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สรีรวิทยาการออกกำลังกายและกีฬา (Sports and Exercise Physiology)

WATER INTAKE ON CARDIORESPIRATORY FUNCTION DURING CONSTANT LOAD EXERCISE UNDER HYPOXIC CONDITION

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ABSTRACT

Objective: The aim of this study was to identify the effect of without and with water intake on cardiorespiratory function responses to exercise under hypoxic conditions in physically active males. **Method:** Nine physically active males (age: 18-22 yrs) voluntarily participated in three trials study: started with exercise under normoxic condition (NOR) to quantitate amount of water loss from 70% $\dot{V}O_{2max}$, exercise followed by two trials of hypoxic condition (15% inspired O_2) exercise under the same protocol without (HOW) and with (HWW) water intake equivalent to the same percentage of predetermined water loss. Exercise was conducted on a cycle ergometer at constant load on individual basis of predetermined workload – induced 70% $\dot{V}O_{2max}$. Cardiorespiratory variables including heart rate (HR), stroke volume (SV), cardiac output ($\dot{Q}$), oxygen saturation (SpO_2), respiratory rate (RR), minute ventilation ($\dot{V}_E$), tidal volume (V_T), with additional oxygen consumption ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), and rating of perceived exertion (RPE) were collected at rest, during exercise at 20, 40 and 60 minutes, and every five min interval recovery period.**Results**: Exercises under NOR and HOW conditions induced weight loss of 1.4 and 1.19% of body weight respectively. Therefore, water intake of 1.19% of body weight was sequentially sipped during HWW condition. Cardiac variables including HR, SV, $\dot{Q}$ showed no significant difference between groups. Within group comparison showed significant increasing HR, SV, $\dot{Q}$ from initial value at 20, 40 and 60 minutes of exercise and at 5, 10 and 15 minutes of recovery ($p<0.05$). Respiratory variables including RR and V_T showed no significant difference between groups with the exception of $\dot{V}_E$ where HWW has significantly higher than NOR ($p<0.05$). Increasing $\dot{V}_E$ in HWW group was most likely compensated by increasing RR while V_T was kept constant. Within group comparison showed significant difference of RR, V_T, $\dot{V}_E$ from initial value throughout the entire period of the study ($p<0.05$). We additionally explored metabolic and subjective variables. Data showed that no significant difference of these variables for between-groups comparison. Within-group comparison revealed significant difference. **Conclusion**: Exercise under hypoxic condition with water intake offers greater air ventilation. The compensation is likely to be due to achieving higher V_T with reflects ability of lung expansion. The underlying mechanism may be either humidity or lower temperature in the lung.

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KEYWORDS: Water Intake, Hypoxic Condition, Exercise, Cardiorespiratory Variables

INTRODUCTION

International sporting events are frequently organized at different terrains and environmental conditions for visitors, for example at high altitude, which may exert some remarkable effect on human physiological functions. Under hypoxic condition, as man descends to altitude of above 2,000 meters from sea level will develop general symptoms like shortness of breath, wheezing and dizzy.[1, 2] Previous studies have focused on the simulation of these hypoxic altitude environments at sea level via use of hypoxic-hypobaric condition. Hypoxic chamber has been used to simulate low oxygen condition by decreasing percentage of inspired oxygen concentration where the atmospheric pressure, at sea level, is kept constant at 760 mmHg. The real environment at altitude composes of hypoxic/hypobaric and low temperature, which causes hyperventilatory compensation, water loss and dehydration.[3, 4] The increasing of sweating and respiratory rate associated with exercise further increases water loss under hypoxic condition.[5, 6, 7] As acute normobaric hypoxia has popularly been used to determine the short-term physiological responses to hypoxic condition.[1] Acute hypoxic has been shown to cause a decline in oxygen delivery, a rise in sympathetic activity[8] and associated with increased in peripheral vasoconstriction[9], reduction in aerobic capacity[10] and a rise in heat storage.[11]

