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Effects of hypoxic training on physiological exercise intensity and recognition of exercise intensity in young men

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ABSTRACT

This study aimed to examine the effects of hypoxic training on physiological exercise intensity and recognition of exercise intensity in young men. The participants included 9 healthy young males (23.2 ± 6.5 years old, 176.2 ± 6.7 cm, 74.3 ± 16.4 kg). VO_2 was measured during running with subjective exercise intensities of "somewhat hard" for 3 min and "fairly light" for 3 min. After the measurements, the participants answered the question "what percentage of your maximal effort was performed during both running exercises." The exercise intensity recognition for the "fairly light" and "somewhat hard" intensities and the physiological exercise intensity measured by relative VO_2 (%) and relative heart rate (HR, %) were then evaluated. The hypoxic training was performed 3 times a week for 4 weeks in a normobaric hypoxic chamber (oxygen concentration, 15.4% and altitude, 2500 m). The participants ran at an exercise intensity of 60% VO_{2max} for 40 min after a 5 min warm-up and then performed a 5 min cool-down. After training, they sat on a chair in the same room for 30 min. VO_{2max} and HR_{max} changed significantly after the training. At "fairly light" intensity, the physiological measures were significantly higher than recognition of exercise intensity, with relative VO_2 (%) increasing after training. In conclusion, hypoxia training causes an increase in VO_{2max} and physiological exercise intensity during running at a "fairly light" intensity.

Keywords: Hypoxic Training; Relative O_2; Relative HR; Recognition of Exercise Intensity

1. INTRODUCTION

Habitually performing aerobic exercises aimed at improving cardiovascular fitness is widely recommended [1]. It is desirable to use an index based on physiological parameters for determining aerobic exercise load [1]. However, more cases can help to determine exercise intensity using subjective measures (*i.e.*, self-selected intensity) rather than physiological indices. However, factors such as physique, exercise ability, exercise experience, and the environment may affect self-selected intensity. In short, even if each person was instructed to run with the same exercise intensity, the intensity selected may differ because of the above factors.

Okura *et al.* [2] reported that people who did not exercise chose significantly higher relative exercise intensity as their favorite intensity than those who did exercise, with their feeling of comfort after exercise being significantly lower. Hayashi *et al.* [1] also reported that exercise characteristics which participants had experienced in the past caused differences in cognition ability to determine the intensity imposed on their body during exercise. As a consequence this affected self-selected intensity. As stated above, although the effects of exercise habit and experience on cognition of exercise intensity have been examined, there is limited information on the effects of environmental factors. Participants may recognize higher exercise intensity by hypoxia even if the intensity is lower than with normoxia because hypoxia itself affects the body in a manner similar to a large load in low oxygen environment.

Hypoxia has been used as a method in altitude training for competitive sports [3,4]. The partial pressure of oxygen in the atmosphere is decreased at high attitudes or in a low-pressure chamber. Consequently, the decline in SpO_2 in human blood causes a lack of oxygen supply to body tissues. Hypoxia training is a method that aims to improve O_2 transport ability, cardiovascular fitness, and competitive performances by using anoxia to stimulate the body (*i.e.*, environmental stimulation) [5]. HR and VO_2 levels in hypoxic training are greater than or equal to those during training in a normoxic environment, even at low exercise intensity.

Numerous studies have been performed on the relationships between hypoxia training and aerobic exercise ability or competitive performances [6-8]. However, the effects of hypoxia training on recognition of exercise intensity and physiological exercise intensity during submaximal exercise have not been investigated extensively.

Therefore, the purpose of this study was to examine the effects of hypoxic training on physiological exercise intensity and recognition of exercise intensity in young men.

2. METHODS

2.1. Participants

The participants included 9 healthy young males (age, 23.2 ± 6.5 years old; height, 176.2 ± 6.7 cm; weight, 74.3 ± 16.4 kg). As a result of a hearing survey, 3 of the 9 subjects carried out club activities regularly, but did not have the habit of jogging. The purpose and procedure of the study were explained in detail and informed consent was obtained from all the participants. The study was approved by the Ethics Committee on Human Experimentation of Faculty of Education, Kanazawa University (No. 19-19).

