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Original Research

The influence of inspiratory muscle training in water for eight weeks on respiratory muscle strength

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Abstract

Background : Physical movement in water can provide a form resistance training for the respiratory muscles on chest expansion in the inspiratory phase. While exercising in water may be useful for developing respiratory muscle strength and promoting overall health, few reports are available on respiratory muscle strength during exercise in water. Purpose : To investigate the effect of inspiratory muscle training (IMT) in water compared with that on land on respiratory muscle strength. Methods : The study included twenty-nine healthy men (fifteen in a water group [WG] and fourteen in a land group [LG]). Before starting IMT, we evaluated the maximum inspiratory pressure (PImax) and maximum expiratory pressure (PEmax) in the oral cavity in both groups on land as the surrogate indexes of the inspiratory and expiratory muscle strength, respectively. The WG performed IMT in a sitting position while immersed in water up to the clavicular level. The LG performed IMT in a sitting position on land. For the duration of the IMT, the subjects performed twenty-min breathing at a respiratory rate of fifteen breaths/min synchronized with a metronome four times per week for eight weeks. Results : In both the WG and LG, the inspiratory muscle strength significantly increased after six and eight weeks of IMT compared with that at the baseline ($p<0.05$). There was no significant differences in the increase in the rate of change of the inspiratory muscle strength after eight weeks of IMT between the groups. Additionally, there was no significant difference in the expiratory muscle strength after eight weeks of IMT between the groups. Conclusion : IMT on land and in water improves the inspiratory muscle strength ; however, there is no difference in the increase in the rate of change of inspiratory muscle strength after IMT between IMT on land and that in water.

Key words : respiratory muscle strength, inspiratory muscle training, immersion in water

Introduction

Diminished respiratory muscle strength results in reduced efficiency of coughing to remove airway secretions, which increases the risk of atelectasis or pneumonia after surgery or prolonged bed rest (McCool, 2006 ; Kulnik et al. 2014). In addition, fatigue of muscles involved in inspiration, such as the diaphragm, external intercostal, or parasternal intercostal muscle, causes shortness of breath, which might result in reduced exercise tolerance (Smith et al. 1992 ; Sasaki, 2005). While diminished respiratory muscle strength is an important concern in clinical settings, the aging-related physiological changes in the respiratory system, such as a decrease in pulmonary elasticity, fusion between the sternal bone and costal cartilage, or increase in thoracic kyphosis, also lead to a reduction of the respiratory muscle strength and respiratory function (Janssens et al. 2004). In Japan, known as having the most rapidly aging society in the world, pneumonia was ranked as the third leading cause of death in 2011, which was higher than cerebrovascular disease-related death. Thus, it is essential to maintain the respiratory function including respiratory muscle strength for the health promotion.

As a part of health enhancement plans, aquatic exercise has recently been introduced to rehabilitation and sport clubs (Cider et al. 2005 ; Wilcock, 2006). Aquatic exercise can reduce the self-weight load, which enables persons with obesity (Sheldahl, 1986), joint diseases (Chi et al. 2011), or lumbago (Sjogren et al. 1997 ; Han et al. 2011 ; Irandoust et al. 2015) to perform exercise safely. In addition, it is known that water viscosity and pressure can be used as exercise loads contributing to the enhancement of extremity muscle strength (Craig et al. 1967 ; Wang et al. 2007 ; Lee et al. 2015).

Breathing underwater requires great effort mainly for the following two reasons : first, the blood volume shifts into the chest cavity because of the increased venous return from the lower extremities ; second, inflexibility of the chest wall and diaphragm shifts toward the cranial side because of the hydrostatic pressure, resulting in restricted pulmonary compliance (Craig et al. 1967 ; Craig et al. 1975). Regarding the effect of the water depth on the respiratory function, the pulmonary vital capacity (VC), forced expiratory volume during the first second ($FEV_{1.0}$), and functional residual capacity (FRC) decrease during water immersion at the clavicular or cervical level (Agostoni et al. 1966 ; Leith et al. 1967 ; Prefaut et al. 1976 ; Buono, 1983). Furthermore, de Andrade et al. reported that the decrease in the maximum inspiratory muscle strength during water immersion was greater when the water level was at the clavicle than at the xiphoid process because of the higher water pressure at the clavicular level (de Andrade et al. 2014). We also suggested that forced respiration during upright water immersion up to the clavicular level resulted in greater inspiratory muscle fatigue than at shallower depths (Yamashina et al. 2016).

Therefore, aquatic exercise, such as swimming or walking in water, is an ideal exercise for health promotion, which can add an aspect of resistance training using water viscosity to aerobic exercise. In addition, the specific conditions of resistance to chest expansion during the inspiratory phase may be useful for developing respiratory muscle strength. However, few reports are available on the respiratory muscle strength during exercise in water.

