Effects of Combined Training with Breathing Resistance and Sustained Physical Exertion to Improve Endurance Capacity and Respiratory Muscle Function in Healthy Young Adults

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Abstract. [Purpose] In this study, combined training with breathing resistance and sustained physical exertion was carried out to evaluate its physiological effects and its effect on improve endurance capacity. [Subjects and Methods] The subjects were nine healthy adults (mean age 20.4, SD ± 1.7 years). The combined training group (n = 5) carried out 6 weeks of combined training using a cycle ergometer, with exercise load tests and respiratory function tests performed before and after the training. The results of the training were compared to a control group (n = 4) that only performed the cycling exercise without the combined training with breathing resistance. [Results] In the combined training group, ventilatory threshold, maximal load of the cycle ergometer in exercise load tests, and maximal voluntary ventilation increased after training. These increases after training were all significant, but none of these variables changed significantly in the control group. [Conclusion] The results imply that in comparison to conventional training methods, combined training with breathing resistance and sustained physical exertion is beneficial for increasing endurance capacity and respiratory muscle function. This result provides important information regarding the effects of the new training method for improving endurance capacity.
Key words: Respiratory muscle training, Exercise tolerance, Cardiorespiratory endurance

INTRODUCTION

Peak oxygen uptake (VO_{2peak}) and ventilatory threshold (VT) reflect the capacity for endurance[1–3], and improving them is beneficial for health[4–6]. To date, many different methods of training have been recommended for effectively improving endurance capacity, and the effectiveness of these methods has been examined. Rhythmic physical exercise such as running or cycling leads to improved VO_{2peak} and VT[3].

Endurance capacity depends on respiratory function in addition to circulatory and muscular function, and for this reason, there has recently been considerable interest in the relationship between respiratory muscle training, which aims to improve respiratory muscle function, and cardiorespiratory endurance. Some studies have reported that inspiratory muscle training during rest improves the cardiorespiratory endurance of patients with weakened respiratory

muscles and that of healthy adults[7–11], whereas other studies have reported no effect[12–15]. Thus, there is no consensus of opinion. In addition, with inspiratory muscle training during rest, it is difficult to combine an increased ventilation requirement brought about by an increase in required oxygen intake with respiratory load. Therefore it is difficult to continually carry out inspiratory muscle training during rest by applying resistance to deep breathing. Physical exercise under hypoxic conditions has been shown to be very effective at increasing endurance capacity[16], but it is not possible to apply resistance to the respiratory muscles during this type of training. The subject needs to go to a location at a high altitude or use an apparatus to control the partial pressure of oxygen; thus, the training is difficult from the point of view of time and the financial costs involved. A training method that resolves these problems and effectively increases endurance capacity and respiratory muscle function would be beneficial not only for healthy adults, but also for elderly people and patients suffering from certain diseases. However, to date, there has been no examination of combined training with breathing resistance and sustained physical exertion in which rhythmic physical exer-

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cise is combined with the application of a respiratory load.

In this study, attempting to effectively improve endurance capacity and respiratory muscle function, we carried out combined training with breathing resistance and sustained physical exertion (CBS) and examined its effectiveness by comparing the results with those of a control group without breathing restrictions.

SUBJECTS AND METHODS

Subjects

The subjects were nine healthy adults (3 men, 6 women) who were randomly divided into two groups: the CBS group, which carried out CBS training on a cycle ergometer wearing a mask that provided resistance to breathing (2 men, 3 women); and the control group, which carried out training on a cycle ergometer with no mask (1 man, 3 women). The subjects performed the training over 6 weeks, and body measurements, respiratory function tests, and exercise load tests were carried out before and after the training period. The study was approved by the Ethics Committee of Saitama Prefectural University (no. 21042), and the subjects consented to participate after receiving a written explanation of the details of the study.

