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# Water exercise and health promotion

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***Abstract*** During water exercise, it was established that heart rate, oxygen uptake and body temperature respond to the influence of water pressure, temperature, buoyancy, and viscosity. This review explains the principle and theory that physiological response could become a benefit of health promotion. The heart rate during water immersion is lower than on land. The blood pressure of young subjects in water is much lower than on land at thermo-neutral conditions, while for old subjects it is higher than on land. Blood pressure increases in water with age due to an age-associated reduction in vascular dispensability. Water pressure and vascular elasticity can affect systolic blood pressure. Capillary vessels expand after exercise in water. When the water level is increased, the volume of the venous return seems to increase; and when the water level decreases, the volume of the venous return decreases. The change in volume of venous return depends on exercise intensity. Physiological indexes apparently change with water temperature to even higher and lower levels than the thermo-neutral. Depending on the viscosity of the water, the oxygen consumption changes. Depending on the water level, the load weight changes. Depending on the exercise movement speed, the oxygen consumption changes. The physical characteristics of water could provide an index and a big benefit for health promotion. In addition, one can expect water exercise to have a beneficial preventive effect on lifestyle-related diseases such as obesity and diabetes.
***Keywords*** : water exercise, health promotion, water pressure, water temperature, buoyancy, viscosity

## Introduction

During temporary acute exercise, physiological function corresponds to mobilizing the respiratory and circulatory function for maintaining homeostasis. Physiological functions are well adapted to exercise adding the morphological and functional changes that the physiological response could decrease if acute exercise were undertaken. It is called the training effect or physiological adaptation. The training effect or physiological adaptation could increase the benefit enough to complement Activity of Daily Living (ADL), to change physiological functions by exercise. During water exercise, it could be established that the heart rate, oxygen uptake and body temperature respond to the influence of the physical characteristics of water (water pressure, temperature, buoyancy, viscosity, etc)[1-26]. Previous studies demonstrated physiological responses to changes in the physical characteristics of water, and that such responses differed from those coming from land-based exercise[27-41]. We introduce the theory that physiological response benefits from water exercise, and explain its practical use for health promotion. And, especially, this review explains the principles (the universal laws of water) and the theories (points of view based on the universal laws) derived from the differences between exercise in water and on land.

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## Heart rate and water immersion

***Changes in heart rate while standing in water.*** The principle: The heart rate during water immersion is slower than on land. The theory: It could quicken the venous return due to the water pressure on the veins. This is believed to be a reason for the increase in stroke volume and decrease in heart rate.

It could cause the transfer of cell sap from cellular tissue to a blood vessel, as working the hydraulic pressure of 0.1 atmospheres while in water. This could enhance the venous return causing an increase in central cardiovascular volume[42]. And it could increase the volume of venous return, which causes an increase in cardiac output[30]. A slower heart rate during water immersion is mainly contributed to the greater venous return-associated increase in cardiac output. These phenomena could happen within about 20 seconds after immersion, and a "delay in arrival" phenomenon could depend upon the water level[43]. Although the decrease in heart rate during immersion occurs regardless of gender or age, age attenuates the decrease in heart rate[44].

***Changes in heart rate during water exercise.*** The principle: The heart rate during water exercise is very low compared to land exercise at a given oxygen demand, especially at low exercise intensity. The theory: Water exercise could increase the benefit of venous return, depending on the lower exercise intensity.

When exercising at the same oxygen uptake, the elevated heart rate in water is lower than on land (Fig. 1, Fig. 2)[45]. Exercise in water includes facial immersion and results in a decreased heart rate known as mammalian diving reflex[43]. While water exercise programs consist of whole body immersion, such as Zen or meditation in water, it takes into consideration the autonomic nerve function.