Previous research has not clearly shown the physiological responses to exercise in the simulated hypoxic condition. One evident showed physiological change during hypoxic exposure is possibly the results of water loss.[12] In addition, there is an increased risk of dehydration at altitude due to increased water vapor loss, energy expenditure and ventilation.[13] It is, therefore, water intake during exercise during acute hypoxia is important to maintain physiological and functional performance. However, due to the limited available document, it remains unclear how water intake can affect physiological responses during acute hypoxia. Thus, the effect of water intake during exercise and acute hypoxic exposure on cardiorespiratory functions remains to be elucidated.

METHODS

Participants

Nine physically active males, undergraduate students from Mahidol University, participated in this study. Their age ranges were between 18-22 yrs with no history of orthopedics and/or lower limb skeletal muscle disorders in the past 6 months before testing, no history of operation, cardiovascular and respiratory disorders in the past one year before testing, no vigorous exercise during the period of laboratory study. Participants who had smoking, taking alcohol within 24 hours and taking caffeine and food within 3 hours before the testing day, slept less than 8 hours, had injury during test were excluded from study. All participants needed to visit laboratory for sequential trials for different experimental protocols of: 1) exercise under normoxic condition and no water intake (NOR); 2) exercise under hypoxic condition without water intake (HOW); and 3) exercise under hypoxic condition with water intake (HWW). The study was approved by the local Ethics Committee on Human Experimentation of Mahidol University. They all read and signed an informed consent form before starting study.

Procedure

Participants attended the laboratory on 4 separated occasions of at least 3-5 days apart. On the first visit, anthropometric data were collected including height, weight, percentage of body fat (%body fat) and body mass index (BMI), resting heart rate (RHR), blood pressure (BP) and percutaneous oxygen saturation (SpO_2). Maximal oxygen consumption ($\dot{V}O_{2max}$) was measured using a gas analyzer (Oxycon® mobile, Germany). Workload at $\dot{V}O_{2max}$ was used as pre-determined exercise workload of 70%$\dot{V}O_{2max}$ for the next two trials which was adjusted for 60 minutes duration.(14) During the second visit, participant performed exercise under normoxic condition with no water intake where pre- and post-exercise nude weights were required to estimate for total water loss. During the third and fourth visits, participants performed exercise under hypoxic condition of 15% oxygen concentration, in a hypoxic chamber, at pre-determined exercise workload without and with water intake from pre-determined water loss, respectively. During 15-min recovery period, participants performed exercise with zero workload. Cardiorespiratory and hemodynamic variables were continuously monitored throughout the experiment. Participants were asked to provide their Rating of Perceived Exertion Borg Scale (RPE).

Statistical Analysis

Statistical analysis was performed using standard statistical package (SPSS® version 16 for Windows). A two-way analysis of variance (ANOVA) for repeated measures was used to test differences between trails over time. A one-way ANOVA with repeated measures was used to compare the mean time within each group. All data are reported as mean ±SEM, with $p<0.05$ significance level.

RESULTS

All participants completed the study without adverse complication. Their characteristics are shown in Table 1 including age, weight, height, BMI, %body fat, %lean body mass and $\dot{V}O_{2max}$.

Table 1. Characteristics of the participants involved in this study (Mean ±SD, n = 9)

Parameters	Values
Age (yrs)	20.00 ±1.12
Weight (kg)	72.90 ±6.54
Height (cm)	174.78 ±7.29
BMI ($kg.min^{-2}$)	23.83 ±1.52
%Body fat	18.59 ±4.00
%Lean body mass	35.19 ±1.62
$\dot{V}O_{2max}$ ($ml.min^{-1}.kg^{-1}$)	32.94 ±5.80

Changes in metabolic variables

No significant differences among the groups were detected. Within-group comparisons revealed that oxygen consumptions ($\dot{V}O_2$) and carbon dioxide production ($\dot{V}CO_2$) during exercise in all conditions showed significant difference from corresponding initial resting values (p<0.05). These characteristics were found throughout the entire period of recovery (p<0.05). All conditions showed similar pattern of significant decline of oxygen consumption abruptly when exercise was terminated. These two gases during recovery process remained significantly higher than the corresponding resting values in all conditions. However, HWW group showed faster recovery in $\dot{V}CO_2$ in 10 min and in RER immediately after exercise.

