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Differences in Vital Capacity and Length of a Dive in Dynamics with and without Glossopharyngeal Insufflation in Breath-hold Divers

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Abstract

The purpose of this study was to determine differences between vital capacity and length of a dive in dynamics (DYN) with and without glossopharyngeal insufflation in breath-hold divers. The sample consisted of 15 elite breath-hold divers (12 male subjects and 3 female subjects) who were in regular training process and members of national team in Croatia. The sample of variables consisted two measures for estimating valuation of vital capacity (VC and VCP) and two measures for determining length of a dive in meters (URON and URONP). All variables have standard their basic statistic parameters and were tested to determine statistically significant differences between the vital capacity and length of a dive with and without glossopharyngeal insufflation as technique of air packaging. One-sided t- test for dependent samples was used and with results (significance level of $p = 0.00$) it can be concluded that there is a statistically significant difference between vital capacity and length of a dive with and without glossopharyngeal insufflation. Technique of packing air (glossopharyngeal insufflation) is producing better results for competitors, but with this advantage athletes must be aware of disadvantages of using this technique which can cause injuries to respiratory system and its organs.

Key words: *Divers, Dynamics, Breathing Technique, Dive Length, Respiratory System*

Introduction

Breath-hold diving, skin diving, freediving, free-diving and free diving are all form of underwater diving which consists of breath-holding until resurfacing without using any of breathing apparatus like scuba gear. In this paper breath-holding diving will be used in further text. Breath-hold diving is a young sport with room for improvement where knowledge of natural laws and physiology is needed to achieve the best possible results. Nowadays science finds new solutions to explain the practice of all long dives and longer periods of apnea. There are no physiological limitations associated with hyperbaric conditions, and the limits are determined by the psycho-physical capacity of the individual (Drviš, 2010). Most breath-hold divers wonder how to extend the stay below the surface, how to adapt the organism to something foreign that opposes what our organism wants, or how to prolong the apnea.

One of a series of techniques and exercises to achieve this goal is the technique of glossopharyngeal breathing or glossopharyngeal insufflation (GI), which is called “air packing” in diving language. Other names are frog breathing, lips pumping, packing of lung and carp (Nygren-Bonnier, 2008). Different terminology for this kind of breathing is used in various papers, but the most common is the glossopharyngeal insufflation (Seccombe et al., 2006). The word breathing also refers to the inhalation phase and the exhalation phase, whereas the glossopharyngeal insufflation refers only to the phase of exhalation. Professional breath-holding di-

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vers use this technique to increase the amount of air stored in the lungs resulting in longer apnea and hence with a longer dive. This manoeuvre originated in France in search of a solution to the problem of constraint imposed by the need to equalize the diving mask pressure. However, this is a difficult manoeuvre, which is recommended only to top level breath-hold divers, and requires expertise and experience (Pelizzari & Tovaglieri, 2004).

The goal of air packing is to fill the lungs with air as much as possible at the end of the last breath. This is achieved using the mouth as a pump, opening them and sealing rhythmically to bring the residual air from the mouth to the lungs. In this way, the air in the lungs is maximally compressed, thus allowing the breath-hold diver to dive with a higher amount of air than would be achieved by a normal maximum inhalation. The advantage is that the breath-hold diver has a larger amount of air at its disposal required for apnea and equalizing pressure in the ears of deep diving.

Glossopharyngeal insufflation is a technique that works by using the muscles of the face, mouth, face, lips, tongue, soft palate, larynx and glands to push the air to the lungs. Tongue is the main organ of this breathing technique. The tongue moves forward and backward to push the air into the gutter. The neck is opened and the air passes into the trap, where it is captured by the closing of the larynx. The suppression mechanism appears in every swallow. Swallow is defined as the projection of the air into the mouth by pushing the tongue. Some people carry glossopharyngeal breathing with their open mouth (with a numbed nose), while others carry glossopharyngeal breathing with their mouth shut, releasing air through the nose. This is an alternative breathing technique that maintains adequate ventilation when the respiratory muscles are weak (Nygren-Bonnier, 2008). Glossopharyngeal insufflation techniques are used by professional breath-hold divers to increase their lung capacity beyond their normal vital capacity, and therefore the performance of diving. Large lung capacity was recorded in the breath-hold divers who are competing at highest level, but it is unknown whether this result is genetically conditioned in divers who had selection process or is the result of the training process of glossopharyngeal insufflation. In several researches of glossopharyngeal insufflation by group of authors (Seccombe et al., 2006; Lemaitre, Clua, Andreani, Castras, & Chollet 2010; Brodin, Lindholm, Lennartsson, & Nygren-Bonnier, 2014; Boussuges et al., 2014), they have concluded that breath-hold divers or air retention competitors would achieve significant increase in lung volume by means of glossopharyngeal insufflation due to increased vital capacity and additional air in the lungs due to air compression.

