International Journal of
EXERCISE SCIENCE

Original Research

How Different Respiratory Rate Patterns affect Cardiorespiratory Variables and Performance

MINAS NALBANDIAN†1, ZSOLT RADAK‡2, JUN TANIGUCHI*3, TAKEDA MASAKI‡2,3

[1]Graduate School of Sports and Health Science, Doshisha University, Kyotanabe, Kyoto, JAPAN; [2]University of Physical Education, Budapest, HUNGARY; [3]Faculty of Sports and Health Science, Doshisha University, Kyotanabe, Kyoto, JAPAN

*Denotes undergraduate, †Denotes graduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 10(3): 322-329, 2017. This study aims to elucidate how respiratory rate (RR) patterns may affect respiratory gas exchange variables and performance during incremental intensity- exercise. 10 healthy young men (mean ± SD, age: 20.7 ± 0.5 years, height: 174.3 ± 5.7 cm, and body mass: 72.6 ± 10.4 kg) performed three incremental tests on a cycle ergometer at three different RR (60, 45 and 30 breaths per min) in each trial. During the tests, tidal volume (TV), minute ventilation (VE), fractional content of oxygen (FeO_2), fractional content of carbon dioxide ($FeCO_2$), oxygen uptake (VO_2), expiratory carbon dioxide (VCO_2), equivalent of oxygen (EqO_2), VE/VCO_2, and respiratory exchange ratio (RER) were determinate breath-by-breath. Additionally, exercise time (as a performance marker) was measured. Statistical analyses for the results were carried out to determine significant differences between the three trials. VCO_2, VO_2, and exercise time did not show statistical differences in the three trials. Therefore, we concluded that RR affects some respiratory gas exchange variables but does not influence the VO2max and endurance performance.

KEY WORDS: VO_2max, respiration, performance limiting factors, incremental-intensity test

INTRODUCTION

A great amount of research has been accrued on endurance performance in humans, and one of the main research focuses for sports physiologists has been the potential limiting factors for endurance performance. Physiological determinants of endurance performance are mostly reflected in the maximum oxygen uptake capacity (VO_2max) (2, 6, 9). It has been reported that higher levels of VO_2max are correlated with endurance performance (1, 2, 12). VO_2max is limited by four possible mechanisms: cardiac output, the cardiovascular system oxygen transport capacity, muscle cell oxygen perfusion and usage capacity, and pulmonary diffusing capacity. From these limiting factors, it is important to notice that the primary limiters are the muscle perfusion capacity and cardiac output (2, 24).

Cardiac output is determined by the heart rate and the systolic volume (2). Comparing trained people with sedentary people of the same age maximum heath rate does not vary significantly, thus differences in cardiac output between trained and sedentary people comes from the systolic volume. Systolic volume increases with endurance training (5, 20).

The oxygen transport capacity of the cardiovascular system is mainly determined by the blood hemoglobin content (13), and can be improved (e.g., by high altitude training (3 ,21) and nutritional treatments (11)).

The cell oxidative capacity is determined by the mitochondrial contents of the cell (organelle in charge of the cell respiration). Mitochondrial activity is also related to the cell oxygen uptake capacity: high rates of mitochondrial activity will induce depletion in the sarcolemma oxygen pressure, producing a difference in oxygen pressure between the sarcolemma and the red blood cell (25), which will facilitate oxygen uptake (9).

Additionally, oxygen uptake by the organism has been studied by modifying the concentration of inspired oxygen: hyperoxia (i.e., high concentration) and hypoxia (i.e., low concentration). The working capacity with hyperoxia showed increases in endurance performance while breathing compressed air with high oxygen concentrations (19). One study showed a 12% increase in VO_2max when breathing compressed air in women, but not in men (14). Furthermore, trained athletes who exhibit exercise-induced hypoxemia increased their VO_2max in hyperoxic conditions, but the same did not occur with trained subjects who did not exhibit exercise-induced hypoxemia (15). In agreement with this, hypoxia showed a remarkable decrease in endurance performance and VO_2max in athletes (18). Thus, it is well recognized that the oxygen concentration of the inspired air influences oxygen uptake during exercise, and that pulmonary gas exchange may contribute significantly to the limitation of VO_2max (15).

