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Ventilatory response to the workload of the same exercise intensity in the presence of thoracic restriction

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ABSTRACT

External thoracic restriction has been employed to study limited ventilation and perceived exertion during exercise. This study investigated ventilation and ratings of perceived exertion during submaximum exercise at the same relative intensity in healthy subjects with approximately 70% of unrestricted lung volume. Sixteen young women performed incremental cycle exercise tests with and without a thoracic corset. The restriction reduced peak O_2 consumption to 91% of the unrestricted value. Their estimated ventilatory anaerobic threshold (AT) values were 48.7% and 53.3% of each peak O_2 consumption reserve with and without corset, respectively, and there was no significant difference between the two conditions. Subsequently, a 10-minute constant workload test was carried out with detected workload at each AT. The time constant for minute ventilation, tidal volume and respiration rate under the restricted condition did not differ from the unrestricted condition. Density of end tidal CO_2 throughout the exercise and the Borg scale in the last of the exercise also were not affected by the restriction. These results suggest that thoracic restriction did not affect ventilatory response and perceived exertion compared with the unrestricted condition during submaximal constant workload exercise of the same relative intensity.

KEY WORDS

minute ventilation, anaerobic threshold, Borg scale, perceived exertion

Introduction

Limited ventilation due to restrictive lung disorder decreases exercise capacity, inducing exertion dyspnea during exercise. For patients with low lung volume, appropriate therapy should be used assessing certain vital signs and/or perceived exertion. Incremental exercise tests have been performed by patients with restrictive lung disorder, showing lower O_2 saturation and hyperventilation at the same workload compared with normal subjects. Hyperventilation related to dyspnea intensity is closely linked to the mechanical constraints on volume expansion[1,2]. Recently, an external thoracic restriction model has been devised to mimic restrictive lung disorder, demonstrating the degree of limitation in maximal intense exercise and ventilation response during constant workload exercise[3-6]. O'Connor et al.[6] showed the difference in ventilatory response between an incremental exercise and a constant workload exercise when restricted, in which hyperventilation was seen only in the constant workload exercise. Furthermore, hyperventilation was assessed by the investigators during constant workload exercise in different ways, setting the workload according to heart rate or tentative submaximum intensity[4,6].

The main purpose of the present investigation was to evaluate pulmonary response and the Borg scale (CR10 scale)[7] with restriction using a thoracic corset in healthy subjects during submaximum constant workload exercise at the same relative intensity. The

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intensity was precisely chosen by means of an incremental exercise test. With regard to assessing perceived exertion, the Borg scale is widely used and is as helpful as the visual analogue scale (VAS)[4-6]. Moreover, as reported elsewhere, the Borg scale is more reproducible than the VAS between tests[8,9]. By taking this approach, we hoped to provide further insights into the symptoms one might expect to find in the patient with restrictive lung disorder during constant workload exercise.

Methods

Sixteen healthy female volunteers (mean±SE age of 21.9±0.2 years old) who had no history of cardiopulmonary disease were used. All subjects had normal values of forced vital capacity (FVC), which was 2877±107mℓ and about 92% of the predicted value. External restriction of the thorax was achieved by use of an inelastic corset (Bustband Hard, Alcare) made of thick canvas tightened with the aid of Velcro straps intended to reduce FVC to 70% of the unrestricted value. The thoracic corset reduced FVC to 69.5% (range ; 65～72%) in the incremental peak test and to 69.7% (range ; 67～73%) in the constant workload exercise test, compared with the unrestricted FVC values, in which there was no significant difference between the two conditions of restriction using paired t test.

Each subject completed four exercise tests, comprising ramped exercise tests to exhaustion and constant workload exercise tests, both with and without thoracic restriction, on four separate days. Each exercise test was performed after resting on a cycle ergometer (Computronic 232CXL, Combi, Japan) for a period of about five minutes. The experimental values obtained in the final minute of the rest period served as data for analysis.