Some of those studies conducted researches using glossopharyngeal insufflation technique like it was used in this research, with main purpose of the study to find whether the vital capacity and the length of the dive with glossopharyngeal insufflation differs statistically from the vital capacity without glossopharyngeal insufflation by breath-hold divers. Research will show differences with and without this technique or air packing. Glossopharyngeal insufflation technique has its side effects and potential health related risks which will be explained trough discussion and in conclusion.

Methods

Subjects

Testing was conducted on the sample of 15 top breath-hold divers from Croatia with an average age of 27.53±2.02 (range from 24 to 30 years). Eight subjects were members of Croatian national breath-hold diving team and 3 of the subjects were also international CMAS recorders. From all subjects 3 subjects were female and 12 were male.

Ethics

All testing procedures were carried out in accordance with ethical principles. Each subject who participated in testing procedures was provided with an explanation of the study, a possible health risk and the envisaged testing procedure. All subjects needed to sign an agreement confirming that they are familiar with the purpose and objectives of the study, the testing protocol and possible risks during procedure, and that he or she approached testing voluntary.

Procedure

Testing of 15 top male and female divers will show their: 1. vital capacity without glossopharyngeal insufflation; 2. vital capacity after glossopharyngeal insufflation; 3. length of dive without glossopharyngeal insufflation and 4. length of dive with glossopharyngeal insufflation. After processing the test results and calculating certain parameters, differences in vital capacity and length of dive before and after the packing of the air will be investigated. Based on the results it will be possible to prove the role and importance of air packing technique in top breath-hold diving. Testing was performed at the Laboratory for Functional Diagnostics of the Diagnostic Center of the Faculty of Kinesiology in Zagreb and Utrine pool in Zagreb.

Variables sample

Respecting the aim of this research, a two predicate and criteria variables were determined. Tests are specific for breath-hold diving and are taken from previous researches. In the test to determine vital capacity of breath-hold divers spirometry system Quark b2 (Cosmed, Italy) which provides continuous ('breath by breath') breathing data, graphic view, storage and analysis of measured ventilation, metabolic and ergometric parameters in a way that is connected via the interface and peripheral inputs and managed by a personal computer and the corresponding software. Measurement is performed indoors (Diagnostic Center of the Faculty of Kinesiology in Zagreb). Testing was carried out in stable microclimate conditions of closed space with air temperature between 18 and 20°C and air humidity of 60%, which requires calibration of the spirometer.

In test vital capacity (VC), the subject makes several (3-5) normal breaths and exhales into the spirometer. On agreed sign subject performs maximal inhale for maximal lung capacity after which with short air retention (no longer than 1 second), subject blows all the air from lungs in the mouth holder (air should not protrude through the nose "tick" or near the mouth). In the second test vital capacity with packing of air (VCP), the subject should sit upright and comfortably because of the possibility of loss of consciousness that can result in a fall injury. Unconsciousness which is also known as "packing blackout" because the packing decreases blood pressure, due to reduced venous blood flow to the heart (increased pressure by packing), arterial pressure and reduced blood flow to the brain arises, hence hypoxia and the possible fall in unconsciousness when sitting or lying due to gravity, the possibility of unconsciousness is decreased. Subject performs the same technique as in first test. The task is performed twice, and a better result is taken. Values of vital capacity are read out (amount of air that can be exhaled from the lungs in litres) after a maximum inhale.

