Effects of Underwater Arm-Cranking Exercise on Cardiac Autonomic Nervous Activity

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ABSTRACT

The purpose of this study was to clarify the beneficial effect of an underwater environment on heart rate (HR) and cardiac autonomic nervous activity (HF) during arm-cranking exercise. Ten healthy young men participated in this study. The arm-cranking exercise (40% peak$\dot{V}O_2$) was performed for 10 minutes under two conditions: in water and in air. After the exercise, a recovery phase for 30 seconds followed. Changes in HR, $\dot{V}O_2$, and HF did not differ between the conditions. The time constant of the heart rate decay for the first 30 seconds after exercise in the water was less than in air. The results suggest that cardiac parasympathetic nervous activity influences earlier recovery of HR after exercise in water. The results of our study suggest underwater exercise may be applied to wider areas of health management for individuals returning from space travel or sedentary patients in simulated microgravity environments.

Key words: Cardiac autonomic nervous system; underwater environment; heart rate; arm-cranking exercise; simulated microgravity; adaptation.

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INTRODUCTION

The human body's autonomic nervous system controls important reflexes regulating heart rate and blood pressure. Space adaptation syndrome is one of the major complications associated with space travel (Thornton et al., 1987). This condition is not dependent on duration but occurs due to deconditioning of the circulation and nervous system. The pathophysiology is due to the decreased total body water, increased vein compliance, etc. These changes also occur among sedentary people, for example patients on prolonged bed rest, obesity, type 2 diabetes, etc. In Japan, it is believed that 22.1 million people are strongly suspected of having diabetes or presumed to have diabetes (Ministry of Health, Labour and Welfare, 2008). Many diabetic patients suffer from complications, such as diabetic nephropathy, retinopathy, and neuropathy. Epidemiological and intervention studies showed that endurance training was effective for improving the conditions of astronauts returning to Earth and aforementioned patients. There are various endurance trainings, namely treadmill walking, cycling, arm cranking exercise, etc. (Ono et al., 2005, 2006). In this study, we determined safe and effective exercise for such patients to avoid orthostatic hypotension. Hence, arm-cranking exercise was chosen. Exercise in air decreases renal blood flow depending on the intensity. However, renal blood flow is maintained during exercise in water. Moreover, buoyancy reduces loading on the leg joints. Additionally, prevention of deconditioning due to spaceflight will lead to prevention of deconditioning in sedentary patients.

The purpose of this study was to determine and clarify beneficial effects of exercise underwater on cardiac autonomic nervous activity during arm-cranking.

METHODS

Ten healthy young men (age: 21.7 ± 1.5 yrs, stature: 171.0 ± 5.7 cm, body mass: 60.7 ± 3.8 kg, BMI: 20.4 ± 1.7; mean ± SD) participated. This study was granted approval by the Health Sciences Ethics Committee in Kobe University.

Initially, the participants' peak$\dot{V}O_2$ was assessed to set the intensity of arm-cranking exercise on land. We used the arm ergometer (Monark; portable ergometer 881E) in this study. Before assessment, the height of the participants' acromial process and ergometer's axis of rotation were set at the same level. Arm-cranking exercise was performed with gradual increase in the load every 2 minutes. Cranking was done at 50 revolutions per minute (rpm). Examination was stopped when revolution could not be maintained. Cranking was conducted with mask on the participants' face in order to measure the $\dot{V}O_2$ by gas analysis (Arco System; AR-1). The participants breathed through a mask connected to a flowmeter for continuous measurement of inspired and expired volume and by sensor for continuous measurement of O_2 and CO_2 concentration. $\dot{V}O_2$ was computed, at 15-seconds interval, using the gas analysis software (Arco System; AR-1 O-jiro series Ver.3.47) through a personal computer (Toshiba; dynabook satellite T42).

The following day, examination was started with a rest on land in a sitting position for 5 minutes. After that, participants entered a water-filled tub and rested in a sitting position for 10 minutes. After the rest in the tub, they started arm-cranking exercise for 10 minutes. The participants exercised at 50 rpm controlled by a metronome. The intensity of exercise was equivalent to 40% peak$\dot{V}O_2$. Two conditions were set: exercise in the water (W-condition) and exercise on the ground (C-condition) as control. All of the experimental procedures were performed in two randomized sessions on separate days at the almost same time each day. The W-condition's water depth was at the level of the xiphoid process. After the exercise, recovery was allowed for 30 seconds continuously in the same position. The parameters for measurements were oxygen uptake ($\dot{V}O_2$), heart rate (HR), rating of perceived exertion (RPE) and rating of perceived fatigue sense (RPFS) of the upper extremity by using the Borg scale (6-20), and cardiac parasympathetic nervous activity (high frequency: HF) during the experiment and time constant of the heart rate decay for the first 30 seconds after exercise (T30). We measured HR and R-R interval by using the HR monitor (GMS; Active Tracer). We calculated HF by using the analysis system (GMS; MemCalc/Tarawa). Room temperature, humidity, and water temperature during the experiments were 27.4 ± 1.0 ˚C, 81.4 ± 11.3 %, and 30.4 ± 0.3 ˚C in W-condition, respectively. Room temperature and humidity were 26.8 ± 1.5 ˚C and 74.0 ± 10.9 % in C-condition, respectively.