In the present study, we hypothesized that the inspiratory muscle strength would increase more after aquatic exercise training for eight weeks compared with that on land. Thus, we investigated the effect of inspiratory muscle training (IMT) in water compared with that on land based on the respiratory muscle strength.

Methods

1. Subjects

Twenty-nine normal healthy males were included in the study. Subjects who had a history of respiratory or cardiovascular disease, hypertension (resting systolic blood pressure (BP)$\geqq$140 and/or diastolic BP$\geqq$90), diabetes, or obesity (body mass index (BMI) $\geqq$30), or a habit of smoking were excluded. The eligible applicants who met the inclusion criteria participated in the study after familiarizing themselves with the experimental protocol, such as the measurement method by spirometry and inspiratory muscle training (IMT) described below. The characteristics of the subjects are summarized in Table 1. This study was approved by AINO University Research Ethics Committee (Aino 2016-002), and also conformed to the standard set by the Declaration of Helsinki, and written informed consent was obtained from all subjects prior to the experiment.

Table 1 The physical characteristics of the subjects

	Land Group	Water Group
Number	14	15
Age (years)	23.2±0.2	23.2±2.7
Height (m)	1.68±0.1	1.71±0.1
%VC	100.6±5.8	98.5±9.5
$FEV_{1.0}$ (%)	90.2±6.3	88.8±6.2
PImax (cmH_2O)	88.4±15.3	83.5±15.4
PEmax (cmH_2O)	92.2±24.3	89.6±23.1

Values are means±SD.
Abbreviations : VC. vital capacity, $FEV_{1.0}$. forced expiratory volume in one second, PImax. maximum inspiratory pressure, PEmax. maximum expiratory pressure.

Figure 1 Inspiratory muscle training in water

2. Anthropometrical measurements

The weight, height, and respiratory function were measured before the first experiment.

3. Experimental protocol

We randomly divided the twenty-nine subjects into fifteen in a water group [WG] and fourteen in a land group [LG]. Before starting IMT, we evaluated the maximum inspiratory pressure (PImax) and maximum expiratory pressure (PEmax) in the oral cavity in both groups on land as the surrogate indexes of the inspiratory and expiratory muscle strength, respectively.

The WG performed IMT in a sitting position while immersed in water up to the clavicular level (Figure 1). The LG performed IMT in a sitting position on land. For the duration of the IMT, the subjects performed twenty-min breathing at a respiratory rate of fifteen breaths/min synchronized with a metronome four times per week for eight weeks. During training, the inspiratory muscle load was adjusted to 30% of the PImax at the baseline using an inspiratory loading device (Threshold IMT, Philips, PA, USA).

The rate of change in the respiratory muscle strength from the baseline was calculated using the following equation :

rate of change (%) = [(a measured value) − (baseline value)]/(baseline value) × 100

4. Evaluation of respiratory functions and respiratory muscle strength

The respiratory function was evaluated using a spirometer (AS-507, Minato, Osaka, Japan), and parameters such as VC and $FEV_{1.0}$. PEmax and PImax in the oral cavity (Black et al. 1969) were also evaluated using a sthenometer (AAM337, Minato, Osaka, Japan) attached to the spirometer, and considered as the surrogate indices of expiratory and inspiratory muscle strength, respectively.

5. Statistical analysis :

Statistical analysis was performed using statistical software (Stat View ; SAS, Cary, NC, USA). Data are expressed as the mean ± standard deviation (SD). Two-way analysis of variance was used to compare the respiratory muscle strength at the baseline, two weeks after IMT, four weeks after IMT, six weeks after IMT, and eight weeks after IMT. When there was significance, a multiple comparison test (Tukey-Kramer) was performed. Significance was defined by a value of $P < 0.05$.

Table 2 Changes in respiratory muscle strength following inspiratory muscle training

Group	Rate of change (%)	2 weeks	4 weeks	6 weeks	8 weeks
Land Group	PImax	0.26±1.68	1.39±2.27	5.01±2.86*	8.49±2.12*
	PEmax	0.01±0.02	2.08±2.91	2.59±3.81	0.96±3.54
Water Group	PImax	0.05±2.94	3.78±4.59	6.49±3.11*	11.14±2.74*
	PEmax	−0.96±2.93	0.31±2.26	0.97±2.61	1.38±2.79

Values are means±SD. *$p < 0.05$ vs. Baseline
Abbreviations are as in Table 1.

Results

All subjects who participated in this study completed IMT for eight weeks.

The effects of IMT on land and in water on the inspiratory muscle strength

In both the WG and LG, the inspiratory muscle strength significantly increased after six and eight weeks of IMT compared with that at the baseline ($p < 0.05$). However, there was no significant difference in the increase in the rate of change of the inspiratory muscle strength after eight weeks of IMT between the groups.