Respiratory Exchange Ratio (RER) at rest in NOR, HOW and HWW showed in Table 2 with no significant difference between conditions. There were similar significantly increased, at the range of 0.96-0.98, from initial values (p<0.05) during exercise in all conditions. Immediately after exercise, RER in all conditions continuously rose toward 1.00.

Table 2. Within-condition comparison of metabolic variables at rest, during exercise and 15 min recovery.

Variables	rials	Rest	Ex 20	Ex 40	Ex 60	Rec 5	Rec 10	Rec 15
VO_2 $(ml.kg^{-1}.min^{-1})$	OR	4.97 ±0.30	21.87 ±1.12*	21.73 ±1.20*	22.06 ±1.44*	7.95 ±0.55*,π	7.69 ±0.48*	7.62 ±0.42*
	OW	5.23 ±0.27	21.56 ±0.94*	21.36 ±0.82*	21.42 ±0.76*	8.26 ±0.38*,π	8.32 ±0.30*	7.58 ±0.34*
	WW	5.93 ±0.27	23.18 ±1.07*	22.68 ±1.00*	22.78 ±1.00*	8.15 ±0.26*,π	7.70 ±0.29*	7.53 ±0.31*
VCO_2 $(ml.kg^{-1}.min^{-1})$	OR	4.34 ±0.26	21.32 ±1.08*	20.77 ±1.10*	20.82 ±1.24*	7.86 ±0.51*,π	7.01 ±0.46*,π	6.58 ±0.41*
	OW	4.78 ±0.30	21.04 ±0.98*	20.27 ±0.73*	20.13 ±0.64*	7.90 ±0.45*,π	7.19 ±0.30*,π	6.38 ±0.28π
	WW	5.32 ±0.24	22.45 ±1.07*	21.79 ±0.92*	21.45 ±1.05*	7.85 ±0.37*,π	6.97 ±0.30*	6.28 ±0.34
RER	OR	0.88 ±0.02	0.98 ±0.01*	0.97 ±0.01*	0.95 ±0.01*	1.00 ±0.03*	0.92 ±0.02	0.85 ±0.02π
	OW	0.91 ±0.02	0.98 ±0.01	0.95 ±0.01	0.94 ±0.01	0.96 ±0.03	0.87 ±0.02π	0.84 ±0.02*
	WW	0.90 ±0.01	0.97 ±0.01*	0.96 ±0.01*	0.95 ±0.01*	0.96 ±0.03	0.91 ±0.03	0.83 ±0.03

* Significant difference from initial value, p < 0.05

π Significant difference from previous value, p < 0.05

Changes in respiratory variables

Respiratory rate (RR) and tidal volume (V_T) at rest in NOR, HOW and HWW (Table 3) showed no significant difference between conditions. As exercise was started, RR in all conditions showed significant increase from initial values (*p*<0.05). All conditions showed similar pattern of significant decline of RR abruptly when exercise was terminated. Data showed that exercise under hypoxic condition with water intake (HWW) had complete recovery within 15th minute. Data of V_T in all conditions showed the complete recovery within 5th minute.

Minute ventilation ($\dot{V}_E$) at rest in NOR, HOW and HWW showed no significant difference between conditions but increased significantly from initial values in all conditions (*p*<0.05). Data showed that when exercise was started until recovery period, $\dot{V}_E$ in NOR had significantly lower than in the HWW (*p*<0.05). $\dot{V}_E$ during recovery period remained higher than initial values which indicated that there was no complete recovery for all conditions.