2.2. Running at Each Rate of Perceived Exertion (RPE) and Measurement of VO_2 and VO_{2max}

The above measurements were conducted before and after training in a normoxia laboratory at Gifu University Sports Medicine and Sports Science. VO_2 and VO_{2max} were measured by a pulmonary exercise test monitoring system (V_{max}, Nihon Cohden, Tokyo, Japan) using the following steps.

Procedure of VO_2 and VO_{2max} measurements before and after training:

STEP 1: Measurement of heart rate and blood pressure at rest.

STEP 2: Warm-up (stretch and walk on the treadmill for 5 min each) (please see Section 2.2.1);

STEP 3: Run on the treadmill at "fairly light" intensity for 3 min with measurement of HR and VO_2 (please see Section 2.2.2);

STEP 4: Run on the treadmill at "somewhat hard" intensity for 3 min with measurement of HR and VO_2 (please see Section 2.2.2);

STEP 5: Run on the treadmill until exhausted with measurement of HR_{max} and VO_{2max} (please see Section 2.2.4);

STEP 6: Survey on recognition of exercise intensity (please see Section 2.2.3);

2.2.1. Preparation for Measurement

Resting HR and blood pressure of the participants were measured before the warm-up. For the warm-up, the participants stretched for 5 min and then walked at 4 km/h on the treadmill for 5 min. During this time, a mask that fitted the face was regulated and checked to ensure that air was not leaking from it during walking.

2.2.2. Run on the Treadmill at Subjective Exercise Intensity with Measurements of HR and VO_2

Hayashi *et al*. (2003) reported that participants could recognize intensity more accurately during exercise at moderate or high intensities than at low intensity. In this regard, the running exercise was performed in the order of low intensity (fairly light) and moderate (somewhat hard) in this study. Participants ran on the treadmill at a subjective "fairly light" intensity for 3 min and after a 5 min walk at a subjective "somewhat hard" intensity for 3 min. They voluntarily adjusted their speed using the speed adjustment button. The speed was not displayed during running. Speed was adjusted for the first minute of each exercise intensity.

2.2.3. Recognition of Exercise Intensity

After the measurements the participants answered the question "what percentage of maximal effort was the exercise (running) performed during 'fairly light' and 'somewhat hard' exercise intensities".

Questions on exercise intensity recognition:

1) What percentage of maximal intensity was used to perform "somewhat hard" exercise?

2) What percentage of maximal intensity was used to perform "fairly light" exercise?

2.2.4. Measurement of VO_{2max}

VO_{2max} was measured using the modified Astrand protocol [9]. Participants ran at 70% HR for 3 min. The angle of the gradient was then increased by 2% every 2 min until exhaustion. Using this protocol and a constant speed carries a slight risk of falling while running, but VO_{2max} can be measured accurately within a short time. VO_2 was recorded continuously using a "breath-by-breath" method, simultaneously with measurement of HR. In addition, RPE (ratings of perceived exertion) during VO_{2max} measurement was recorded every 2 min by a research investigator.

2.2.5. Parameters

The following parameters were used to examine differences between physiological exercise intensity (%) and recognition of exercise intensity during runs at "fairly light" and "somewhat hard" intensity.

1) Physiological parameters

a) VO_{2max} (ml/kg/min).

b) HR (BPM; beats per minute).

c) VO_2 when running at "fairly light" and "somewhat

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hard" exercise intensity.

d) HR when running at "fairly light" and "somewhat hard" exercise intensity.

The means of VO_2 and HR in the final min of the three min run were used in the analyses.

2) Physiological exercise intensity

Physiological exercise intensities were calculated using the following equations:

a) Relative $VO_2(\%) = \{VO_2/VO_{2max}\} \times 100$.

b) Relative

$$HR(\%) = \{(HR - HR_{rest})/(HR_{max} - HR_{at\ rest})\} \times 100.$$

3) Recognition of exercise intensity.

