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Research Article

The Effect of 6-Meter Underwater Diving Intervention on Recovery of Exercise-Induced Fatigue

Ma Q[1-3]; Wu D[2]; Yue Y[2]; Zhong T[1]; Yu X[1]; Xiao Y[1]; Wang L[1*]

[1]Faculty of Medicine, Macau University of Science and Technology, Macau, China

[2]School of Physical Education, Guangdong Business and Technology University, Zhaoqing, China

[3]School of Physical Education, Guangdong Business and Technology University, Zhaoqing, China

***Corresponding author:** Wang L

Faculty of Medicine, Macau University of Science and Technology, Macau, China

Email: lingwang@must.edu.mo

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Abstract

Objective: To evaluate the effect of 6-meter underwater diving on recovery of exercise-induced fatigue and explore the potential mechanism.

Method: Thirty-three male sophomores majored in physical education were included in this self-control, cross-over study. The fatigue was induced through programed swimming exercise at same intensity for both control and intervention groups. After exercise-induced fatigue, the subjects recovered through sitting on the floor and 6-meter underwater diving for 15 minutes in control and intervention groups respectively. The parameters observed included Heart Rate (HR), Critical Flicker Frequency (CFF), Simple Reaction Time (SRT) and Standing Long Jump (SLJ).

Results: The HR was faster after exercise and recovery compared to that before exercise in both groups. SLJ was shorter after recovery compared to before exercise fatigue in both groups. After diving recovery, the CFF was lower than that before exercise fatigue, while the index of SRT was higher than that before exercise fatigue. Compared with the control group, the HR and SRT were significantly lower, but the SLJ and CFF were significantly higher in the intervention group than those of control group (HR, $p<0.05$; SRT, $p<0.01$, SLJ, CFF $p<0.01$).

Conclusion: The fatigue recovery effect of 6m underwater environment is better than that of land recovery. The low temperature, mild hyperbaric oxygen, water pressure and buoyancy in under water environment may promote the repair of muscle and motor nerve after exercise and improve the exercise performance after intervention.

Keywords: Fatigue; Recovery; Underwater diving; Exercise

Introduction

Sport fitness is an important way to improve physical fitness, but it inevitably results in exercise fatigue. Therefore, the recovery of exercise-induced fatigue is crucial for both athletes and general population. Although a variety of fatigue recovery methods are available, as a way to restore physical strength and spirit relaxation, fatigue recovery through shallow underwater diving has limited reports. Some studies showed that individual factors, such as low temperature, high water pressure, and hyperoxia in the underwater environment could promote the recovery of exercise-induced fatigue [1-3]. Therefore, it is of great significance to study the effect of six-meter underwater diving on exercise-induced fatigue recovery. It might provide a new measure for the recovery from exercise-induced fatigue through special environment and expand the research scope of underwater diving medicine.

Research Method

Subjects

Thirty-eight subjects were recruited from the male sophomores majored in physical education in a vocational and technical university of Guangdong province, China, five subjects dropped-out during the study, 33 finished the study.

Inclusion and exclusion criteria

Inclusion criteria

- Gender: Male;
- Age: 18-19 years old;
- Be proficient at breaststroke and crawl swimming, without any professional swimming training experience;

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- Right-handed;
- After training, one will be able to balance the underwater diving ear pressure.

Exclusion criteria

- Having congenital heart defect and rheumatic heart disease;
- Having myocarditis and cold;
- Having family history of coronary heart disease and severe arrhythmia;
- Having acute nephritis;
- Unintentional participants.

During the experiment, the subjects were required to have normal diet and regular life-style, but should not have vigorous exercise, medication, and beverages containing coffee, alcohol.

Study Design

The study was self-control, cross-over design. Physical fatigue was induced through 1700-meter swimming exercise, including 400m breaststroke and crawl swimming warm-up (decomposition exercise and complete exercise) in 10 minutes, and 1300-meter breaststroke and crawl swimming interval exercise (decomposition exercise and complete exercise) in 55 minutes. The subjects in control and intervention groups received same content of fatigue induction. The recovery had two ways, one was Land Recovery (LR) for control group, and the other was underwater Diving Recovery (DR) for intervention group. The LR was simply sitting on the floor near the swimming pool and the DR was 6-meter underwater diving kept the body with flat posture in the water. The subjects in both groups experienced 15-minute recovery period. To avoid the individual variation, all of the subjects experienced LR in the first experiment and then DR in the second experiment. The washout period of one week was applied between two experiments to eliminate the influence of previous experiment. All of the subjects were well trained to dive and balance ear pressure under water. Licensed lifeguards and divers were on duty during the experiments. All of the standard facilities for underwater diving were carried by the subjects during the underwater diving activity.