Table 3. Within-condition comparisons of respiratory variables at rest, during exercise and 15 in recovery.

Variables	rials	Rest	Ex 20	Ex 40	Ex 60	Rec 5	Rec 10	Rec 15
RR (times/min)	OR	18.15 ±1.21	33.61 ±1.94*	34.59 ±1.94*	36.52 ±2.48*	27.31 ±1.53$^{*,\pi}$	26.50 ±0.87*	25.44 ±0.97*
	OW	18.78 ±1.67	37.44 ±2.17*	39.22 ±2.48*	40.22 ±2.37*	28.78 ±3.28$^{*,\pi}$	24.22 ±1.98*	24.67 ±1.99*
	WW	20.56 ±1.81	37.33 ±2.28*	38.11 ±1.41*	40.78 ±2.09*	30.67 ±1.71$^{*,\pi}$	26.33 ±1.35	26.56 ±1.38
V_T (L)	OR	0.63 ±0.06	1.36 ±0.08*	1.27 ±0.08*	1.28 ±0.10*	0.76 ±0.06$^{\pi}$	0.68 ±0.04	0.67 ±0.03
	OW	0.73 ±0.08	1.38 ±0.10*	1.32 ±0.08*	1.28 ±0.07*	0.87 ±0.12$^{\pi}$	0.88 ±0.12	0.77 ±0.08
	WW	0.72 ±0.17	1.46 ±0.08*	1.38 ±0.03*	1.33 ±0.06*	0.72 ±0.04$^{\pi}$	0.73 ±0.05	0.67 ±0.04
$\dot{V}_E$ (L.min^{-1})	OR	10.93 ±0.57	45.06 ±2.52^{*,b}	44.37 ±2.02*,^{b}	45.61 ±2.23*,^{b}	19.41 ±0.85$^{*,\pi,b}$	18.00 ±0.80^{*,b}	16.65 ±0.85$^{*,\pi,b}$
	OW	12.56 ±1.00	50.00 ±2.84*	50.00 ±2.60*	50.11 ±1.82*	21.67 ±1.00$^{*,\pi}$	19.11 ±0.72*	17.11 ±0.65
	WW	13.67 ±0.80	52.67 ±1.94*	52.22 ±1.95*	53.89 ±1.91*	21.56 ±0.87$^{*,\pi}$	18.89 ±0.54*	17.33 ±0.78*

* Significant different from initial value, $p < 0.05$

π Significant difference from previous value, $p < 0.05$

a Significant difference between NOR-HOW, $p<0.05$

b Significant difference between NOR-HWW, $p<0.05$

c Significant difference between HOW-HWW, $p<0.05$

Changes in cardiac variables

Heart rate (HR), stroke volumes (SV), cardiac outputs ($\dot{Q}$) and resting oxygen saturation (SpO_2) at rest in NOR, HOW and HWW showed in Table 4 with no significant difference between conditions. As exercise was started, HR and SV in all conditions showed significant difference from corresponding initial values throughout the entire period of study ($p<0.05$). All conditions showed similar pattern of significant decline of HR and SV abruptly when exercise was terminated. HR during recovery process remained significant difference from initial values ($p<0.05$) indicated that there was no complete recovery in HR. SV in all conditions showed similar pattern of significant decrease abruptly when exercise was terminated and data showed all conditions had been completely recovery within 5^{th} minute. $\dot{Q}$ in NOR during recovery process remained higher than initial value indicating that there was no complete recovery in this condition, however $\dot{Q}$ in HOW and HWW data showed complete recovery within 10^{th} and 5^{th} minute respectively. Normoxic condition had unchanged SpO_2 when compare with exercise levels. However, exercise under hypoxic condition induced significant lower SpO_2 value since the beginning of exercise.

Table 4. Within-group to comparison of cardiac variables at rest, during exercise and 15 min recovery.