Methods

Both groups carried out three 2-week courses of training, for a total of 6 weeks. The training intensity was set using the heart rate reserve (HRR) method[17]. HRR value is calculated by subtracting heart rate at rest (HR_{rest}) from maximum heart rate (HR_{max}). Target heart rate during exercise was calculated according to the formula:

$$Target\ HR = [(HR_{max} - HR_{rest}) \times \%\ intensity] + HR_{rest}$$

Target HR was 75% HRR during the first course, 80% HRR during the second course, and 85% HRR during the third course. HR_{max} was estimated by the formula $HR_{max} = 220 - age$[3]. Frequency of exercise was three times per week, and the control group performed cycle ergometer exercise for 30 min at a load that maintained the target heart rate. The pedaling cadence was 60 rpm. The CBS group wore a ReBNA (Patent Works Inc.; Fig. 1) and exercised at the same target heart rate as the control group. The ReBNA is a mask-type device with valves arranged such that inhalation is only through the nose and exhalation only through the mouth, and ventilation through two inspiratory valves and two expiratory valves produces respiratory load[18]. Cycle ergometer load and rating of perceived exertion (RPE) were recorded immediately before the end of training. An amended Borg scale[19] was used for RPE. On completion of the third course of training, difficulty in breathing and fatigue in the legs were investigated using a questionnaire.

Height, weight, body fat percentage, muscle mass, and abdominal circumference were measured. Weight, body fat percentage, and muscle mass were measured using an InnerScan 50V (Tanita Co.).

Ramp load maximal exercise tests were carried out using a 232C xL cycle ergometer (Combi Co.). Measurements were taken using a Vmax respiratory metabolism measur-
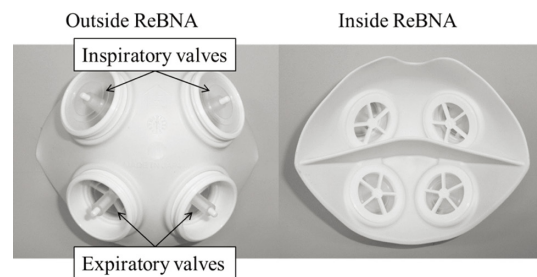

Fig. 1. Appearance of the ReBNA
There are separate spaces inside the mask for the nose and mouth.

ing device (Nihon Kohden Co.). For exercise load measurement, subjects rested for 3 min and then warmed up for 3 min (men, 25 W; women, 15 W); this was followed by ramp load exercise (men, 25 W/min; women, 15 W/min) until either no further increase in oxygen extraction fraction was seen or the subject reached total exhaustion and was unable to continue. The criteria for discontinuing exercise tests were in line with the "General Indications for Stopping an Exercise Test in Low-Risk Adults," according to the guidelines of the American College of Sports Medicine. After the exercise test, subjects cooled down for 3 min (men, 25 W; women, 15 W). The pedaling cadence was 60 rpm. VT was determined using the V-slope method[20].

Vital capacity of the lungs (VC), forced vital capacity (FVC), and maximal voluntary ventilation (MVV_{12}) were measured using a FUDAC-70 spirometer (Fukuda Denshi Co., Ltd). VC and FVC were measured twice each, the values were checked to ensure less than 10% measurement error between the two, and the larger value was adopted. If the measurement error exceeded 10%, measurements were repeated until the error came within 10%. MVV_{12} was measured three times, and the largest value was adopted. Maximum inspiratory mouth pressure (P_{Imax}) and maximum expiratory mouth pressure (P_{Emax}) were measured using a HI-801 spirometer (Chest M.I., Inc). Each measurement was taken three times, and the largest value was adopted.

All statistical analyses were performed using SPSS software (SPSS Statistics version 19). Data were tested for normality using the Shapiro-Wilk test. The paired t-test, or Wilcoxon's signed-rank test in cases of non-normality, was used to compare baseline (BL) values of all measures before training with their values after 6 weeks (6W) within each group. The unpaired t-test, or Wilcoxon's test in cases of non-normality, was used to compare the results of the CBS and control groups.