DATA ANALYSIS AND STATISTICS

Cardiac parasympathetic nervous activity values (HF) were analyzed with logarithmic transformation to normalize the data (ln HF). Data were expressed as mean ± SD except for RPE. RPE was expressed as median ± SD.

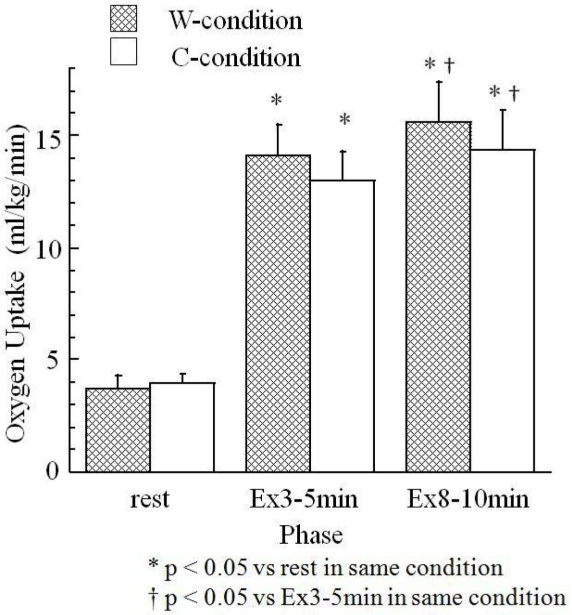
Repeated-measures factorial ANOVA compared changes between the conditions in $\dot{V}O_2$, HR, and ln HF, respectively. The paired Student's *t*-test compared differences between the conditions in HR at rest phase and T30, respectively. The statistically significant value was set to $p<0.05$. Effect sizes (Cohen's d-presented as ''d'') was calculated for exercise induced changes in HR and T30 with 0.2, 0.5, and 0.8 representing small, medium, and large effect, respectively (Mullineaux et al., 2001).

RESULTS

The peak$\dot{V}O_2$ was 27.0 ± 3.9 ml/kg/min.

The intensity of exercise was set at 11.5 ± 4.9 W. Figure 1 shows changes in oxygen uptake during the experiment. The levels of $\dot{V}O_2$ of W-condition and C-condition during the end of the arm-cranking exercise for 2 minutes were 15.6 ± 1.8 ml/kg/min and 14.4 ± 1.8 ml/kg/min, respectively. No significant differences were found in the oxygen uptake.

Figure 2 shows changes in heart rate during arm-cranking exercise for 10 minutes. HR of W-condition at rest (62.0 ± 8.3 bpm) was significantly lower than that of C-condition (74.3 ± 8.6 bpm) ($p<0.05$, d=1.46). The changes in HR during exercise were not significantly different in the two conditions, though HR at the end of exercise in W-condition (109.4 ± 14.6 bpm) was lower than C-condition (123.6 ± 19.6 bpm).



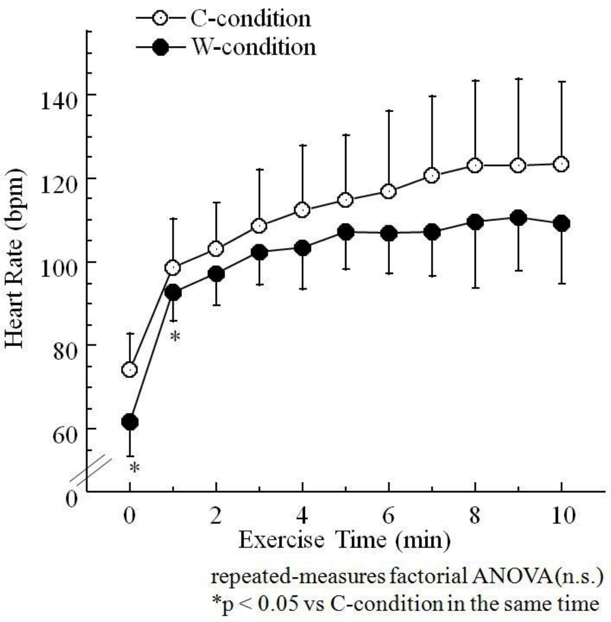
* $p < 0.05$ vs rest in same condition
† $p < 0.05$ vs Ex3-5min in same condition

Figure 1. Changes in oxygen uptake during the experiment. There were no significant differences in the two conditions, exercise in the water (W-condition) and on the ground as control (C-condition), at the same phase.