Parameters and Data Collecting

The parameters were measured including Heart Rate (HR) (before fatigue, after fatigue, and after recovery), Critical Flicker Frequency (CFF), Simple Reaction Time (SRT), Rating of Perceived Exertion scale (RPE), and Standing Long Jump (SLJ) (before fatigue and after recovery) for both control and intervention groups.

The indicators and methods for evaluation of fatigue and recovery

1) Rating of Perceived Exertion scale (RPE scale). RPE score could not only express the subjective feeling of fatigue, but also reflect the local muscle fatigue state. There are 15 grades of RPE sensory scale. The RPE scores of different grades multiplied by 10 are approximately equivalent to the heart rate value at the same time.

2) Isokinetic measurement of skeletal muscle strength using the SLJ method. The subjects were fully prepared before the test. During the test, the subjects naturally stood behind the specified line with their feet separated, and put their hands on their hips to reduce the impact of arm swing on the results. The subjects took off on both feet at the same time, and jumped as far as possible. The test result was the vertical distance from the trailing edge of the jumper to the trailing edge of the nearest landing point. Each subject received three tests, and the farthest score was recorded as the test result. Record two decimal places in meters.

3) Heart Rate (HR): Counting the heart beat for 10 seconds and then times by 6 to get the heart beat per minute.

4) Simple Reaction Time (SRT): Using standard instrument Beida Qingniao BD-II-510 (A reaction time tester) to test the reaction time. The subject pressed the button and waits for the stimulation signal from the instrument. Once the subject saw the light, he should immediately press the button to stop. The time between the signal sent by the instrument to be seen by the subject was the SRT. The test was conducted for three time for each subject and the result was the average of the three.

5) Critical Flicker Frequency (CFF): Standard instrument Beida Qingniao BD-II-118 critical flicker frequency meter was used to test the visional fusion frequency, which is a commonly used method to evaluate the fatigue reflexed through eye test. The subject was asked to have his eyes close to the observation tube, and the flicker frequency was adjusted by turning the "frequency adjustment" knob on the right side of the instrument. When the flashing was just about disappeared (fusion), the adjustment should be stop immediately and the frequency was record. The average value was obtained by repeated testing for 3 times near the fusion point.

Data Analysis

The HR, The Normal distributed data were represented by mean and standard deviation, and the difference between the two groups was compared by paired t-test. The non-normal distributed data were represented by the median and Quartile. Shapiro Wilk test was used to compare the differences between the two groups. Wilcoxon rank sum test was used to analyze RPE. Spearman correlation analysis was applied to analyze the parameters of RPE and HR.

Results

Exercise-Induced Fatigue

The swimming-induced fatigue was successful, which could be judged through HR, SLJ, SRT. Since the subjects in the intervention group should dive into water right after exercise, the fatigue parameters were only measured in the subjects in control group. It could be seen that the HR, SRT were significantly increased, but the SLJ was significantly decreased after swimming exercise compared with before exercise in the subjects ($P<0.05$). According to the Borg formula of RPE, "heart rate=RPE*10", the corresponding heart rate was calculated. The heart rate was increased after exercise in the subjects. The result of Spearman correlation analysis showed that the correlation of heart rate with exercise was significant ($p<0.01$), and the correlation coefficient was 0.906.

The Effect of Washout

To eliminate the influence of the previous experiments on the following activity, one week of washout period was conducted between the two experiments for both groups. The data showed that the HR, CFF, SLJ and SRT were not significantly different between control and intervention groups before and after washout period (data not shown), which implied that the washout period was long enough and the influence between two experiments could be ignored.

The Comparison of Four Parameters between Control and Intervention Groups, as well as, within Group

The HR was significantly increased after exercise-induced fatigue and decreased after recovery in both groups (p<0.001 or <0.05), but was significantly lower in intervention group than that in control group after recovery (p=0.01).

The SRT was significantly longer in control group after fatigue and after land recovery compared to before fatigue (p<0.05), also longer than that in intervention group after recovery (p<0.01), but not significantly different in the intervention group before fatigue and after recovery (p>0.05).