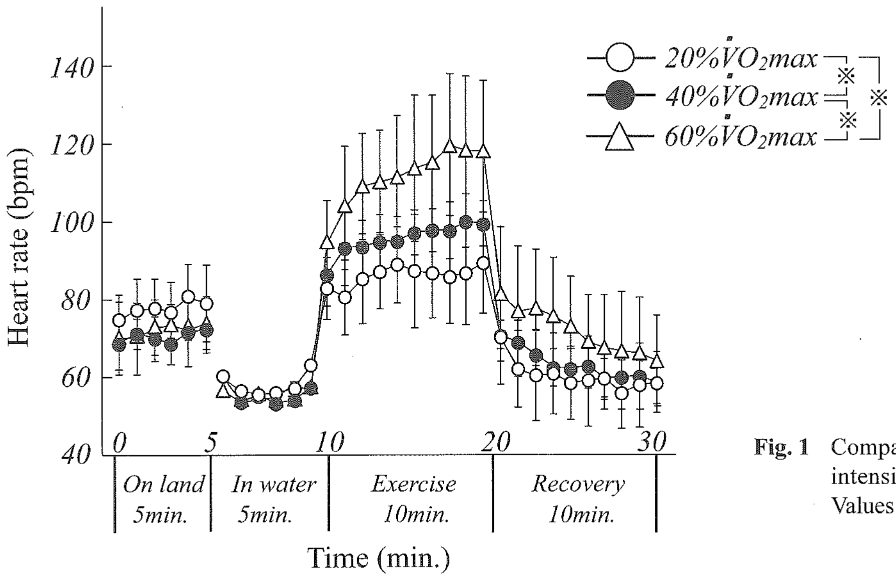



**Fig. 1** Comparision of heart rate during different intensity arm cranking exercises in water. Values are means ± SD. *p<0.05

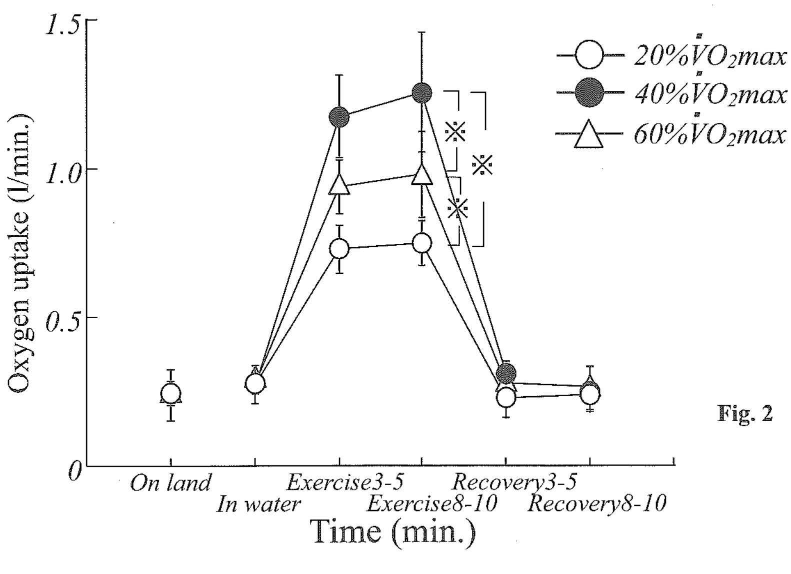



**Fig. 2** Comparison of oxygen uptake during different intensity arm cranking exercises in water. Values are means ± SD. *p<0.05

## Blood pressure and water immersion

***Changes in blood pressure while standing in water.*** The principle: The blood pressure of young subjects in water is low compared to on land, while for older subjects the blood pressure is higher in water than on land. This tendency is the same regardless of gender. The theory: The blood pressure in water decreases due to an age-associated reduction in vascular dispensability.

The blood pressure of 20-year-old men standing in water was significantly lower than on land. In contrast to young men, older men demonstrated that their blood pressure in water was higher than on land[43,46,47]. It is speculated that these changes may be related to vessel stiffening with advancing age, but remains unclear[43,47].

***Changes in blood pressure while in water.*** The principle: The systolic blood pressure is lower during exercise in water than on land, while diastolic blood pressure is lower during recovery in water than on land. The theory: The water pressure and vascular elasticity could affect systolic blood pressure. Capillary vessels expand more after exercise in water.

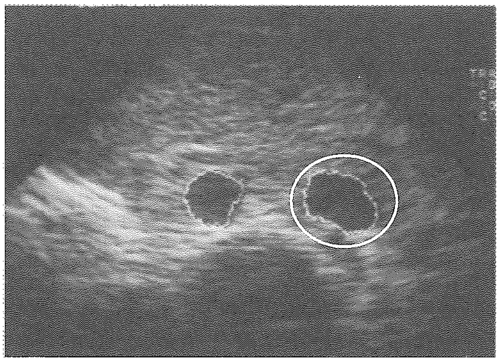
Changes were noted in blood pressure of young men during exercise in water and on land at the same exercise intensity[29]. The systolic blood pressure in water tends to be lower than on land; and, furthermore, the diastolic blood pressure after exercise in water is also lower[29]. Normotensive subjects demonstrate a tendency for a reduction in blood pressure in water immersion[44]. However, changes in blood pressure of hypertensive and older subjects are inconsistent with normotensive and young subjects. Aging, arterial stiffening and weakening of baroreflex sensitivity are seen as the causes of this[43,47].

