『トップアスリートが実践　人生が変わる最高の呼吸法』原注

かんき出版

Notes

Chapter 1

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[6] A study by Dr. van den Elshout from the department of pulmonary diseases at the University of Nijmegen in the Netherlands explored the effect on airway resistance when there is an increase of carbon dioxide (*hypercapnia*) or a decrease (*hypocapnia*). Altogether, fifteen healthy people and thirty with asthma were involved. The study found that an increase of carbon dioxide resulted in a "significant fall" in airway resistance in both normal and asthmatic subjects. This simply means that the increase of carbon dioxide opened the airways to allow a better oxygen transfer to take place. Interestingly, individuals without asthma also experienced better breathing. Van den Elshout FJ, van Herwaarden CL, Folgering HT. Effects of hypercapnia and hypocapnia on respiratory resistance in normal and asthmatic subjects. *Thorax*.1991;46(1):28–32.

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Chapter2

[1] A study by Japanese researchers Miharu Miyamura and colleagues from Nagoya University, of ten marathon runners and fourteen untrained individuals found that athletes had a significantly greater tolerance to carbon dioxide at rest when compared with untrained individuals. The study found that for the same amount of exercise, athletes experienced 50 to 60 percent less breathlessness than that of untrained individuals. Miyamura M,

Yamashina T, Honda Y. Ventilatory responses to CO_2 rebreathing at rest and during exercise in untrained subjects and athletes. *Jpn J Physiol.* 1976; 26(3): 245–54.

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In a paper entitled “Low exercise ventilation in endurance athletes” that was published in *Medicine and Science in Sports*, the authors found that non athletes breathe far heavier and faster to changes in oxygen and carbon dioxide when compared with endurance athletes at equal workloads. The authors observed that the lighter breathing of the athlete group may explain the link between “low ventilatory chemosensitivity and outstanding endurance athletic performance.” Martin BJ, Sparks KE, Zwillich CW, Weil JV. Low exercise ventilation in endurance athletes. *Med Sci Sports*. 1979 Summer;11(2):181–5.

[4] In a study published in the *Journal of Applied Physiology* that compared thirteen athletes and ten non athletes, the athletes’ response to increased carbon dioxide was 47 percent of that recorded by the non athlete controls. The authors noted that athletic ability to perform during lower oxygen pressure and higher carbon dioxide pressure corresponded to maximal oxygen uptake or VO_2 max. Byrne-Quinn E, Weil JV, Sodal IE, Filley GF, Grover RF. Ventilatory control in the athlete. *J Appl Physiol*. 1971 Jan;30(1):91–8. In another study conducted at the Research Centre of Health, Physical Fitness and Sports at Nagoya University in Japan, researchers evaluated nine

initially untrained college students. Five out of the nine students took up physical training for three hours a day, three times a week for four years. The researchers found that VO_2 max increased after training and the response of breathing to increased arterial carbon dioxide decreased significantly during each training period. Moreover, CO_2 responsiveness was found to correlate negatively with maximum oxygen uptake in four out of the five trained subjects. Similarly to the previous study, subjects with reduced sensitivity to CO_2 experienced increased delivery of oxygen to working muscles. Miyamura M, Hiruta S, Sakurai S, Ishida K, Saito M. Effects of prolonged physical training on ventilatory response to hypercapnia. *Tohoku J Exp Med*. 1988 Dec;156 Suppl: 125–35.

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[6] Scientists investigated whether controlling the number of breaths during swimming could improve both swimming performance and running economy. A paper published in the *Scandinavian Journal of Medicine and Science in Sports* involved eighteen swimmers, ten men and eight women, who were assigned to two groups. The first group was required to take only 2 breaths per length and the second group 7 breaths. As swimming is one of the few sports that naturally limits breath intake, it is often of interest to scientists since reducing the amount of air consumed during training adds an additional challenge to the body and may lead to improvements in respiratory muscle strength. Interestingly, the researchers found that running economy improved by 6 percent in the group that performed reduced breathing during swimming. Lavin K M, Guenette J A, Smoliga J M, Zavorsky GS. Controlled-frequency breath swimming improves swimming performance and running economy. *Scand J Med Sci Sports*. 2015 Feb;25(1):16–24.

