timing patterns of ventilation and central inspiratory drive did not differ between exercise modes, the relationship of respiratory timing to f_R appeared not to be influenced by entrainment. However, since our subject population did not exhibit a high degree of entrainment, no definite conclusions could be made about the effects of exercise intensity on entrainment, or the influence of entrainment on timing patterns and inspiratory drive.

Thus, the quantitative description of the variability of ventilation on a breath-by-breath basis in this study shows that decreases in the duration of both expiratory and inspiratory time contribute significantly to increases in breathing frequency. Also, the relationship of timing patterns to breathing frequency is independent of mode of exercise, and intensity, over the range of leg and breathing frequencies observed. Qualitatively, our data indicate that the relationship between breath timing and breathing frequency in man is similar to that of cats and dogs. Establishment of this fundamental relationship between species may allow for stronger comparisons between species when evaluating the effects of various stimuli on respiratory timing.

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Disclaimer. The views, opinions, and/or findings contained in this report are those of the authors and should not be construed as official Department of the Army position, policy, or decision, unless so designated by other official documentation. Human subjects participated in this investigation after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.

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