As the criterion variable, the length of the dynamics with monofin was taken. Variables are without packing of air and with packing of air. The results were obtained based on the length of the dive in a 50-meter basin. The temperature of the water was 26±1°C, and the air temperature was 27 °C. The variation in the dive length is scaled in such a way that the longer dive length signifies a better result. Subject must dive as much horizontal distance as possible using the monofin. The task is performed according to the AIDA rules (International Association for the Development of Apnea, version 1.2.). Subject has to be in his track precisely at the scheduled time and after the sign of the starting referee subject has 10 seconds to start the procession. Dive is performed with discipline of dynamic apnea with fins (DYN). The goal is to cover as much of the length as possible which is expressed in meters and the task is completed when the subject drains out of the water, removes the mask and shows a sign that everything is fine. Task is performed only once. The difference between the two criterion variables is in packaging and without packing the air before the dive.

Data Analysis

The statistical package Statistica (data analysis software system, version 9.0) was used for the statistical analysis. Central and dispersion parameters, arithmetic mean (AM) and standard deviation (SD) were calculated. Differences between the vital capacity with and without glossopharyngeal insufflation and the length of the dive with and without glossopharyngeal insufflation from a breath-hold divers were tested with a T-test for the dependent samples. Test was used to determine statistically significant difference between two variables and level of significance was set at $p<0.05$.

Results

In Table 1 descriptive parameters are presented for the results of the study using variables vital capacity, vital capacity after GI, dynamic with monofin and dynamic with monofin after GI.

Tabela 1. Descriptive statistical parameters

VAR	MEAN	MIN	MAX	SD
VC	6.74	4.37	8.07	1.20
VCP	8.69	5.11	11.12	1.80
URON	156.33	130	205	24.24
URONP	177.55	140	250	30.81

Note: VC – vital capacity, VCP – vital capacity after GI, URON – dynamic with monofin, URONP – dynamic with monofin after GI, Mean – arithmetic mean, MIN – minimal result, MAX – maximal result, SD – standard deviation

In Table 1 it can be seen that the variable total vital capacity (VC) average value is 6.74 litres, while the minimum result is 4.37 litres and a maximum of 8.07 litres. While in variable vital capacity after glossopharyngeal insufflation (VCP) average value is 8.69 litres, minimum result is 5.11 litres and the maximum result is 11.12 litres. In the variable length of dive (URON) average length of dive is 156.33 meters, the minimum length is 130 meters and the maximum length is 205 meters. In length of dive with glossopharyngeal insufflation average length of dive is 177.55 meters, the minimum result is 140 meters and the maximum result is 250 meters.

Tabela 2. Statistical significance and results of T-test for variables VC and VCP

VAR	MEAN	SD	SD	t	df	p
VC / VCP	6.74 / 8.69	1.20 / 1.80	.82	- 9.19	14	.000

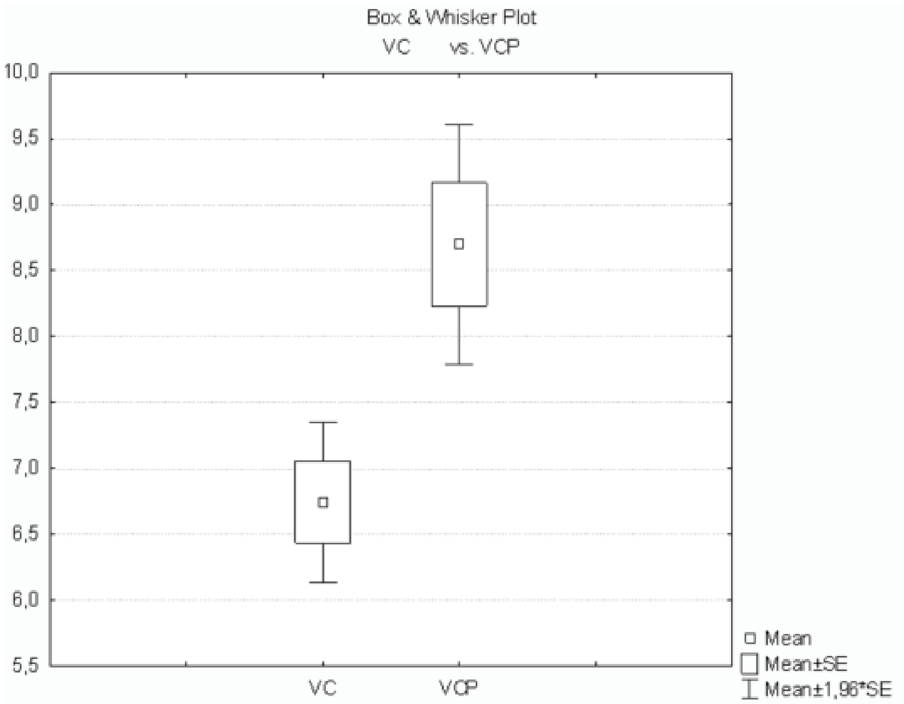
Note: VC –vital capacity, VCP – vital capacity after GI, Mean – arithmetic mean, SD – standard deviation, t -value of t-test, df – degrees of freedom, p – statistical significance value ($p<0.05$)