The effects of IMT on land and in water on the expiratory muscle strength

There was no significant difference in the expiratory muscle strength after eight weeks of IMT between the groups.

Discussion

In the present study, we investigated whether there was an increase in the inspiratory muscle strength following IMT for eight weeks on land and in water at a water depth of the clavicular level, and revealed that there is no difference in the increase in the rate of change of the inspiratory muscle strength between the groups. In previous research, it was reported that IMT from a four- to twelve-week period increased the inspiratory muscle strength (Tenório et al. 2013 ; Souza et al. 2014), and our results support those of this previous research. In other words, regardless of being performed on land or in water, IMT can be considered effective to increase the inspiratory muscle strength. However, in this study, there was no difference in the rate of increase of the inspiratory muscle strength between the groups following eight weeks of IMT. Although hydrostatic pressure would have affected the entire chest region in the water at the clavicular level, it is possible that the load was insufficient for healthy young men to increase their inspiratory muscle strength. In general, in water environments, due to compression of the abdominal wall by hydrostatic pressure, the diaphragm elevates and compresses the lungs, and pulmonary compliance decreases through water pressure being applied to the abdominal wall (Craig et al. 1967 ; Craig et al. 1975). As a result, compared with water depth at the navel, lung capacity decreases when the water depth is at the clavicle (Kurabayashi et al. 2001 ; Yamashina et al. 2016). For these reasons, in this study, it was considered that when the water depth was at the clavicle, the chest region would be more compressed due to hydrostatic pressure, compared to when on land. However, the water resistance during aquatic exercise varies according to the kinetic rate (Castillo-Lozano et al. 2014), which means that a lower kinetic rate correlates with reduced water resistance on aquatic exercise. It is possible that respiration in water at a low frequency reduces the load against the chest wall on aquatic respiration exercise. In this study, the inspiratory phase was performed in two seconds in conjunction with a metronome, which might not be long enough load for a sufficient load to be applied to the inspiratory muscles even in water compared with on land. Regarding the expiratory muscles, improvement could not be confirmed for both LG and WG. In the present study, we did not apply any loads to the expiratory muscle in the expiratory phase during IMT. Furthermore, hydrostatic pressure against the chest wall could possibly assist expiratory muscles to contract. Therefore, our submerged IMT may have resulted in on effect to the expiratory muscles. In addition, it has been reported that treadmill walking in water induces greater respiratory muscle fatigue than treadmill walking on land at the same exercise intensity in healthy young men (Yamashina et al. 2016). This suggests that dynamic motion in water such as walking might affect respiratory muscles more than exercise in water in a stationary position. In the future, it will be necessary to assess whether there would be an effect on the respiratory muscle strength with an exercise load where water pressure is more readily applied to the chest, such as walking in water, rather than stationary exercise. There are some limitations of the present study. Subjects performed IMT with prescribed inspiratory loads and respiratory rates, as described in the above "Methods" section. However, subjects were only asked to maintain their tidal volume with normal respiration at rest. It is not certain whether the subjects could keep their tidal volume during IMT constant in all trials. Therefore, there is a possibility that differences in the tidal volume influenced the magnitude of the inspiratory muscle load. Furthermore it needs to be clarified whether the same results would be obtained if the subjects were persons with chronic respiratory diseases whose respiratory muscles are weakened. In addition, the water resistance during aquatic exercise varies according to the kinetic rate (Castillo-Lozano et al. 2014), which means that a lower kinetic rate correlates with a smaller water resistance in aquatic exercise. It is possible that respiration in water at a low frequency reduces the load against the chest wall in aquatic respiration exercise. Therefore, it is necessary to develop effective aquatic exercise protocols to strengthen the respiratory muscles.

Conclusion

IMT on land and in water improves the inspiratory muscle strength. However, there is no difference in the increase in the rate of change of the inspiratory muscle strength after IMT between IMT on land and that in water.

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Conflicts of interest statement

The authors declare no conflicts of interest.

References

Agostoni E, Gurtner G, Torri G, Rahn H : Respiratory mechanics during submersion and negative-pressure breathing. J Appl Physiol 21 : 251–258, 1966

Buono MJ : Effect of central vascular engorgement and immersion on various lung-volumes. J Appl Physiol 54 : 1094–1096, 1983

Black LF, Hyatt RE : Maximal respiratory pressures : normal values and relationship to age and sex. Am Rev Respir Dis 99 : 696–702, 1969

Castillo-Lozano R, Cuesta-Vargas A, Gabel CP : Analysis of arm elevation muscle activity through different movement planes and speeds during in-waterand dry-land exercise. J Shoulder Elbow Surg 23(2) : 159–165, 2014

Chi D, Back Y, Park G, Giduck P, Sung-bum J, HyunJeong J : The effect of aquatic exercise on peak torque and stability of knee joints of elderly women. J phys Ther Sci 23 : 871–873, 2011