Parameters on recognition of exercise intensity included subjective recognition of "fairly light" and "somewhat hard" intensities (Note: see Section 2.3. Exercise intensity recognition).

2.3. Hypoxic Training (Figure 1)

Participants performed hypoxic training in a normobaric hypoxic chamber set at an altitude of 2500 meters (oxygen level 15.4%). The participants ran at an exercise intensity of 60% VO_2 for 40 min after a 5 min warm-up and then performed a 5 min cool-down. After training, they sat on a chair and rested in the same room for 30 min. The hypoxic training was performed 3 times a week for 4 weeks. Training in this study used the same treadmill run for measuring changes in VO_{2max}.

2.4. Statistical Analyses

Paired t-tests were used to assess the mean differences between before- and after-training values for VO_{2max}, HR_{max}, and VO_2 and HR during the subjective intensity runs ("fairly light" and "somewhat hard"). A repeated-measures two-way ANOVA was used to assess mean differences between recognition of exercise intensity and physiological exercise intensities (relative HR, relative VO_2) ANOVA included before and after training as Factor 1 and exercise intensity recognition and physiological exercise intensity as Factor 2. Tukey's HSD method was used for multiple comparison of significant variables. A probability level of $p < 0.05$ was considered statistically significant. The effect of size was calculated to assess the size of the mean differences.

3. RESULTS

Table 1 shows the mean differences in VO_{2max} and HR_{max} before and after training. Significant differences were found for both parameters, with VO_{2max} being greater after training and HR_{max} being higher before training (ES = 1.26 and 0.39, respectively).

Table 2 shows the mean differences in VO_2 and HR before and after training during the subjective intensity runs ("fairly light" and "somewhat hard"). VO_2 was greater after training than before training at both exercise intensities.

Table 3 shows the mean differences between recognition of exercise intensity and relative VO_2. Significant main effects [exercise intensity recognition and relative VO_2 (F1) and before and after training (F2)] were only found during fairly light intensity exercise. Multiple comparison showed that the difference between recognition of exercise intensity (%) and relative VO_2 was larger after training and that relative VO_2 was larger than recognition of exercise intensity.

Table 4 shows the mean differences between recognition of exercise intensity and relative HR. A significant difference was found between the main effect of exercise intensity recognition and relative HR (F1) only during "fairly light" intensity exercise. Multiple comparison showed that relative HR was larger than recognition of exercise intensity.

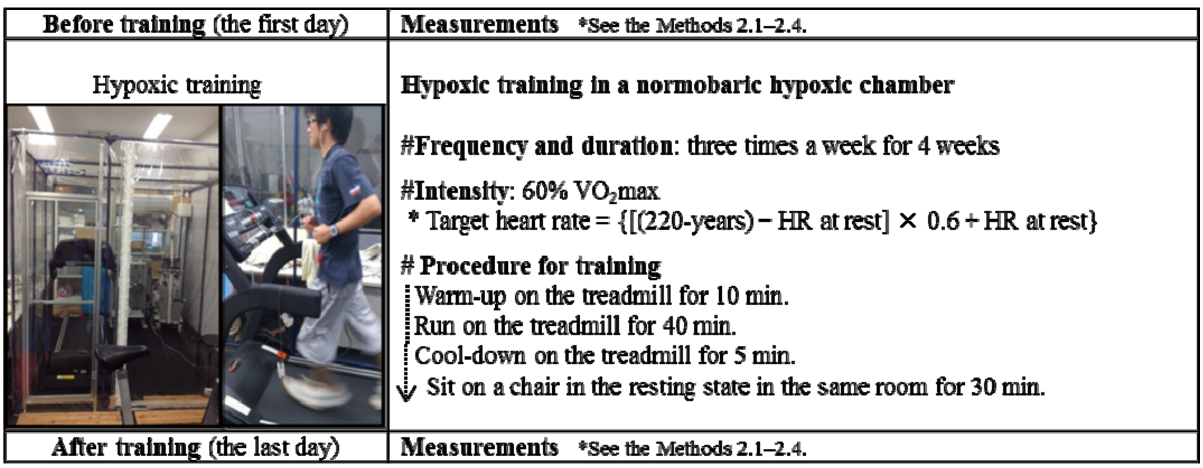

Figure 1. The procedure for hypoxic training.