## Changes in the venous return while standing in water

***At rest.*** The principle: When the water level is increased, the volume of the venous return could be augmented, and the increased volume could decrease following a reduction in water level, which shows a similar tendency regardless of gender. This relationship is attenuated with advancing age. The theory: The volume of the venous return is positively associated with the water pressure or water level.

When the water level is increased or the depth of the water is deepened, the volume of venous return is promoted[30]. However, when the water level is low, the volume of blood vessel return is almost the same as while standing on land. Fig. 3 shows a comparison between in water and on land of a cross-sectional area of the abdominal vena cava in a standing position[43,47]. The cross-sectional area of the abdominal vena cava is significantly increased following a rise in water level (Fig. 4)[30]. This shows that the volume of venous return could increase depending on the water pressure. Also, the stroke volume is significantly increased when the water level reaches to the xiphoid process[30]. Considering these increases in venous return and stroke volume depending on water level, there is a corresponding increase in stroke volume that exceeds the standard value (the threshold), and a higher volume of blood is retained in the abdominal vena cava.

On land condition



In water condition

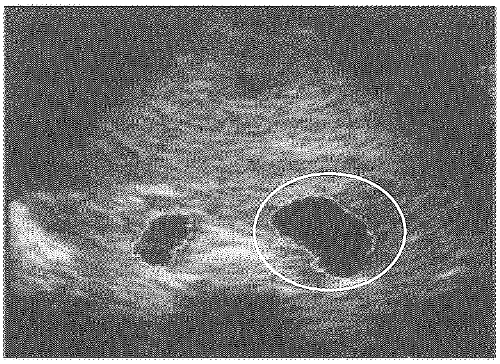


**Fig. 3** Comparison of the cross sectional area of inferior vena cava between on land condition and in water condition using a B-mode echocardiography. ○: inferior vena cava

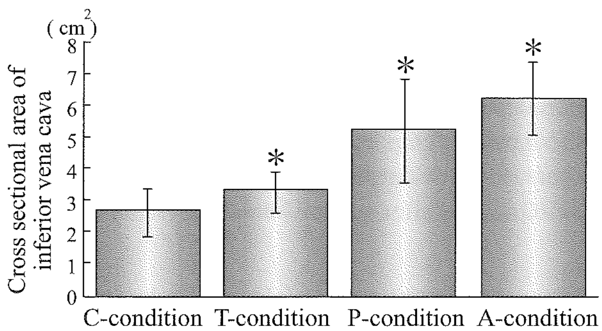



**Fig. 4** Changes in cross area of inferior vena cava in different water depths. C-condition, out of water, T-condition, trochanter major, P-condition, processus xiphoidens, A-condition, axilla. Values are means ± SD. *p<0.05 compared with control.

***Changes in the venous return during exercise.*** The principle: The changes in volume of venous return are dependent on exercise intensity. The theory: Based on the level of intensity, it could pool the blood in the abdominal vena cava, and could control the quantity of blood to the pulmonary artery.

The previous study compared the change in the cross-sectional area of the abdominal vena cava in water and on land during hand ergometer exercise at identical intensities (20%, 40%, 60% $\dot{V}O_{2max}$). Water temperature was 30 degrees Celsius, and water level was at the xiphoid process (Fig. 5)[45]. The cross-sectional area of the abdominal vena cava significantly expanded during immersion. During water exercise at 20% $\dot{V}O_{2max}$, the cross-sectional area of the abdominal vena cava was unchanged from the baseline value and was unchanged immediately after exercise; though there were signs of recovery at around ten minutes. During water exercise, the cross-sectional area was a significantly greater value in all phases compared to on land exercise. During on land exercise, the cross-sectional area of the abdominal vena cava became smaller after the exercise ended. During water exercise at 40% $\dot{V}O_{2max}$, the cross-sectional area of the abdominal vena cava immediately decreased from the onset of exercise. However, the decreased cross-sectional area during water exercise was significantly greater than the same condition on land. During water exercise at 40% $\dot{V}O_{2max}$, the cross-sectional area of the abdominal vena cava decreased from the onset of exercise, and was almost the same value on land after 10 minutes from the onset of exercise. After exercise, the cross-sectional area of the abdominal vena cava decreased on land and increased in water, and the difference was significant. These scientific findings suggest some physiological benefit to in water exercise. The reasons why there is more venous return during in water exercise than on land exercise is because of the difference in the muscle pump action and the effect of the water pressure. In particular, exercise in water to an intensity of 60% $\dot{V}O_{2max}$ has effective and beneficial results.