Variables	rials	Rest	Ex 20	Ex 40	Ex 60	Rec 5	Rec 10	Rec 15
HR (beats/min)	OR	80 ±3.39	143 ±4.50*	146 ±4.75*	150 ±5.55*	107 ±4.85*,π	100 ±4.54*,π	100 ±4.26*
	OW	80 ±2.69	142 ±3.02*	145 ±3.82*	149 ±4.06*	107 ±3.16*,π	103 ±2.56*	99 ±2.26*,π
	WW	79 ±3.23	141 ±4.13*	142 ±3.85*	143 ±3.67*	102 ±4.14*,π	97 ±3.24*,π	94 ±3.11*,π
SV(ml)	OR	72.72 ±4.56	93.00 ±4.56*	96.81 ±5.06*	94.93 ±4.31*	80.13 ±5.38π	79.22 ±5.90	79.11 ±6.17
	OW	74.44 ±3.29	99.67 ±3.52*	99.44 ±4.33*	101.00 ±3.96*	81.67 ±5.45	79.22 ±4.97	77.89 ±5.24
	WW	76.00 ±2.72	104.78 ±4.47*	107.00 ±4.26*	105.33 ±3.81*	86.00 ±6.06π	82.78 ±5.80	84.22 ±4.92

$\dot{Q}$ (L.min^{-1})	OR	5.84 ±0.27	13.35 ±0.65*	14.19 ±0.70*	14.23 ±0.70*	8.56 ±0.54$^{*,\pi}$	7.97 ±0.56*	7.88 ±0.59*
	OW	5.97 ±0.22	14.22 ±0.54*	14.55 ±0.75*	15.18 ±0.69*	8.86 ±0.69$^{*,\pi}$	8.28 ±0.58*	7.84 ±0.60
	WW	6.02 ±0.17	14.81 ±0.63*	15.14 ±0.81*	14.92 ±0.79*	8.83 ±0.62$^{\pi}$	8.07 ±0.61	7.95 ±0.51
SpO_2	OR	100 ±0.00	100 ±0.00^{a,b}	100 ±0.15^{a,b}	100 ±0.15^{a,b}	100 ±0.11^{a,b}	100 ±0.00^{a,b}	100 ±0.14^{a,b}
	OW	98 ±0.29	93 ±0.73*	93 ±0.94*	93 ±0.73*	97 ±0.41$^{\pi}$	97 ±0.58	97 ±0.60
	WW	97 ±0.37	93 ±0.88	93 ±0.83	94 ±0.64*	98 ±0.41$^{\pi}$	97 ±0.41	96 ±0.65

* Significant different from initial value, $p < 0.05$

π Significant difference from previous value, $p < 0.05$

a Significant difference between NOR-HOW, $p<0.05$

b Significant difference between NOR-HWW, $p<0.05$

c Significant difference between HOW-HWW, $p<0.05$

Changes in subjective variables

RPE at the beginning was determined as six which indicated that subjects felt comfortable, when exercise was started, RPE increased up to 12 with represented somewhat hard feeling. Up to exercise at 60th minute, RPE increased up to 15 with showed hard feeling. All conditions showed similar pattern of significant decline of RPE abruptly when exercise was terminated.

DISCUSSION

This study found that all characteristics were in normal ranges of Thai population at this age .[15] Resting $\dot{V}O_2$, $\dot{V}CO_2$ RER, RR, V_T, $\dot{V}_E$, HR, SV and $\dot{Q}$ in all conditions are in normal ranges and not significantly different during conditions. However, some variables showed little higher values because of the unusual breathing circumstance.