[7] Stanley NN, Cunningham EL, Altose MD, Kelsen SG, Levinson RS, and Cherniack NS. Evaluation of breath holding in hypercapnia as a simple clinical test of respiratory chemosensitivity. *Thorax*. 1975 Jun;30(3):337–43.

Japanese researcher Nishino acknowledged breath holding as one of the most powerful methods to induce the sensation of breathlessness, and that the breath hold test "gives us much information on the onset and endurance of dyspnea (breathlessness)." The paper noted two different breath-hold tests as providing useful feedback on breathlessness. According to Nishino, because holding of the breath until the first definite desire to breathe is not influenced by training effect or behavioral characteristics, it can be deduced to be a more objective measurement of breathlessness. Nishino T. Pathophysiology of dyspnea evaluated by breath-holding test: Studies of furosemide treatment. *Respir Physiol Neurobiol*. 2009 May 30;167(1):20–5.

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[10] The department of physiotherapy at the University of Szeged, Hungary, conducted a study that investigated the relationship between breath-hold time and physical performance in patients with cystic fibrosis. Eighteen patients with varying stages of cystic fibrosis were studied to determine the value of the breath-hold time as an index of exercise tolerance. The breath-hold times of all patients were measured. Oxygen uptake (VO_2) and carbon dioxide elimination was measured breath by breath as the patients exercised. The researchers found a significant correlation between breath-hold time and VO_2 (oxygen uptake), concluding "that the voluntary breath-hold time might be a useful index for prediction of the exercise tolerance of CF patients." Taking this one step further, increasing the BOLT of patients with CF corresponds to greater oxygen uptake and reduced breathlessness during physical

exercise. Barnai M, Laki I, Gyurkovits K, Angyan L, Horvath G. Relationship between breath-hold time and physical performance in patients with cystic fibrosis. *Eur J Appl Physiol*. 2005 Oct;95(2–3):172–8. Results from a study of thirteen patients with acute asthma concluded that the magnitude of breathlessness, breathing frequency, and breath-hold time was correlated with severity of airflow obstruction and, secondly, that breath-hold time varies inversely with the magnitude of breathlessness when it is present at rest. In simple terms, the lower the breath-hold time of asthmatics, the greater the breathing volume and breathlessness. Pérez-Padilla R, Cervantes D, Chapela R, Selman M. Rating of breathlessness at rest during acute asthma: Correlation with spirometry and usefulness of breath-holding time. *Rev Invest Clin*. 1989 Jul–Sep;41(3):209–13.

Chapter3

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paranasal sinuses. *Anat Rec (Hoboken)*. 2008 Nov;291(11):1479–84. Vural C, Güngör A. Nitric oxide and the upper airways: Recent discoveries]. *Kulak Burun Bogaz Ihtis Derg*. 2003 Jan;10(1):39–44.

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Chapter5

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Chapter6

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[22] A study by Baković et al. from University of Split School of Medicine, Croatia, was conducted to investigate spleen responses resulting from 5 maximal breath holds. Ten trained breath-hold divers, ten untrained volunteers, and seven volunteers who had their spleen removed were recruited. The subjects performed 5 maximum breath holds with their face immersed in cold water, and each breath hold was separated by a 2-minute rest. The duration of the breath holds peaked at the third attempt, with breath-hold divers reaching 143 seconds, untrained divers reaching 127 seconds and splenectomized persons achieving 74 seconds. Spleen size decreased by a total of 20 percent in both breath-hold divers and the untrained volunteers. Researchers concluded that the results show rapid, probably active contraction of the spleen in response to breath hold in humans. Rapid spleen contraction and its slow recovery may contribute to prolongation of successive, briefly repeated-breath hold attempts. Baković D, Valic Z, Eterović D, et al. Spleen volume and blood flow response to repeated breath-hold apneas. *J Appl Physiol*. 2003 Oct;95(4):1460–6.

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[25] This study in particular provides pertinent information about the consequence of breath holding: Since there was no visible increase in the results of breath holding with the subjects' faces immersed in water, the authors concluded that the breath hold, or its consequences, is the major stimulus evoking splenic contraction. Schagatay, Anderson, Nielsen 2007 Sep, 125–32.

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[27] In his doctoral thesis entitled "Haematological changes arising from spleen contraction during breath hold and altitude in humans", Matt Richardson investigated the role played by higher levels of carbon dioxide.