RESULTS

All subjects completed the study (Table 1), and the exercise performance rate was 100%. Mean load during training for the three courses was 120.9 ± 3.1 W in the control group and 117.7 ± 3.6 W in the CBS group. Mean RPE was 7.0 ± 0.2 W in the control group and 8.4 ± 0.1 W in the CBS group (Table 2). The measured items at baseline (BL) and

Table 1. Characteristics of all subjects at baseline

	Control Group (n = 4)	CBS Group (n = 5)
Age (y)	21±2.1	20±1.1
Male/Female	1/3	2/3
Body height (cm)	161.8±7.7	163.3±10.8
Body weight (kg)	56.4±5.9	56.7±9.3
BMI (kg/m^2)	21.5±0.6	21.2±1.7
Body fat percentage (%)	20.8±5.3	21.5±9.4
Muscle mass (kg)	42.4±6.9	42.6±10.7
Abdominal circumference (cm)	70.5±3.3	70.8±4.7
Number of exercises per week (times)	2.5±2.6	1.2±1.9
Initial VO_{2peak} (ml/kg/min)	33.4±4.1	35.6±6.7
Initial ventilatory threshold (ml/kg/min)	20.2±4.6	20.1±3.4

mean ± SD

Table 2. Load of bicycle ergometer and RPE for the training

	Control Group (n = 4)		CBS Group (n = 5)	
	Load (watts)	RPE	Load (watts)	RPE
1st course	119.0±6.3	6.2±0.2	106.5±6.8	7.2±0.2
2nd course	120.3±5.4	6.9±0.3	114.3±4.8	8.3±0.2
3rd course	123.4±4.2	7.9±0.2	132.5±7.0	8.9±0.2
Mean of 1st–3rd courses	120.9±3.1	7.0±0.2	117.7±3.6	8.4±0.1

mean ± SE

RPE: rating of perceived exertion. Load for each training course is the value immediately before the end of training.

RPE: perceived exertion was rated using a modified Borg scale (0–10).

after training (6W) are shown in Table 3.

Abdominal circumference in the CBS group was 70.8 ± 2.1 cm at BL and 69.7 ± 2.2 cm at 6W, showing a significant reduction at 6W ($p < 0.01$).

VO_{2peak} in the control group was 33.4 ± 2.0 mL/min/kg at BL and increased significantly ($p < 0.05$) to 37.3 ± 2.6 mL/min/kg at 6W. VO_{2peak} in the CBS group was 35.6 ± 3.0 mL/min/kg at BL and increased significantly ($p < 0.05$) to 42.2 ± 3.1 mL/min/kg at 6W. VCO_{2peak} in the control group was 43.9 ± 4.2 mL/min/kg at BL and increased significantly ($p < 0.05$) to 50.3 ± 5.2 mL/min/kg at 6W. VCO_{2peak} in the CBS group was 47.3 ± 5.4 mL/min/kg at BL and increased significantly ($p < 0.05$) to 56.0 ± 5.3 mL/min/kg at 6W. VT in the CBS group was 20.1 ± 1.5 mL/min/kg at BL and increased significantly ($p < 0.01$) to 27.3 ± 1.2 mL/min/kg at 6W. VT at 6W was 20.6 ± 1.6 mL/min/kg in the control group and 27.3 ± 1.2 mL/min/kg in the CBS group, a significantly higher value in the CBS group ($p < 0.05$). Ergometer maximal load at VO_{2peak} in the CBS group was 199.0 ± 31.7W at BL and increased significantly ($p < 0.05$) to 221.8 ± 30.8 at 6W. Tidal volume at the ventilatory threshold (T_{VVT}) in the control group was 1.17 ± 0.20 l at BL and 1.20 ± 0.22 l at 6W, an increase of 3%. T_{VVT} in the CBS group was 1.33 ± 0.16 l at BL and 1.59 ± 0.14 l at 6W, an increase of 20% ($p = 0.06$).

In the questionnaire about fatigue after the third training course (Table 4), in the control group, three subjects reported greater fatigue in their legs than in their breathing, and one subject reported the same level of fatigue in their breathing and legs. In the CBS group, three subjects reported greater fatigue in their legs than in their breathing, and two subjects reported greater fatigue in their breathing than in their legs (Table 5).

MVV_{12} in the CBS group was 113.8 ± 17.1 l/min at BL and increased significantly ($p < 0.05$) to 133.2 ± 15.2 l/min at 6W.

DISCUSSION

The present study aimed to achieve an effective increase in endurance capacity and respiratory muscle function through CBS, in which rhythmic physical exercise was combined with respiratory load. To clarify the effectiveness of this training, a comparison was made with a control group that exercised with no respiratory load. The results yielded two major findings.