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Table 1. Mean differences in VO_{2max} and HR_{max} before and after training (n = 9).

	Before training		After training		Paired t-test		
Parameters	Mean	SD	Mean	SD	t-value	p-value	ES
VO_{2max} (ml/kg/min)	51.2	9.2	62.6	8.8	4.3	0.00*	1.26
HR (BPM)	193.6	13.5	188.9	10.6	2.0	0.04	0.39

*p < 0.05/2; ES: effect size.

Table 2. Mean differences in VO_2 and HR during subjective intensity runs before and after training (n = 9).

Parameters	Subjective exercise intensity	Before training		After training		Paired t-test		
		Mean	SD	Mean	SD	t-value	p-value	ES
VO_2 (ml/kg/min)	Fairly light	25.6	5.4	33.6	4.3	3.4	0.01*	1.64
	Somewhat hard	33.4	6.8	40.0	5.1	2.4	0.02*	1.09
HR (BPM)	Fairly light	132.3	16.4	133.9	18.7	0.6	0.28	0.09
	Somewhat hard	156.3	17.0	152.4	17.8	1.2	0.13	0.22

*p < 0.05; ES: effect size.

Table 3. Mean differences between recognition of exercise intensity and relative VO_2 (n = 9).

Subjective exercise intensity	Training	REI (%)		Relative VO_2 (%)		Two-way ANOVA			
		Mean	SD	Mean	SD		F-value	p-value	Tukey's HSD
Fairly light	Before training	28.9	6.0	49.9	3.3	F1	174.53	0.00*	Before and after training: REI < Relative VO_2
	After training	36.7	7.1	54.2	5.7	F2	6.33	0.03*	REI, Relative VO_2: before < after training
						F3	1.37	0.27	
Somewhat hard	Before training	63.3	7.1	65.0	3.6	F1	1.49	0.26	n.s
	After training	61.1	3.3	64.4	7.4	F2	0.42	0.53	
						F3	0.49	0.50	

*p < 0.05; REI: recognition of exercise intensity; ES: effect size; relative $VO_2 = \{VO_2/VO_{2max}\} \times 100$; F1: REI × relative VO_2; F2: Before and after training; F3: interaction.

Table 4. Mean differences between recognition of exercise intensity and relative HR (n = 9).

Subjective exercise intensity	Training	REI (%)		Relative HR (%)		Two-way ANOVA			
		Mean	SD	Mean	SD		F-value	p-value	Tukey's HSD
Fairly light	Before training	28.9	6.0	46.1	8.6	F1	13.50	0.01*	Before and after training: REI < Relative HR
	After training	36.7	7.1	49.4	14.0	F2	4.00	0.08	REI: before < after training
						F3	1.50	0.26	
Somewhat hard	Before training	63.3	7.1	67.1	7.0	F1	4.00	0.08	n.s
	After training	61.1	3.3	66.9	9.3	F2	0.60	0.44	
						F3	0.30	0.58	

*p < 0.05; REI: recognition of exercise intensity; ES: effect size; relative HR: $\{(HR - HR_{at\ rest})/(HR_{max} - HR_{at\ rest})\} \times 100$; F1: REI × relative HR; F2: Before and after training; F3: interaction.

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4. DISCUSSION

This study examined the effects of hypoxic training on physiological exercise intensity and recognition of exercise intensity in young men.