An incremental test was carried out on a cycle ergometer in which the workload was increased 20 W/min until the subject was unable to maintain the work rate due to fatigue. Respired air was sampled into an airomonitor (AE-280S, Minato, Japan) which analyzed air flow rate, and O_2 and CO_2 gas densities. The gas exchange data (O_2 and CO_2 volume curves) were analyzed breath by breath to estimate the ventilatory anaerobic threshold (AT) using the V-slope method[10,11]. In addition, Heart rate (HR) was also monitored continuously.

Subsequently, relative intensities of exercise in $\dot{V}O_2$peak and HRpeak were calculated using standard formulae[12]. Workload intensity for peak reserve in $\dot{V}O_2$peak was calculated as

$$\text{Intensity (\%)} = \Delta\dot{V}O_2(AT)/\Delta\dot{V}O_2(peak)\times 100$$

where $\Delta\dot{V}O_2$ (AT) represents the difference between $\dot{V}O_2$ at the AT and $\dot{V}O_2$ at rest, and $\Delta\dot{V}O_2$ (peak) is the difference between $\dot{V}O_2$peak and $\dot{V}O_2$ at rest. The intensity for peak reserve in HRpeak was calculated in the same way. Workload ratio was represented by the workload at the estimated AT divided by the workload at its peak.

A 10-minute constant workload test was performed, with and without a corset, at each workload at the AT estimated by the incremental test, with results of 62.1±3.0 vs. 74.6±5.7 W (mean±SE), respectively. Sampling by airomonitor were conducted for later analysis to determine mean values of tidal volume (TV), minute ventilation ($\dot{V}E$), respiration rate (RR), and density of end tidal CO_2 ($ETCO_2$) for every 30 sec. The Borg scale was utilized for assessing the subject's perceived exertion in response to a verbal command.

Time constants for $\dot{V}E$, TV, and RR during the constant workload test were determined from semilogarithmic representation[6,10] where the range of the vertical scale was set from the mean value during the final minute of the resting period to the mean value during the final minute of exercise. Time constant was utilized for showing the increasing time of values during exercise to represent ventilatory responding speed to the exertion.

Paired t test was used to compare relative intensities of exercise and time constants for ventilatory values between the unrestricted and restricted conditions. For $ETCO_2$, the sampled values per 30 sec were compared between the conditions using ANOVA. Wilcoxon test was performed for the scores for the Borg scale between the conditions. In all comparisons, $p<0.05$ was taken to indicate statistical significance.

Results

At the peak workload in the incremental test, a

Table 1. Relative intensity of exercise at the estimated AT during the incremental test.

	Unrestricted	Restricted
$\dot{V}O_2$peak reserve, %	53.3±3.4	48.7±2.0
HRpeak reserve, %	53.4±3.9	46.4±2.7
Workload ratio, %	53.3±3.1	48.4±2.1

Values are means±SE in 16 subjects. There was no significant difference between the two conditions using paired t test.

Table 2. Time constants of ventilatory parameters during the constant workload test.

	Unrestricted	Restricted
$\dot{V}E$, min	2.1±0.1	2.0±0.1
TV, min	1.6±0.2	1.4±0.1
RR, min	2.2±0.3	1.6±0.3

Values are means±SE in 16 subjects. There was no significant difference between the two conditions using paired t test.

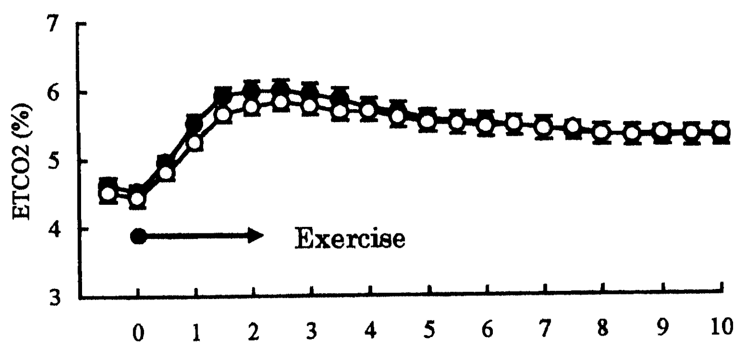

Fig. 1. Density of end tidal CO_2 ($ETCO_2$) for 16 subjects with (○) and without (●) thoracic restriction during the constant workload test. Values are mean±SE. There was no significant difference between the conditions by ANOVA.