The distance of SLJ after fatigue and after recovery was significantly shorter than that before fatigue (p<0.05, p<0.01), but was significantly longer after recovery in intervention group than that in control group (p<0.01).

No significant differences were found before and after fatigue, as well as after recovery between and within groups for CFF (p>0.05), please refer table 1 & 2 for details.

Table 1: Intra and inter group t-test results for each indicator (n=33).

Indicator/time point	Mean±SD	Comparison	t	p-value
SLJ (m)				
CB	2.61±0.11	CB vs. CA	5.05	<0.001
CA	2.43±0.16	CB vs. CLR	2.19	0.036
CLR	2.55±0.13	CA vs. CLR	-14.1	<0.001
IB	2.61±0.13	IB vs. IDR	7.41	<0.001
IDR	2.56±0.13	IDR vs. CLR	3.25	0.003
CFF (Hz)				
CB	34.73±2.42	CB vs. CA	1.41	0.168
CA	33.84±2.07	CB vs. CLR	1.16	0.255
CLR	34.09±1.83	CA vs. CLR	-0.52	0.606
IB	34.83±2.25	IB vs. IDR	0.13	0.894
IDR	34.75±2.18	IDR vs. CLR	1.68	0.104
HR (bpm)				
CB	78(72,84)	CB vs. CA	-35.78	<0.001
CA	168(156,174)			

Note: B: Before Fatigue; A: After Fatigue; C: Control Group; I: Intervention Group; R: Recovery; L: Recovery On Land; D: Recovery Through Underwater Diving; Based On Above, CB: Control Group Before Fatigue; CA: Control Group After Fatigue; CLR: Control Group Land Recovery; IB: Intervention Group Before Fatigue; IA: Intervention Group After Fatigue; IDR: Intervention Group Recovery Through Underwater Diving; Parameters: HR: Heart Rate; SLJ: Standing Long Jump; CFF: Critical Flicker Frequency.

Table 2: Rank sum test results of intra and inter group for each indicator (n=33).

Indicator/Time point	Median (quartile)	contrast	z	p-value
HR (bpm)				
CB	78(72,84)	CB vs. CLR	-4.69	<0.001
CA	168(156,174)	CA vs. CLR	-4.95	<0.001
CLR	96(84,108)	IB vs. IA	-5.02	<0.001
IB	72(66,84)	IB vs. IDR	-2.24	0.025
IA	168(162,174)	IA vs. IDR	-5.02	<0.001
IDR	90(75,96)	IDR vs. CLR	-2.58	0.010
SRT (s)				
CB	0.232(0.219~0.246)	CB vs. CA	-2.99	0.003
CA	0.249(0.232~0.265)	CB vs. CLR	-2.12	0.034
CLR	0.247(0.231~0.253)	CA vs. CLR	-2.51	0.012
IB	0.232(0.219~0.233)	IB vs. IDR	-1.65	0.100
IDR	0.232(0.223~0.249)	IDR vs. CLR	-3.79	<0.001

Note: B: Before Fatigue; A: After Fatigue; C: Control Group; I: Intervention Group; R: Recovery; L: Recovery On Land; D: Recovery Through Underwater Diving; Based On Above, CB: Control Group Before Fatigue; CA: Control Group After Fatigue; CLR: Control Group Land Recovery; IB: Intervention Group Before Fatigue; IA: Intervention Group After Fatigue; IDR: Intervention Group Recovery Through Underwater Diving; Parameters: HR: Heart Rate; SRT: Simple Reaction Time.

Discussion

The effect of underwater environment on muscle tissue fatigue recovery

The results showed that the SLJ performance of the subjects was recovered close to the level before fatigue after 6-metre underwater diving recovery, which indicated that the underwater environment helped the recovery of muscle fatigue. Even though the heart rate did not recover to the level before fatigue, the effect of recovery through underwater diving was much better than the land recovery, which also implied that underwater environment has benefit for the recovery of physical fatigue. The intervention effect on SLJ and HR in the intervention group was significantly better than that of the control group, indicating that the 6-meter underwater diving intervention could promote the recovery of muscle fatigue after exercise, but the effect might be varied on the myocardium and skeletal muscles.