Furthermore, it has been reported that modifying breathing patterns may have an influence on physiological variables. For instance, breathing at a rate of 5 breaths per minute (bpm) with equal inhalation to exhalation ratio increases heart variability (10). What is more, the effects of respiratory rate (RR) on VO_2 during exercise at submaximal intensities has been studied (4, 7, 16, 22). It was shown that with spontaneous breathing, the coordination between breathing and cycle pedaling is increased in an intensity-dependent manner (16). Additionally, it has been reported that with moderate intensities when breathing is synchronized with pedal frequency, the VO_2 is lower (4, 22). Also, when compared with spontaneous breathing with a fixed RR of 30 bpm (uncoupled with pedaling) there were no differences found in VO_2 at submaximal intensities (7). However, it still remains unknown how different RR patterns (coordinated with cycling pedaling) could affect oxygen uptake and performance at VO_2max intensity. It may be beneficial for athletes to be aware of the aforementioned, and to consider the effective RR during training.

We hypothesize that different RR will affect the respiratory gas exchange variables, and this may lead to changes in oxygen consumption, and ultimately performance. Therefore, for the current study, we decided to examine the effects different RR (while performing incremental intensity tests in cycle ergometer) in respiratory gas exchange variables, VO_2max, and performance.

METHODS

Subjects

Ten healthy moderately trained men participated in this study as volunteers (table 1). All subjects were college students and members of a sport club (rugby, basketball or handball). Subjects were previously informed of the experiments and associated risks of this study and signed informed consent was obtained. It was also made clear that if for whatever reason they wanted to discontinue the experiments they were free to do it without any moral or economic consequences. All the experiments designed in this study, as well as the informed consent document were approved by the Local Research Ethics committee (Doshisha University ethical committee approval number: 15091) in strict accordance with the standards set by the Declaration of Helsinki.

Table 1. Subjects characteristics.

	Value	SD
Age (years)	20.7	0.5
Weight (kg)	72.6	10.4
Height (cm)	174	5.7
Gender	Male	

SD, standard deviation.

Protocol

The experiments consisted of a repeated measures design study where the subjects were asked to come four times to the laboratory, with a minimum of two days of recovery between each session. The tests were completed within 14 days. In the first visit, the subjects were informed about the experiments, personal information was obtained and an incremental intensity test was performed for familiarization. For the last three visits the subjects performed an incremental intensity test on a cycle ergometer, each time with different respiratory rate.

Three incremental tests with different RR were randomly performed by each subject. The tests were all completed on a Monark cycle ergometer (model 874E, Monark, Inc., Stockholm, Sweden). During last moments of the tests, the subjects were verbally encouraged by two researchers to attain maximum performance during exercise.

For the tests, the initial power was set at 50 watts and it was increased 50 watts every two min by incrementing the ergometer workload (8). Subjects were asked to synchronize pedaling with a metronome in order to maintain pedal frequency at 60 revolutions per min through the tests. The metronome was set at 120 tics per min, so every 2 tics one revolution was performed. The three RR patterns were: 60 breaths per min (one inhalation per tic and one exhalation per tic); 45 breaths per min (one inhalation for two tics and one exhalation for one tic) and 30 breaths per min (one inhalation for two tics and one exhalation for two tics). In order to make it easier for the experimental subjects to perform the experiments the respiration and the pedalling were coordinated, and two research assistants were controlling pedalling and respiratory ratio. Tests were terminated when the pedal cadence was lower than 50 rev per min for 10 s, and each stage was counted when subjects completed two min with the same workload without failing the pedaling frequency.

Expired gas was collected and analyzed every 30 s with a Jaeger Oxycon Pro gas machine (Viasys Healthcare, Yorba Linda, CA). From the gas analysis the following data were obtained: respiratory rate (RR); tidal volume (TV); minute ventilation (VE); fractional content of expired oxygen (FeO_2); fractional content of expired carbon dioxide ($FeCO_2$); oxygen uptake (VO_2); expiratory CO_2 volume (VCO_2); VO_2max; equivalent of oxygen (EqO_2); fractional content of expired oxygen and expiratory ratio (VE/VCO_2) and respiratory exchange ratio (RER). Heart rate (HR) was also obtained during the test with a heart rate monitor (model S810i, Polar Electro, Kempele, Finland) and rating of perceived exertion (RPE) was collected (both every one minute). Moreover, the time to end the test was also measured with a hand chronometer.