significant lower $\dot{V}O_2$ were shown with the restriction (1353±46 vs. 1233±46 mℓ・kg^{-1}・min^{-1} ; unrestricted vs. restricted condition). This reduction in $\dot{V}O_2$peak was 91% of unrestricted condition. Exercise intensities of the estimated AT for peak reserve were 48.7% and 53.3% of $\dot{V}O_2$peak, and 46.4% and 53.4% of HRpeak, with and without the corse respectively (Table 1). These relative intensities $\dot{V}O_2$ and HR did not differ by thoracic restrictic statistically. Furthermore, there was no significa difference in the workload ratio between the tv conditions.

During the constant workload test, the increase in $\dot{V}E$ under the restricted condition seemed rapid in the time constant, though there was no significant difference between the two conditions. In addition, time constants for TV and RR did not differ, though the time constants in TV tended to be shorter than those in RR (Table 2). $ETCO_2$ increased during the initial few minutes, but there was no significant difference between the conditions by ANOVA (Fig. 1). Mean scores (95% confidence intervals) of the Borg scale without and with a thoracic corset was 0 (0～0) and 0.1 (0.1～0.2) at rest and achieved 6.5 (5.3～7.7) and 6.3 (5.3～7.2) at the end of exercise, respectively, also showing no significant difference between the two conditions.

Discussion

Reproducibility of the AT obtained from a single, short-duration ramp test was reported by Whipp et al.[10], and $\dot{V}O_2$peak and $\dot{V}O_2$ at the AT are known to be determined from a single ramp test of 4-8 min duration up to the limit of tolerance. In the present study, the duration of the incremental exercise was around 6-7 min, which was an appropriate time to detect $\dot{V}O_2$peak and $\dot{V}O_2$ at the AT. In addition, the V-slope method is usually applied to studies on the cycle ergometer. Following this method, the present study detected the relative intensity of the estimated AT based on $\dot{V}O_2$peak or HRpeak reserve as being approximately 50% in the incremental exercise test with no significant difference between the restricted and unrestricted conditions. This suggests that HR with low FVC respond to relative intensities of exercise in a similar way to the unrestricted condition. Moreover, workload ratios under both conditions were similar to the relative intensities of $\dot{V}O_2$peak reserve, which suggests that oxygen is utilized for exercise at the same rate of work efficiency (i.e. ratio of work load to the change in $\dot{V}O_2$ from the resting value)[10], despite the thoracic corset.

The reason for arranging the incremental test for the constant workload test was so as to choose a workload of the same relative intensity at submaximal level regardless of FVC. The submaximal intensity chosen by previous investigators was 80% of maximum power output without restriction[3], 65% Hrmax[4], or a workload equivalent to midway between 20 watts and the AT load[6] in the restricted condition. The absolute same workload as set by the previous studies[3,6] means a higher relative intensity under restriction. When 65% HRmax was the intensity attained, the workload increased until the target HR was achieved.

Previous investigators[4-6] reported increased dyspnea intensity both at rest and at any given work rate with the thoracic corset. They restricted vital capacity to 35-60% of control and the Borg scale or VAS showed a significant increase. Their corsets were reported to induce a perception of chest tightness in all subjects throughout rest and exercise. In the present study, the subjects also complained of chest tightness with the corset, but this did not affect the Borg scale. In addition, patients with interstitial lung disease with 64% of predicted FVC showed no difference in overall dyspnea on the Borg scale from normal subjects at peak exercise[2]. Thus, the present study has the advantage that discomfort due to the thoracic corset was negligible in assessing perceived exertion, because of the difference in materials used for the corset, and the degree of restriction, i.e. 35-60% vs. 70% of vital capacity.