Cider A, Sunnerhagen KS, Schaufelberger M, Andersson B : Cardiorespiratory effects of warm water immersion in elderly patients with chronic heart failure. Clin Physiol Funct Imaging 25 : 313–317, 2005

Craig AB, Dvorak M : Expiratory reserve volume and vital capacity of lungs during immersion in water. J Appl Physiol 38 : 5–9, 1975

Craig AB, Ware DE : Effect of immersion in water on vital capacity and residual volume of lungs. J Appl Physiol 23 : 423–425, 1967

de Andrade AD, Junior JC, Lins de Barros Melo TL, Rattes Lima CS, Brandao DC, de Melo Barcelar J : Influence of different levels of immersion in water on the pulmonary function and respiratory muscle pressure in healthy individuals : observational study. Physiother Res Int 19 : 140–146, 2014

Han G, Cho M, Nam G, Taeyoung M, Jeehee K, Seonrye K et al. : The effects on muscle strength and visual analog scale pain of aquatic therapy for individuals with low back pain. J phys Ther Sci 23 : 57–60, 2011

Irandoust K, Taheri M : The effects of aquatic exercise on body composition and nonspecific low back pain in elderly males. J phys Ther Sci 27 : 433–435, 2015

Janssens JP, Krause KH : Pneumonia in the very old. Lancet Infecti Dis 4 : 112–124, 2004

Kulnik ST, Rafferty GF, Birring SS, Maxham J, Kalra L : A pilot study of respiratory muscle training to improve cough effectiveness and reduce the incidence of pneumonia in acute stroke : study protocol for a randomized controlled trial. Trials 15 : 123, 2014

Kurabayashi H, Tamura K, Kubota K, Tamura J : Analysis of the Circumferences of Chest, Abdomen, Thigh and Calf during Head-out Water Immersion. J Jpn Soc of Balneol Climatol Phys Med 64 : 199–202, 2001

Lee DG, Jeong SK, Kim YD : Effects of underwater treadmill walking training on the peak torque of the knee in hemiplegic patients. J phys Ther Sci 27 : 2871–2873, 2015

Leith DE, Mead J : Mechanisms determining residual volume of the lungs in normal subjects. J Appl Physiol 23 : 221–227, 1967

McCool FD : Global physiology and pathophysiology of cough — ACCP evidence-based clinical practice guidelines. Chest 129 : 48–53, 2006

Prefaut C, Lupih E, Anthonisen NR : Human lung-mechanics during water immersion. J Appl Physiol 40 : 320–323, 1976

Sasaki M, Kurosawa H, Kohzuki M : Effects of Inspiratory and Expiratory Muscle Training in Normal Subjects. J Jpn Phys Ther Assoc 8 : 29–37, 2005

Sheldahl LM : Special ergometric techniques and weight-reduction. Med Sci Sports Exerc 18 : 25–30, 1986

Sjogren T, Long N, Storay I, Smith J : Group hydrotherapy versus group land-based treatment for chronic low back pain. Physiother Res Int 2 : 212–222, 1997

Smith K, Cook D, Guyatt GH, Madhavan J, Oxman AD : Respiratory muscle training in chronic airflow limitation : a meta-analysis. Am Rev Respir Dis 145 : 533–539, 1992

Souza H, Rocha T, Pessoa M, Rattes C, Brandão D, Fregonezi G et al. : Effects of inspiratory muscle training in elderly women on respiratory muscle strength, diaphragm thickness and mobility. J Gerontol A Biol Sci Med Sci 69 (12) : 1545–53, 2014

Tenório LH, Santos AC, Câmara Neto JB, Amaral FJ, Passos VM, Lima AM et al. : The influence of inspiratory muscle training on diaphragmatic mobility, pulmonary function and maximum respiratory pressures in morbidly obese individuals : a pilot study. Disabil Rehabil 35(22) : 1915–20, 2013

Wang TJ, Belza B, Thompson FE, Whitney JD, Bennett K : Effects of aquatic exercise on flexibility, strength and aerobic fitness in adults with osteoarthritis of the hip or knee. J Adv Nurs 57 : 141–152, 2007

Wilcock IM, Cronin JB, Hing WA : Physiological response to water immersion — A method for sport recovery ? Sports Med 36 : 747–765, 2006

Yamashina Y, Yokoyama H, Naghavi N, Hirasawa Y, Takeda R, Ota A et al. : The forced respiration during the deeper water immersion causes the greater inspiratory muscle fatigue in healthy young men. J Phys Ther Sci 28 : 412–418, 2016

Yamashina Y, Yokoyama H, Naghavi N, Hirasawa Y, Takeda R, Ota A et al. : Treadmill walking in water induces greater respiratory muscle fatigue than treadmill walking on land in healthy young men. J Physiol Sci 66 : 257–264, 2016