Statistical Analysis

Before statistical analysis was carried out, assumptions of normality were verified with the Kolmogorov - Smirnov test. To evaluate the effects of the three different interventions (60, 45 and 30 respirations per minute) at different intensities (incremental tests stages) on respiratory gas exchange variables (RR; TV; VE; FeO_2; $FeCO_2$; VO_2; VCO_2; EqO_2 and RER) and HR a two-way ANOVA with Bonferroni pot-hoc test was used. To compare the performance and the VO_2max in the three different instances, a one-way ANOVA was used. Data are expressed as mean value ± standard deviation, and the p values were accepted as statistically significant at $p < 0.05$. The used software for the statistical analysis was IBM SPSS Statistic version for Windows (IBM SPSS Co. Chicago, IL, USA).

RESULTS

Subjects completed the incremental intensity tests at different intensities; therefore, stages reached by subjects were different. Of the 10 subjects, four ended at 350 watts (before 14 min), three at 400 watts (before 16 min), two at 450 watts (before 18 min), and one at 500 watts (before 20 min). According to the experimental protocol designs, RR was different in each one of the three trials: 30 bpm; 45 bpm and 60 bpm.

Statistical analysis showed significant interactions between exercise intensity and some respiratory gas exchange variables (HR, TV, VE, FeO_2, $FeCO_2$, VO_2, VO_2, VCO_2, EqO_2, VCO_2 and RER) ($p < 0.05$).

Time to end the test and the VO_2max reached in the different trials did not present significant differences (Table 2).

Table 2. Respiratory and gas exchange variables, and time to complete the tests.

	VO_2 (ml.min^{-1})			*VCO_2 (ml.min^{-1})*			*RER*			*VE/VCO_2*		
	30 bpm	45 bpm	60 bpm	30 bpm	45 bpm	60 bpm	30 bpm	45 bpm	60 bpm	30 bpm	45 bpm	60 bpm
50 Watts	855 ± 68	877 ± 122	867 ± 97	831 ± 130	858 ± 123	801 ± 106	0.98 ± 0.13	0.98 ± 0.11	0.87 ± 0.11* #	39.7 ± 5.6	45.2 ± 6.6*	46.0 ± 7.1*#
100 Watts	1178 ± 89	1157 ± 93	1220 ± 135	978 ± 79	969 ± 89	998 ± 126	0.85 ± 0.07	0.84 ± 0.05	0.83 ± 0.08	35.3 ± 4.8	40.5 ± 3.5*	42.3 ± 2.6*#
150 Watts	1482 ± 81	1511± 123	1465 ± 180	1254 ± 84	1295 ± 116	1276 ± 182	0.85 ± 0.06	0.86 ± 0.07	0.87 ± 0.09	31.0 ± 4.6	35.1 ± 4.9*	38.0 ± 2.9*#
200Watts	1858 ± 152	1820 ± 157	1807 ± 207	1652 ± 124	1671 ± 172	1683 ± 227	0.89 ± 0.09	0.92 ± 0.07	0.93 ± 0.07	28.1 ± 2.6	32.1 ± 3.5*	35.5 ± 1.9*#
250 Watts	2245 ± 289	2157 ± 349	2258 ± 119	2141 ± 273	2045 ± 354	2192 ± 175	0.95 ± 0.7	0.95 ± 0.09	0.97 ± 0.7	26.9 ± 8.3	28.7 ± 11.3*	33.8 ± 7.0*#
300 Watts	2549 ± 205	2492 ± 169	2524 ± 213	2542 ± 181	2479 ± 188	2503 ± 237	1.00 ± 0.07	0.99 ± 0.07	0.99 ± 0.9	25.7 ± 2.4	29.3 ± 3.1*	32.2 ± 2.3*#
350 Watts	2859 ± 230	2873 ± 214	2888 ± 250	2964 ± 177	2982 ± 209	2970 ± 231	1.04 ± 0.09	1.04 ± 0.07	1.03 ± 0.7	25.4 ± 2.6	28.8 ± 3.3*	32.0 ± 2.5*#
400 Watts	3197 ± 266	3185 ± 285	3195 ± 292	3306 ± 139	3321 ± 238	3418 ± 232	1.04 ± 0.06	1.05 ± 0.10	1.08 ± 0.10	23.9 ± 2.2	28.1 ± 3.5*	33.1 ± .2*#
450 Watts	3585 ± 472	3683 ± 353	3682 ± 170	3687 ± 391	3892 ± 334	3742 ± 67	1.03 ± 0.07	1.06 ± 0.05	1.02 ± 0.05	25.0 ± 0.3	27.1 ± 2.7*	31.3 ± 1.2*#