VO_{2max} increased after hypoxic training for 4 weeks. Haga and Ohno [10] classified endurance capacity into maximal ability such as VO_{2max} and submaximal ability as LT and emphasized that it is necessary to perform training to enhance both VO_{2max} and LT level to improve whole cardiovascular fitness. They also reported that high exercise intensity is important for improving VO_{2max} [10]. The current study used 60% VO_{2max} as the exercise intensity for hypoxic training. VO_{2max} increased markedly after training (ES = 1.0) despite this being performed at moderate intensity. VO_2 during subjective exercise intensity also increased after training.

VO_{2max} at high altitude decreases exponentially by approximately 10% with every rise of 1000 m [11]. This decrease is attributed to decreased oxygen supply to tissues that involves a decrease in CaO_2 and SpO_2 [12]. Hypoxic training by maintaining hypoxia for a given period of time is therefore expected to result in a stimulatory effect in addition to improving the cardiorespiratory response at rest [13]. The ability to transport oxygen to tissues shifts from an acute adaptation to a chronic adaptation when during hypoxic training continually for a certain period [14]. This represents altitude acclimation [14], which may contribute to an increase in VO_{2max} and a decrease in HR with increased cardiac output (*i.e*., an increase in cardiovascular fitness).

On the other hand, recognition of exercise intensity was lower for "fairly light" intensity exercise than for physiological exercise intensity (relative HR, relative VO_2) both before and after training. In short, this infers that participants ran with higher intensity than during subjective exercise intensity. In addition, relative VO_2 was also higher after training than before training. As the increase in VO_2 relative to increased VO_{2max} was high ("fairly light" intensity VO_2 before-training of 49.9% for VO_{2max} 51.2 ml/kg/min vs after-training of 54.2% for VO_{2max} 62.6 ml/kg/min indicates that the participants considered physiological exercise intensity was "fairly light" after training compared with before training even if they exercised at high intensity.

Imakawa [14] and Kacin *et al*., [15] reported that if people performed endurance training at high attitude with the same intensity as that at sea level, the hypoxic stimulation to tissues at high altitude may be increased because of the relative exercise intensity being increased compared with that at sea level. In our study, the participants felt comfortable running at pace in normoxic conditions because of the effect of hypoxic training, which may have influenced the physiological exercise intensity of "fairly light" intensity. Asano and Kobayashi [16] also reported that RPE in a 3 min run test conducted before and after a short period of hypoxic training (altitude: 2400 m) tended to decrease after training even during a run at the same speed under normoxic conditions.

Training in this study was performed in a normobaric hypoxic chamber instead of at high attitude, although it is inferred that the participants ran comfortably even if the exercise intensity was higher after training than before training.

However, there was no difference between recognition of exercise intensity and physiological exercise intensity. In short, "somewhat hard" intensity was approximately 65% (61.1% - 67.1%) of HR and VO_{2max} and was similar to physiological exercise intensity and recognition of exercise intensity. Robertson *et al*. [17] and Hayashi *et al*. [18] reported that people recognized fatigue in breathing and metabolism with emphasis on physical fatigue awareness at 70% VO_{2max}. This was similar to the "somewhat hard" exercise intensity used in this study (approximately 65%). When subjective exercise intensity is greater than moderate intensity, recognition of exercise intensity which people perceive subjectively agrees roughly with the intensity of physiological exercise. However, it is inferred that if it is low, the difference between both sides becomes larger and physiological exercise intensity is higher than recognition of exercise intensity. This study had not control group, and the sample size were small. Hence, further study is needed to examine the effects of hypoxic training on physiological exercise intensity and recognition of exercise intensity from comparisons with normoxic group.

5. CONCLUSION

After hypoxic training, both VO_{2max} and VO_2 increased during runs at "fairly light" and "somewhat hard" intensities. Physiological exercise intensity during running at "fairly light" intensity was higher than subjective recognition of exercise intensity. At "fairly light" intensity, physiological exercise intensity was increased after hypoxic training. Physiological exercise intensity and recognition of exercise intensity during a run at "somewhat hard" intensity are similar. In conclusion, hypoxia training causes an increase in VO_{2max} and physiological exercise intensity during a run at "fairly light" intensity.

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