During the constant workload test, the time constants in TV tended to be shorter than those in RR under both conditions. This suggests that the increase in $\dot{V}E$ was due to the comparatively rapid increase of TV and the subsequent increase in RR, which occurred regardless of FVC. Previous investigators documented no increase in $\dot{V}E$[3] or hyperventilation followed by relative hypocapnia[4,6] during the constant workload exercise with restriction, though they failed to demonstrate definitively the mechanism of hyperventilation. Poulin et al.[13] showed that hypoxia induced a significant increase in $\dot{V}E$, especially in hypercapnia rather than eucapnia in young subjects. In the present study, as the degree of hypercapnia, i.e. the increase of $ETCO_2$, was not different between the two conditions, the hyperventilation represented by the defined increase in $\dot{V}E$ was not observed during restriction.

Furthermore, the Borg scale showed no difference between the two conditions in the constant workload exercise. The Borg scale is known to correlate with

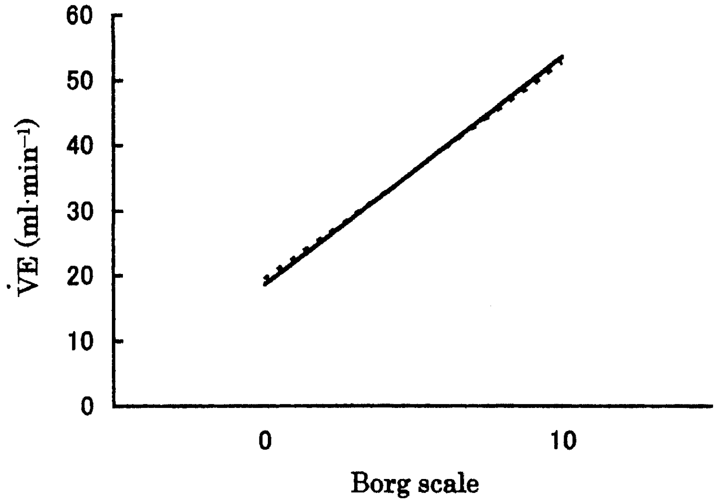

Fig. 2. Regression lines for minute ventilation (V̇E) against Borg scale for 16 subjects in the unrestricted and restricted conditions derived from all sampled values for 10 min of constant workload exercise, excluding resting time. The equations for the lines are $y=3.50x+18.61$ ($r=0.69$) for the unrestricted condition (a solid line), and $y=3.31x+19.50$ ($r=0.69$) for the restricted condition (a dotted line). $P<0.05$ for each line.

V̇E[8, 9]. Fig. 2 shows correlations between the Borg scale and V̇E during the constant workload exercise under the two conditions in the present study in which the two regression lines ($r=0.69$, $p<0.05$ for both lines) are almost identical. We therefore suggest that the Borg scale in the present study was also affected by V̇E but not directly by thoracic restriction.

In conclusion, the AT was represented by an exercise intensity of approximately 50% of $\dot{V}O_2$peak or HRpeak reserve both under the unrestricted and restricted conditions. During submaximal constant workload exercise of the same relative intensity, thoracic restriction did not affect ventilatory response compared with the unrestricted condition. In addition, the Borg scale related to V̇E almost identically under both conditions, and during exercise at the same relative intensity, perceived exertion appeared to be similar despite restriction.

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胸部拘束下での同等運動負荷に対する呼吸器系反応

染矢富士子，前田　眞一

要　　旨

胸部をバストバンドで外側から拘束し，肺活量を普段の70%に制限し，運動中の呼吸器系反応と息切れの自覚症状について検討した。対象は女子大生16名で，まず，胸部拘束の有無それぞれについて，自転車エルゴメーターを用いた漸増負荷により最大負荷となるまで呼吸代謝機能を測定した。その結果，胸部拘束により最大酸素摂取量は91%と有意に減少したが，嫌気性代謝閾値（AT）は最大酸素摂取量の48.7%（胸部拘束なしでは53.3%）であり有意差は認めなかった。次に，酸素摂取量が AT となった時点で加えられていた運動負荷（エルゴメーターにおける仕事率）で10分間の定常運動をさせたところ，分時換気量，１回換気量，呼吸数の時定数において胸部拘束は影響しなかった。また，呼気終末二酸化炭素濃度とボルグスケールにおいても，胸部拘束の有無による差を認めなかった。以上より，運動負荷強度が相対的に同じであれば，胸部拘束は，呼吸器系の反応や息切れの自覚症状には影響しないことが示唆された。