	VO_2 max average	*Time to exhaustion*
30 bpm	47.3 ± 6.3	1014±137
45 bpm	46.9 ± 5.9	1009±110
60 bpm	47.2 ± 4.7	1028±110
p value	0.92	0.57

All values are expressed in mean ± standard deviation. VO_2, Oxygen uptake; VCO_2, expired CO_2; RER, respiratory exchange ratio and VE/VCO2. * = Significant differences 30 bpm; # = Significant differences with 45 bpm.

Significant differences were observed in the different trials for TV; VE; FeO_2; $FeCO_2$; VE/VCO_2 and EqO_2. TV was significantly higher with 30 bpm than with 45 bpm and 60 bpm, and 45 bpm was higher than 60 bpm. VE, FeO_2, $FeCO_2$, and EqO_2 were significantly higher with 60 bpm than 30 bpm and 45 bpm and with 45 bpm than with 30 bpm. VO_2, VCO_2, and RER did not reveal significant differences between the three RR trials (Table 3). HR and RPE did not show significant differences between trials (data not shown).

DISCUSSION

The aim of this study was to elucidate how different RR may affect respiratory gas exchange variables and performance during an incremental test. The main findings were that RR does not affect the VO_2 and cycling performance during incremental-exercise (data shown in table 2). To our knowledge, this is the first study which demonstrates that RR`s are not a limiting factor for incremental intensity tests performance. Additionally, TV, FeO2, EqO2, and

VE/VCO_2 showed significant differences when comparing the three different RR trials. This suggests that that EqO2 and VE/VCO_2 may not be good predictors of performance, and RR should be considered when analyzing these variables.

With regards to the RER, it also remained without statistical differences between the three different trials, indicating that there were no differences in metabolism comparing the three trials. As for the submaximal as well as maximal intensities, we found that by modifying VE, the metabolism would not change.

Table 3. Respiratory and gas exchange variables.