To sustain muscle contraction during prolonged exercise the body requires continuous energy-derived ATP (adenosine triphosphate), which can be produced via three metabolic pathways: the phosphagen system, glycolysis and mitochondrial respiration. The latter pathway is found to produce energy predominantly through mitochondrial respiration, or aerobic metabolism via biochemical processes within the mitochondria of the cells. This means that mitochondrial function is remarkably and continuously activated for long period of time.[16] It is no doubt that this biochemical reactions involved in mitochondrial respiration will not abruptly ceased during recovery phase. Indicators for the slowing down of this biochemical engine are demonstrated with higher respiratory rate, heart rate, as well as body heat.[17, 18] Levels of metabolism during recovery were higher than resting values as the factor of excess post-exercise oxygen consumption (EPOC). This EPOC has different relationships to levels of exercise intensity and duration. For example, there is an exponential relationship between exercise intensity and the magnitude of the EPOC at 50-60% $\dot{V}O_{2max}$[19] and may be doubled at intensity of 90%.[20] It is proved that metabolic rate is not static where it fluctuates throughout the day according to physical activity, food intake and time of day. Apart from exercise intensity, other factors affecting changes in post-exercise metabolic rate have been focused with type of exercise, duration.[21, 22]

Water supplement at the same amount water loss contributes for physiologic adjustments in that water loss via sweating is a normal physiological response to prolonged exercise where heat dissipation will diminish risks of thermal accumulation. It is reported that the substantial fluid loss may impair physical performance.[23] Dehydration also results in higher deteriorating physiologic responses resulting from the lower volume of blood plasma. Fatigue from prolonged exercise is a result of either dehydration or fuel substrate depletion. Exercise performance is impaired when an individual is dehydrated by as little as 2% of body weight. Losses in excess of 5% of body weight can decrease the capacity for work by about 30%.[24] The present study indicated that moderate exercise at 70%$\dot{V}O_{2max}$ in normoxic and hypoxic conditions caused reduction in body weights of 1.4 and 1.2% respectively. Previous study indicated that adequate hydration during endurance exercise will bring about continuous oxygen supply to working muscles and vital organs.[25] The present study did not demonstrate the effect of hydration during constant load endurance exercise, in particular under hypoxic condition to conceptually maintain or enhance performance. The main reason is that the redistribution of regional blood flow from some parts, intestines to liver, may reduce the rate of gastric emptying and intestinal absorption. This will, therefore, mismatch with the high rates of sweat loss via skin.[26]

Previous study indicated the normal ranges of breathing frequency, tidal volume and ventilation of 36.1 ±9.2 bpm, 2.7 ±0.48 L and 97 ±25 L/min respectively.[27] Comparing to the literature, it is quite certain that subjects in the present study respond to their maximal breathing frequencies but did not achieved their maximum tidal volumes and ventilations. Throughout the entire period of exercise, subjects increased RR and V_T of about 2 folds from resting levels while $\dot{V}_E$ increase of about 4 folds. Since ventilation is the product of tidal volume (V_T) and respiratory rate (RR), subjects may automatically combine these 2 variables to increase ventilation. However, there is some evidence that maintaining a higher V_T and lower RR may result in both lower metabolic and respiratory demands for oxygen.[28] However, it is suggested to increase V_T will appear only at high exercise intensity since greater generation of V_T will induce excessive intrathoracic pressure.[29]

The present study revealed that cardiac contractility, cardiac output and SpO_2 in all groups fully recover as exercise was terminated. Only cardiac rhythms remained activated. Previous report specified the lower SV, increasing in SV compared to increasing in HR, is the result of lower ejection fraction in the upright position.(30) Lower SpO_2 in HOW and HWW were the result of lower inspired oxygen.(31)

CONCLUSION

The results of this study indicate that water intake is required during we exercise under hypoxic condition. Exercise under hypoxic condition with water intake fastens recovery in rate of carbon dioxide production and RER and offers greater air ventilation. The compensation is likely due to achieving higher V_T with reflects ability of lung expansion. The underlying mechanism may be either humidity or lower temperature in the lung. When exercise under hypoxic condition with water intake enhance better recovery of RER within 15th minute. There is early compensation of cardiac contractility during the first ten minute of exercise while cardiac rhythm remained high.

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