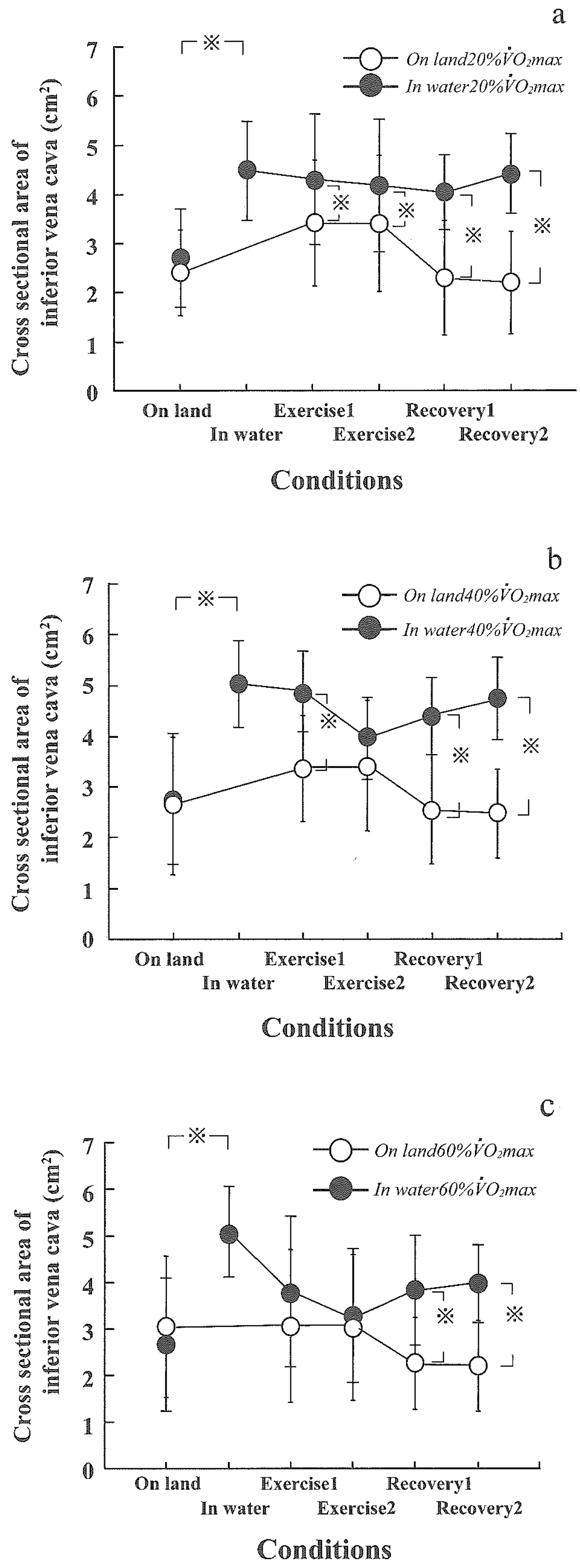



**Fig. 5** Comparison of cross sectional area of inferior vena cava between exercise on land and exercise in water. (a: 20%$\dot{V}O_2$max b: 40%$\dot{V}O_2$max c: 60%$\dot{V}O_2$max) Values are means ± SD. *$p<0.05$

### Relationship between physiological index and water temperature

The principle: Physiological indexes could be affected by water temperatures higher and lower than the thermo neutral. The theory: Changes in autonomic nervous activity in water are almost the same as those on land if the water temperature is thermo neutral. When the water temperature is lower than thermo neutral, sympathetic nerve activity is enhanced; and when higher, parasympathetic nerve activity is increased.

The water temperature (a swimming pool in Japan) during water exercise is usually within the range of 30~32℃ . At these ranges of water temperature, the rectal temperature is lower, because thermal conductivity of the water is high. The body temperature temporarily decreases immediately after submersion, and the heart rate slightly rises. Also, systolic blood pressure increases immediately after water immersion. When water and air temperatures change, the temperature control function in healthy adults acts to maintain homeostasis; but the elderly, infants and young children are more easily affected by changes in temperature. This disadvantage of blood pressure in the elderly and children is due to the autonomic nervous system and body composition (e.g. fat mass), respectively. Concerning the cases of in water exercise for such subjects, we recommend that exercise instructors monitor water conditions carefully just after subjects enter the water. Wearing a thermal insulation swimsuit is an effective countermeasure for the winter season[48]. The autonomic nervous system contributes to maintaining the body temperature in response to changes in ambient temperatures, which is subconsciously regulated. In addition, when exercising, the autonomic nervous and endocrine system cooperate to favorably promote an increased heart rate, blood pressure, excessive sweating, and generate heat for metabolic function. Heart parasympathetic system activity after exercise is significantly increased after immersion in a face-up position[49]. Although heart parasympathetic system activity is attenuated by exercise, water immersion at the supine position augments the attenuated activity[49]. The heart parasympathetic system activity of older and middle-aged subjects is enhanced following water immersion after exercise[50]. These enhancements are significantly different between in water and on land exercise. This suggests that immersion after exercise has benefit (the surplus energy that the water environment brings) for older and middle-aged subjects.