A statistically significant difference between the vital capacity and the vital capacity after glossopharyngeal insufflation at the significance level of $p = 0.00$ was found. A statistically significant difference was also found in the length of dive without glossopharyngeal insufflation and dive with glossopharyngeal insufflation.

Tabela 3. Statistical significance and results of T-test for variables URON and URONP

VAR	MEAN	SD	SD	t	df	p
URON / URONP	1.56.33 / 177.55	22.24 / 30.81	10.15	- 8.09	14	.000

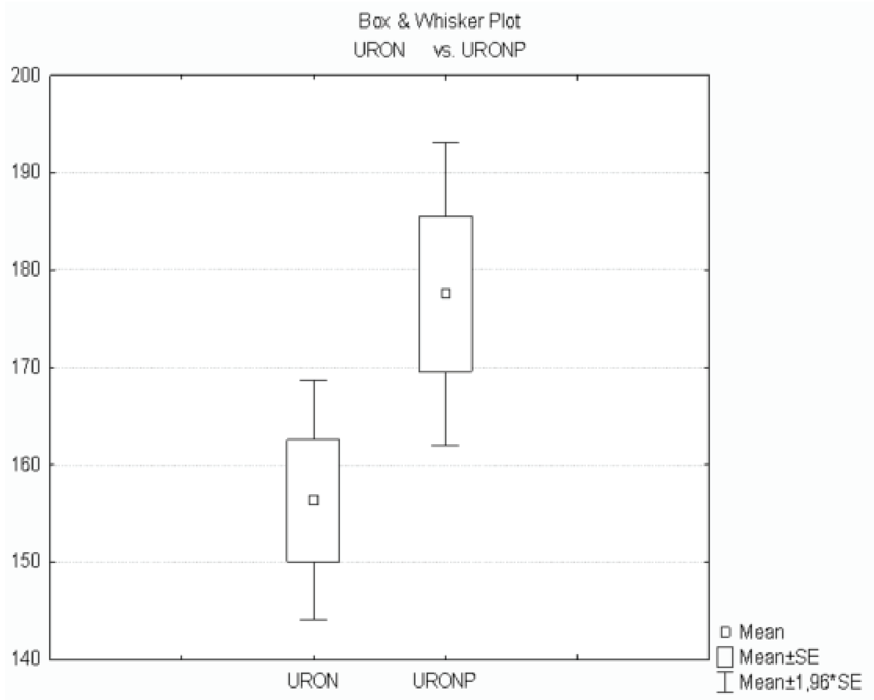
Note: URON – dynamic with monofin, URONP – dynamic with monofin after GI, Mean – arithmetic mean, SD – standard deviation, t -value of t-test, df – degrees of freedom, p – statistical significance value ($p<0.05$)



Picture 1. Dispersion of results and centroids of variables VC and VCP

In picture 1 there is dispersion of results in vital capacity and vital capacity with glossopharyngeal insufflation.

In picture 2 dispersion of results in length of dive and length of dive with glossopharyngeal insufflation is showed.



Picture 2. Dispersion of results and centroids of varibales URON and URONP

Discussion

As it can be seen from results of T-test in Table 2 there is a statistically significant difference between the arithmetic mean at the significance level of error $p<0.05$ in the amount of packed air in the lungs that is manifested between total vital capacity of 6.74 litres (VC) and vital capacity after glossopharyngeal insufflation of 8.69 litres (VCP). Difference between arithmetic means of 1.95 litres is amount which differs according to breathing technique in 15 top level breath-hold divers. The reasons why breath-hold divers achieve a significant increase in lung volume by glossopharyngeal insufflation is due to increased vital capacity, which also has a great part in the flexibility of the chest and compression of air for which one third of the air is located in the lungs (Loring et al., 2007). According to Seccombe et al. (2006) in the analysis of 7 top breath-hold divers, the difference in vital capacity before and after the glossopharyngeal insufflation technique is increased in the average volume of vital capacity after glossopharyngeal insufflation for 1.92 litres. Similar results are obtained in this research also. While Chung et al. (2010) assert that for maximum amount of air which can be stored in the lungs by glossopharyngeal insufflation technique can be increased for up to 3 litres above normal lung volume which is also similar to findings in this research.