The end of the exercise's RPE was 11 ± 2.6 at W-condition and 13 ± 3.3 at C-condition. The intensity showed from 'Fairly light' to 'Somewhat hard.' The end of the exercise's RPFS was 15 ± 1.0 at W-condition and 15 ± 2.2 at C-condition. The intensity showed 'Hard.' The changes in RPE and RPFS were not significantly different between W-condition and C-condition.

Figure 3 shows changes in ln HF during the experiment. Ln HF at rest was 7.03 ± 1.08 at W-condition and 5.96 ± 1.59 at C-condition. These results were not significantly different, though the W-condition's ln HF was higher than that of C-condition. Ln HF at exercise phase of both conditions was lower than at rest. These results were not significantly different between W-condition and C-condition.

T30 at W-condition was 153.5 ± 42.5 and at C-condition was 254.6 ± 97.7. T30 at W-condition was significantly lower than that of C-condition ($p<0.05$, d=1.31).



repeated-measures factorial ANOVA (n.s.)
*$p < 0.05$ vs C-condition in the same time

Figure 2. Changes in heart rate during arm-cranking exercise for 10 minutes. There were no significant differences in the two conditions, exercise in the water (W-condition) and on the ground as control (C-condition), during exercise. Heart rates in W-condition at rest (time 0) and time 1 were lower than that of C-condition significantly ($p<0.05$).

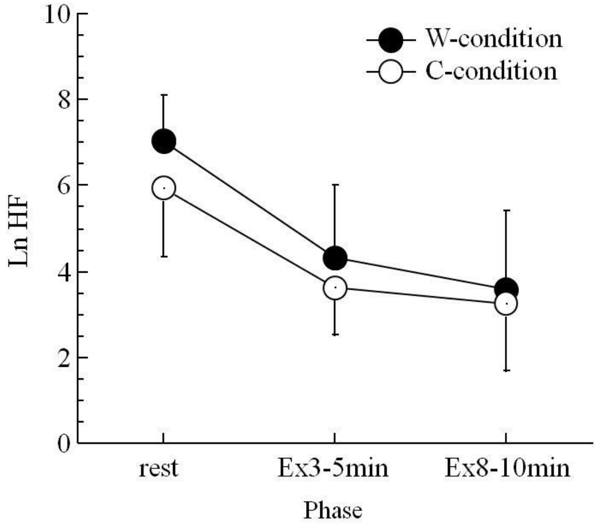


Figure 3. Changes in ln HF during the experiment. There were no significant differences in the two conditions, exercise in the water (W-condition) and on the ground as control (C-condition), at the same phase.

DISCUSSION

The participants' peak$\dot{V}O_2$ levels were similar to the preceding study (Arakane et al., 2011). Hence, valid testing before the experiment was feasible.

The $\dot{V}O_2$, HR, RPE, and RPFS were not significantly different in the two conditions during exercise. The water level in W-condition was kept below the participants' upper extremities to match the C-condition's exercise pattern. It is suggested that since water resistance was not affected, there was no difference in the exercise intensity based on the condition. It is reported that the cross sectional areas of the vena cava during 60% $\dot{V}O_2$max arm cranking exercise in water decreased in 10 minutes and became equal to the areas on land exercise at 10 minutes (Onodera et al., 2005). Actually in this study, the intensity at the end of exercise showed about 59% peak$\dot{V}O_2$ at W-condition and 54% peak$\dot{V}O_2$ at C-condition. It is reported that arm cranking exercise's peak$\dot{V}O_2$ was about 60% of lower extremity ergometer exercise (Arakane et al., 2011). In addition to the increased HR during exercise in both conditions, a lower intensity than the calculated should be set when giving exercise prescription of arm-cranking in order to maximize the effect of underwater exercise. W-condition's T30 was significantly lower than that of C-condition. The participants at W-condition may have been affected by water pressure that led to increased venous return during the recovery phase. T30 could be an index of vagally-mediated heart rate recovery after exercise (Imai et al., 1994). With these factors, it is suggested that cardiac parasympathetic nervous activity plays a role in the early recovery of HR immediately following exercise in water.

CONCLUSION

Arm-cranking exercise in the sitting position in water could lead to faster recovery of heart rate than on the ground. This exercise is deemed safe in consideration of the human's circulation. The results of our study suggest underwater exercise may be applied to wider areas of health management for individuals returning from space travel or sedentary patients in simulated microgravity environments.

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