First, the results imply that CBS is more beneficial at improving endurance capacity than conventional training. VO_{2peak} in both groups was significantly greater after the training, indicating that the amount of training performed in the present study was sufficient to increase endurance capacity. Maximal load and VT did not show any significant changes after the training in the control group, but these variables were both significantly greater after training in the CBS group. In the CBS group, valves provided

Table 3. Body composition and cardiorespiratory variables at baseline (BL) and 6 weeks (6W)

	Control Group (n = 4)		CBS Group (n = 5)	
	BL	6W	BL	6W
BMI (kg/m^2)	21.5±0.3	21.2±0.2	21.2±0.8	21.1±0.7
Body weight (kg)	56.4±2.9	55.8±2.8	56.7±4.2	56.3±3.6
Body fat percentage (%)	20.8±2.6	20.2±4.1	21.5±4.2	18.4±4.0
Muscle mass (kg)	42.4±3.5	42.3±4.4	42.6±4.8	43.7±4.3
Waist circumference (cm)	70.5±1.6	70.4±2.9	70.8±2.1	69.7±2.2[b]
VC (l)	4.0±0.5	4.1±0.5	4.2±0.5	4.3±0.5
%VC (%)	109.3±8.2	117.9±5.0	114.0±4.9	116.7±4.5
FVC (l)	4.0±0.5	4.1±0.5	4.2±0.5	4.1±0.4
%FVC (%)	109.7±8.6	117.2±5.1	113.9±4.3	113.9±3.9
FEV_1 *(l)*	3.5±0.5	3.6±0.5	3.7±0.4	3.7±0.4
$FEV_{1\%}$ (%)	86.5±1.5	87.3±0.5	88.5±2.2	89.3±2.0
MVV_{12} (l/min)	142.6±25.1	131.5±20.2	113.8±17.1	133.2±15.2[a]
P_{Imax} (cmH_2O)	92.0±11.7	94.7±12.6	86.8±5.3	96.0±5.2
P_{Emax} (cmH_2O)	110.7±13.4	110.2±8.8	109.8±15.1	114.3±12.0
Maximal load (W)	183.0±27.1	203.3±23.3	199.0±31.7	221.8±30.8[d]
VO_{2peak} (ml/min/kg)	33.4±2.0	37.3±2.6[a]	35.6±3.0	42.2±3.1[a]
VCO_{2peak} (ml/min/kg)	43.9±4.2	50.3±5.2[a]	47.3±5.4	56.0±5.3[a]
VE_{peak} (l/min)	90.2±14.2	104.2±19.2	104.8±22.6	116.0±20.7
HR_{peak} *(bpm)*	182.0±7.5	186.3±4.5	186.6±2.2	188.6±2.8
RR_{peak} (breaths/min)	43.0±2.6	46.5±3.0	41.4±4.1	42.8±4.8
Tv_{peak} (l)	1.93±0.31	2.04±0.31	2.12±0.27	2.36±0.26
VE/VO_{2peak}	46.6±1.9	48.3±2.5	49.1±5.3	47.1±3.6
VE/VCO_{2peak}	35.7±1.5	35.9±1.3	36.8±3.0	35.4±2.1
VT (ml/min/kg)	20.2±2.3	20.6±1.6	20.1±1.5	27.3±1.2[b,c]
RR_{VT} (breaths/min)	30.0±1.5	32.0±3.0	24.4±2.5	27.2±1.7
Tv_{VT} (l)	1.17±0.20	1.20±0.22	1.33±0.16	1.59±0.14
VE/VO_{2VT}	31.3±0.8	32.0±1.5	28.0±1.6	28.4±2.2
VE/VCO_{2VT}	31.8±1.1	31.5±1.4	29.6±2.1	27.8±1.6

mean ± SE
[a] Comparison of BL and 6W within groups (Paired t test $p < 0.05$), [b] Comparison of BL and 6W within groups (Paired t test $p < 0.01$), [c] Comparison between groups at 6W (Student's t-test $p < 0.05$), [d] Comparison of BL and 6W within groups (Wilcoxon's Signed-Rank test $p < 0.05$). Italic variables were tested non-parametrically.
VC: vital capacity; FVC: forced vital capacity; FEV_1: forced expiratory volume in 1 second; MVV_{12}: maximal voluntary ventilation; P_{Imax}: maximum inspiratory mouth pressure; P_{Emax}: maximum expiratory mouth pressure; Maximal load: load at the end of exercise load experiment; HR: heart rate; RR: respiratory rate; Tv: tidal volume; VT: ventilatory threshold