Statistically significant difference was found between arithmetic mean at the significance level of $p<0.05$ in dive length between the URON variable (dive length without glossopharyngeal insufflation) and variable URONP (length of dive with glossopharyngeal insufflation). According to numbers in table we can conclude that difference between two techniques of breathing before taking a dive result by 10-11% longer length in dive per litre of additional packed air. For example, breath-hold divers without glossopharyngeal insufflation dive 100 meters and with glossopharyngeal insufflation they will dive approximately (assuming that they packed 2 litres more of air) 120 meters. Glossopharyngeal insufflation increases the amount of air in the lungs, i.e. the lung volume is increased by 3.2 litre, but the actual amount of air is increased by 4 litre due to pressure increase due to "packaging" and 0.8 litre is gained in the pressure inside the lungs. The amount of air increases on the basis of two parameters: chest flexibility and pressure increase due to glossopharyngeal insufflation. For example, by the glossopharyngeal insufflation, the volume of lungs is increased by 50%. Of this, 40% percent goes to the flexibility of the chest and 10% on the increase in pressure. A higher percentage cannot be obtained based on increased pressure due to the physiological characteristics of the epiglottis that cannot withstand higher pressure within the lungs. A larger amount of air means a higher amount of oxygen available (no higher oxygen percentage) that the body can use during the dive.

The glossopharyngeal insufflation technique from all the advantages has also its disadvantages that may arise as a side effect of its performance. Therefore, there are potential risks in glossopharyngeal insufflation such as: injury possibility of trachea, bronchi, bronchioles and alveolus. Those can be mild from appearance of blood droplets in saliva because of the stretching of wall to severe discontinuities leading to barotraumatic injuries such as mediastinal emphysema (characterized by air bubbles in the area around the heart), pneumothorax (occurs when the air penetrates the pleural space between the two layers and forces them to break apart). Because of these lungs or more often, one pulmonary wing collapses, subcutaneous pulmonary emphysema (characterized by skin bubbles in the area of the neck and key bones). Linerl & Andersson (2008), Eichinger et al. (2010) along with Lindholm & Lundgren (2008) indicate that acute effects most commonly occurring breath-hold divers during glossopharyngeal insufflation and diving in depths are barotraumas due to packaging (medial emphysema, gas embolism, subcutaneous emphysema).

Using breathing technique of glossopharyngeal insufflation will improve breath-hold divers' total vital capacity as well as length of dive which is increased using this technique. It is proved that glossopharyngeal insufflation has significant impact on results which are better than without using glossopharyngeal insufflation. It is concluded that the length of dive with glossopharyngeal insufflation technique is 10-11% longer per liter of charged air above the maximum vital capacity, then technique without glossopharyngeal insufflation. This compression of the air and the increase in pressure causes an increase in the amount of oxygen in the lungs. With well-trained breath-hold divers, and in particular professionals in this sport, glossopharyngeal insufflation can provide them additional 1 to 2 minute of apnea. Although glossopharyngeal insufflation technique has its advantages in view of statistically proved better results, breath-hold divers must be careful with it due to health-related issues to trachea, bronchi, bronchioles and alveolus. Breath-hold divers increase intrathoracic pressure voluntarily by taking a deep breath followed by glossopharyngeal insufflation, and with this technique they sometimes experience hypotension and syncope during the manoeuvre and breath-hold divers should be under constant control when performing glossopharyngeal insufflation technique. Those results are showing better values in performing dives for breath-hold divers which is significant cognition for coaches. On other side there would be guidance for medically qualified scientists to make more deeper researches, especially on higher number of subjects, about exact risks in undertaking glossopharyngeal insufflation technique especially as a longitudinal study of health of respiratory system for breath-hold divers who compete at a professional level.

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Conflict of Interest
The authors declare that there are no conflicts of interest.

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