### Relevance of physiological responses and water viscosity

The principle: Oxygen consumption is affected by the viscosity of the water. The theory: When the viscosity of the water increases, the level of resistance increases, leading to greater oxygen consumption.

Dissolving carboxymethyl cellulose (CMC) permits changing the viscosity of water without affecting the buoyancy. At 30 degrees Celsius, water of 1% CMC has a viscosity of 470 cP. The viscosity of fresh water at 20 degrees Celsius is 1 cP. When subjects walked using the water treadmill in fresh water, the heart rate and oxygen uptake significantly increased. There is an exponential relationship between the concentration of CMC and the viscosity of water. Oxygen uptake is highest for treadmill walking on land, followed, respectively, by treadmill walking in water with the knees at water level, water treadmill walking with the hips at water level, water treadmill walking with the knees at water level of water with viscosity, water treadmill walking with the hips at water level of water with viscosity[51]. When working on the water treadmill in both 22 degrees Celsius and 1% of 30 degrees Celsius CMC water (with viscosity), the rectal temperature in 22 degrees Celsius fresh water decreased and the viscosity of the water increased[7]. It is speculated that an increased rectal temperature in viscosity water was induced by the higher resistance of the viscosity and lower thermal conductivity. Therefore, exercise intensity can be adjusted by regulating viscous density.

### Relevance of physiological indexes and buoyancy

The principle: A change in load weight depends on the water level. The theory: When increasing the water level, the body's buoyancy is increased, according to Archimedes' principle.

Our study predicted a load weight loss based on water level (Fig. 6)[42]. It was measured with the load weight of seven sites (water level). The mean of the percent of body fat was 20 ± 2.3%. This equation can estimate load weight when substituting the ratio of water level to height as an independent variable[42]. When the percent of body fat is higher than 20%, it is speculated that the curve shifts lower and more to the left. In the case of lower than 20% body fat, the curve would shift upwards and more to the right. We postulate that this knowledge is useful in exercise prescriptions for obese patients.

### Relevance of physiological responses and speed of body motion

The principle: A change in oxygen consumption depends on the speed of body motion. The theory: When movement is faster, resistance is increased in proportion to the square of the speed, resulting in increased oxygen consumption.

The basic movement of aqua (in water) exercise consists of a vertical motion, right and left action, and movement to and fro. A faster movement tempo/rhythm/beat significantly increases of the movement the heart rate and oxygen uptake[27]. This suggests that the tempo/rhythm/beat of music could be utilized as an index for exercise

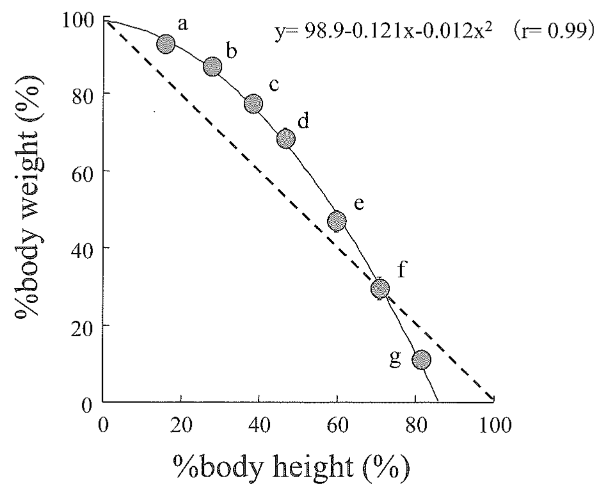



**Fig. 6** The relationship between %body weight and %body height.a: center of tibia, b: knee joint, c: thighbone, d: the pubis, e: the navel, f: xiphoid process, g: collarbone

intensity[27]. It is considered that water viscosity, as a method for changing the speed of movement during in water exercise, is an effective methodology[27].

## Summary

In the water, it is the environment that is extremely useful for the health promotion in elderly people. The physical characteristics of water could provide greater benefit, as assessed by the physiological indexes for health promotion. In addition, water exercise is effective for improving health indicators and the prevention of lifestyle-related diseases such as obesity and diabetes.

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