High-intensity exercise or exhaustive exercise might induce myocardial and skeletal muscle injury through damaging mitochondrial structure and interfering mitochondrial free radical metabolism [4-10], this is also the main reason for the decline of muscle strength. In terms of the impact of low temperature factor of underwater environment on the recovery of exercise fatigue, water bath with a temperature between 10℃ to 20℃ has the moderate influence on the sport performance after short-term intensive or exhaustive exercise [11-13], but better effect on the recovery of endurance sports [1,14,15], which were similar with the result of the present study. The reason may be due to endurance exercise takes longer time than resistance exercise, body temperature rises at the late stage of endurance exercise, and the effect of low temperature on nerve conduction velocity and muscle enzyme activity are not remarkable, hence, low temperature has stronger impact on resistance exercise than endurance exercise. Unlike resistance exercise, in general, the endurance exercise has sufficient oxygen supply, which prevents from the accumulation of lactic acid, the latter is known as an important influence factor on exercise performance, especially for resistance exercise. After the cold water bath intervention, the 24-hour recovery effect will be more significant for both endurance and resistance exercises [16,17]. The potential mechanisms of hypothermia intervention of underwater environment mainly include promoting the stability of myocardial and skeletal muscle lysosomal membrane, lowering tissue temperature and metabolic level, reducing the level of inflammatory factors, decreasing mitochondrial swelling and maintaining the fluidity of cellular membrane [18-20]. This may be partially explained the effect of muscle recovery by underwater hypothermia in this study.

In this study, underwater with steady body condition made most of the body's stretch reflex muscles against gravity at a neutral buoyancy state and relaxed, the compression of blood vessels was reduced, blood flow was increased in muscle tissue, which enhanced recovery efficiency. Water pressure also promotes the fluid flow from extracellular to capillaries, accelerates the transport of cellular metabolites, and improves the recovery of athletes' muscle tissue from fatigue [2,21-24]. It is conducive to the recovery of exercise fatigue.

The subjects inhaled mild pressurized oxygen gas during 6-meter underwater diving, which could improve the oxidase activity of motor neuron, the oxidative metabolism of neuromuscular units is improved [25]. When the amount of physical dissolved oxygen in blood is increased, the oxygen content in the body is increased [26], and the cell apoptosis is reduced, which might prevent the oxidative damage of the cells. The decreased HR and increased blood flow and metabolism could prevent the body from oxidative stress [27]. With the decrease of HR in underwater diving environment, it could spare more oxygen and material support for the recovery of myocardial cells from micro injury and the elimination of metabolic waste after high-intensity exercise or exhaustive exercise and accelerate the recovery of myocardial and skeletal muscle.

Effect of Underwater Environment on Motor Nerve Fatigue Recovery

The results showed that the SRT in control group did not recover to the pre-exercise level after land recovery, which suggests that motor nerve and skeletal muscle may be still under the condition of fatigue. After underwater diving, SRT was recovered to the pre-exercise level, indicating that motor nerve fatigue has been recovered. Some studies pointed out that low temperature might have the influence on the exchange between Ca^{2+} and Na^{+} in nerve cells, the opening of Ca^{2+} channel on the cellular membrane, which in turn, might reduce the current of nerve membrane, prolong the refractory period after stimulation, increase the duration of nerve action potential resulting in the delay of action potential generation, reduce nerve conduction and muscle contraction speed, increase the reaction time [3,28-30]. In this study, the effect of low temperature of underwater environment on SRT was not significant, which may be due to the offsetting effect of the increased body temperature after exercise in the cold-water immersion effect or the recovery period (15 minutes) was relative short, which was not enough to cool down the body temperature.

Effect of Underwater Diving Environment on Visual Fatigue Recovery

Critical Flicker Frequency (CFF) test showed no significant difference before and after exercise in control group, as well as between the control and intervention groups after recovery, which suggested that the exercise fatigue induction scheme had no significant effect on the CFF. It may be because the exercise intensity of this study was not high enough or the fatigue duration was relatively short, the result was different from other reports [3,31-33], which induced fatigue through longer period and also had accumulation effect. In the current study, the subjects in the intervention group had a higher degree of awakening in nervous system, which might hind the development of fatigue induced psychological fatigue. Compared with the visual nerve cells, the exercise induction in this study made the motor neurons more exhausted than the visual nerve cells, which might partially explain the result of non-significant difference between the two recovery ways for CFF.

Conclusion

Six-meter underwater diving intervention could reduce heart rate, improve muscle strength, improve visual reaction speed, and improve the recovery of exercise-induced muscle and nerve fatigue.

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