	TV ($L.min^{-1}$)			VE ($L.min^{-1}$)			FeO_2 (%)			$FeCO_2$ (%)			EqO_2		
	30 bpm	45 bpm	60 bpm	30 bpm	45 bpm	60 bpm	30 bpm	45 bpm	60 bpm	30 bpm	45 bpm	60 bpm	30 bpm	45 bpm	60 bpm
50 Watts	1.1 ± 0.3	0.9 ± 0.2*	0.6 ± 0.1*#	33.6 ± 8.8	39.1 ± 9.4*	37.0 ± 8.0*	17.7 ±0.7	18.1 ± 0.6*	18.1 ± 0.5*	3.2 ± 0.5	2.8 ± 0.4*	2.5 ± 0.5*#	34.4 ± 5.8	36.3 ± 5.6*	35.8 ± 5.4*
100 Watts	1.2 ± 0.2	0.9 ± 0.2*	0.7 ± 0.1*#	34.8 ± 7.6	39.1 ± 6.6*	42.0 ± 5.2*#	16.8 ±0.7	17.4 ± 0.6*	17.6 ± 0.4*	3.5 ± 0.5	3.1 ± 0.4*	2.8 ± 0.4*#	26.7 ± 3.4	28.8 ± 4.5*	29.6 ± 4.4*#
150 Watts	1.4 ± 0.3	1.1 ± 0.2*	0.9 ± 0.1*#	38.9 ± 7.6	45.6 ± 7.7*	48.2 ± 5.6*	16.3 ± 0.5	16.9 ± 0.5*	17.4 ± 0.4*#	4.0 ± 0.5	3.6 ± 0.4*	3.0 ± 0.5*#	24.1 ± 2.4	27.1 ± 4.2*	28.8 ± 3.5*#
200Watts	1.6 ± 0.2	1.3 ± 0.4*	1.0 ± 0.1*#	46.3 ± 6.2	53.7 ± 9.3*	59.8 ± 9.0*#	16.1 ± 0.4	16.8 ± 0.4*	17.3 ± 0.3*#	4.4 ± 0.4	3.8 ± 0.4*	3.5 ± 0.2*#	23.1 ± 3.0	26.4 ± 3.6*	29.5 ± 3.0*#
250 Watts	2.0 ± 0.4	1.7 ± 0.3*	1.3 ±0.1*#	58.0 ± 5.2	58.8 ± 13.1	74.0 ± 7.6*#	16.1 ± 0.5	16.4 ± 0.7	17.2 ± 0.3*#	4.6 ± 0.4	4.4 ± 0.6*	3.7 ± 0.3*#	24.3 ± 2.5	25.5 ± 4.2*	29.8 ± 2.8*#
300 Watts	2.2 ± 0.3	1.6 ± 0.3*	1.4 ± 0.1*#	65.9 ± 11.2	74.3 ± 10.9*	81.4 ± 10.7*#	16.2 ± 0.4	16.9 ± 0.6*	17.1 ± 0.4*#	4.9 ± 0.4	4.0 ± 0.6*	3.8 ± 0.9*#	24.5 ± 5.2	27.7 ± 3.6*	29.7 ± 3.7*#
350 Watts	2.5 ± 0.4	1.9 ± 0.3*	1.6 ± 0.2*#	75.6 ± 9.1	86.6 ± 14.5*	95.2 ± 12.6*#	16.2 ± 0.6	16.8 ± 0.6*	17.1 ± 0.4*#	4.9 ± 0.5	4.3 ± 0.6*	3.9 ± 0.3*#	25.3 ± 3.7	28.3 ± 4.8*	30.8 ± 3.8*#
400 Watts	2.5 ± 0.3	2.2 ± 0.3*	2.0 ± 0.3*#	79.2 ± 9.5	93.7 ± 17.2*	113.8 ± 18.0*#	15.9 ± 0.3	16.7 ± 0.5*	17.4 ± 0.5*#	5.2 ± 0.5	4.4 ± 0.6*	3.7 ± 0.4*#	23.7 ± 1.3	27.4 ± 2.8*	33.3 ± 5.3*#
450 Watts	2.8 ± 0.6	2.5 ± 0.3*	2.0 ± 0.1*#	92.3 ± 10.7	106.0 ± 19.5*	117.0 ± 6.1*#	16.2 ± 0.2	16.7 ± 0.6*	17.0 ± 0.3*#	4.8 ± 0.2	4.5 ± 0.6*	4.0 ± 0.6*#	24.7 ± 1.3	27.4 ± 2.8*	30.1 ± 2.6*#

All values are expressed in mean ± standard deviation. TV, Tidal Volume; VE, Ventilation; FeO_2, Fractional content of Expired Oxygen; $FeCO_2$, Fractional content of expired CO_2; VO_2, Oxygen uptake; VCO_2, expired CO_2; RER, respiratory exchange ratio; EqO_2, equivalent O_2 and VE/VCO_2. * = Significant differences 30 bpm; # = Significant differences with 45 bpm

Moreover, respiratory gas exchange variables have been studied as indicators of physical fitness (23), and also to predict the anaerobic threshold (17). In this study we provided evidence that changing RR affects many respiratory gas exchange variables but not performance, VO_2 and VCO_2, thus we suggest that TV, VE, EqO_2, VE/VCO_2 and FeO_2 may not be the best indicators of physical fitness and anaerobic threshold. Others studies have shown that different RR affects physiological variables; for instance changes in the respiration ratio during repose (five breaths per minute vs. spontaneous breathing) have been reported to induce changes in heart rate variability (10). To clarify if this effect also happens during exercise, and if other physiological variables are affected by the respiration frequency further research must be done.

Furthermore, other studies reported that VO_2 was decreased when synchronizing respiration with pedaling (4, 22). In the present research pedaling was synchronized with breathing. With different RR, alterations in VO_2 were not observed. The mechanism behind the decreased metabolic rate when synchronizing pedaling with respiration may be argued for as a consequence of a mechanic efficiency (as a result of the synchronization).

In summary, by modifying the RR in the range of 30 bpm to 60 bpm, performance and oxygen consumption during incremental intensity-exercise was not affected. Nevertheless, different RR did affect some respiratory gas exchange variables, however these respiratory gas exchange variables did not limit the oxygen consumption in the studied conditions.

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