Table 4. Questionnaire about fatigue

Please select the statement from 1 to 6 that best describes your fatigue during the three training courses
1. My breathing feels more fatigued than my legs.
2. My breathing feels much more fatigued than my legs.
3. My breathing and my legs feel the same level of fatigue.
4. My legs feel more fatigued than my breathing.
5. My legs feel much more fatigued than my breathing.
6. I don't know.

Table 5. Responses to questionnaire about fatigue

Control Group	Subject A	3
	Subject B	4
	Subject C	4
	Subject D	4
CBS Group	Subject E	2
	Subject F	4
	Subject G	1
	Subject H	5
	Subject I	4

resistance to inhalation and exhalation, thus exerting a load on the respiratory muscles during exercise. It is likely that the combined training involves physiological mechanisms different from those involved in exercise with no breath-ing resistance, and that this different mechanism influences the increase in maximal load and VT. Also, when the tidal

volume increases, there is a decrease in the dead space ventilation, and ventilation efficiency increases, so that this breathing pattern reduces the oxygen consumption required for breathing movement. In the present study, although T_{VVT} in the control group was almost unchanged after training, it increased by 20% in the CBS group (p = 0.06). CBS therefore tended to aid deep breathing. In studies to date of healthy adults, one report indicated that inspiratory training at rest increased endurance capacity[7], and other studies reported that it did not produce an increase[14, 15]. Thus, there is no consensus of opinion. The CBS carried out in the present study differs from the respiratory training of previous studies in that a load was applied to both inhalation and exhalation. Furthermore, it was carried out under the increased ventilation requirement brought on by physical exercise, and there was no decline in the dust cleaning or humidifying effects on the air that accompanies inhalation through the nose. Thus, it appears that one of these training loads, or a combination of two or more factors, contributed to the improvement of maximal performance and cardiorespiratory endurance. The training effectiveness of CBS has not been reported in prior studies, and this new finding that a combination of respiratory load and physical exercise can contribute to an increase in endurance capacity is likely to be important when selecting training methods for sports or therapeutic exercise. However, the subject sample in the present study was small, which could possibly have influenced the result. Studies examining a greater number of subjects are needed to verify the effectiveness of CBS.

The second major finding of the present study is the implication that CBS improves respiratory muscle function. MVV did not change significantly after training in the control group, but in the CBS group, it showed a 17% increase (p < 0.05) after training. Increases in MVV of about 10% in healthy subjects as a result of respiratory training at rest have previously been reported[7, 21], but no increases as a result of CBS have been reported. The present results show that CBS increased MVV, and to a greater degree than respiratory training at rest. Therefore this result suggest that CBS effectively increases MVV. Neither P_{Imax} nor P_{Emax} changed significantly in the CBS group; thus, it is possible that factors other than maximum respiratory muscle strength are involved in the increase in MVV. Both MVV and endurance capacity improved in the present training, suggesting that respiratory muscle function and endurance capacity are related.

Although the results of the present study suggest that CBS yields superior improvements in endurance capacity and respiratory muscle function, there are many points regarding the mechanisms involved that are unclear. In the responses to the fatigue questionnaire, many subjects in the CBS group reported greater fatigue in breathing than in the legs, indicating the possibility that CBS brings about changes in load on the respiratory muscles and the leg muscles. It will be necessary to investigate muscle activity during training to test this possibility. In addition, there is also a need to measure the actual resistance to breathing experienced by subjects to clarify the exact load.

In conclusion, the present study yielded results suggesting that CBS achieves greater improvements in maximal performance, cardiorespiratory endurance, and maximal voluntary ventilation than conventional methods. These results provide important information regarding the effectiveness of the new training method aiming to improve endurance capacity. The degree to which these results can be generalized to training for subjects other than healthy young adults is unclear. Therefore, further studies are needed to clarify the rationale and mechanism through which the training improves endurance capacity and respiratory muscle function.

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