Eight non-divers performed 3 sets of breath holds on three separate days under different starting conditions, varying the levels of carbon dioxide available to the subjects before each test. The first test was preceded by the breathing of 5 percent CO_2 in oxygen (hypercapnic), the second with pre-breathing of 100 percent oxygen (normocapnic), and the third with hyperventilation of 100 percent oxygen (hypocapnic).

The duration of each breath hold was kept constant in all 3 sets, and baseline values of Hb and Hct were the same for all conditions. After the 3 breath holds, the increase in Hb in the hypercapnic (higher carbon dioxide) trial was 9.1 percent greater than in the normal carbon dioxide trial (normocapnic) and 71.1 percent greater than in the lower carbon dioxide trial (hypocapnic). Richardson concluded that an increased capnic stimulus during breath hold may elicit a stronger spleen response and subsequent Hb increase than breath hold preceded by hyperventilation. Richardson, M X. Hematological changes arising from spleen contraction during apnea and altitude in humans. *Doctoral dissertation*. Mid Sweden University; 2008.

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[32] The concentration of EPO: De Bruijn and colleagues from the department of natural sciences, Mid Sweden University, investigated whether subjecting the body to lower oxygen levels by holding the breath could increase EPO concentration. The study involved ten healthy volunteers performing 3 sets of 5 maximum duration breath

holds, with each set separated by 10 minutes of rest. Results showed that EPO concentration increased by 24 percent, peaking three hours after the final breath hold and returning to baseline two hours later. De Bruijn R, Richardson M, Schagatay E. Increased erythropoietin concentration after repeated apneas in humans. *Eur J Appl Physiol*. 2008 Mar;102(5):609–13.

[33] Cahan C, Decker MJ, Arnold JL, Goldwasser E, Strohl KP. Erythropoietin levels with treatment of obstructive sleep apnea. *J Appl Physiol*. 1995 Oct;79(4):1278–85. A study by Winnicki and colleagues from the Medical University of Gdansk, Poland, tested the hypothesis that the repetitive lowering of oxygen levels from breath holds during sleep apnea increase EPO. The study involved eighteen severe and ten very mild patients. Results showed a 20 percent increase to EPO in patients with severe obstructive sleep apnea, which decreased following elimination of the breath holds by treatment. Winnicki M, Shamsuzzaman A, Lanfranchi P, et al. Erythropoietin and obstructive sleep apnea. *Am J Hypertens*. 2004 Sep;17(9):783–6.

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[36] Over the years many: J. Edge and colleagues at the University of Australia in Perth conducted a study of the effects of bicarbonate of soda on the ability of muscles to neutralise the acid that accumulates during high-intensity training. In Edge's study, sixteen recreationally active women were recruited and randomly placed in two groups of eight. One group ingested bicarbonate of soda and the other ingested a placebo. The results showed that the bicarbonate group experienced greater improvements in lactate threshold and time to fatigue. There working muscles were better able to neutralise the acid resulting from training, showing improvements to endurance performance. Edge J, Bishop D, Goodman C. Effects of chronic $NaHCO_3$ ingestion during interval training on changes to muscle buffer capacity, metabolism, and short-term endurance performance. *J Appl Physiol*. 2006 Sep;101(3):918–25.

In a study at the University of Bedfordshire in the UK, researchers investigated the effects of sodium bicarbonate on maximum breath hold time. Eight recreational breath-hold divers were recruited to partake in two bouts of 3 monitored breath holds while their faces were immersed in water. Following the study, the authors suggested that ingestion of bicarbonate of soda before breath holds prolongs maximum breath-hold time by approximately 8.6 percent. Sheard PW, Haughey H. Sodium bicarbonate and breath-hold times. Effects of sodium bicarbonate on voluntary face immersion breath-hold times. *Undersea Hyperb Med*. 2007 Mar–Apr;34(2):91–7.

Researchers from the Academy of Physical Education in Katowice, Poland conducted a study to evaluate the effects of oral administration of sodium bicarbonate on swim performance in competitive youth swimmers. The swimmers completed two time trials: one after ingestion of bicarbonate and one after ingestion of a placebo. Total time for the 4 x 50 m test trial improved from 1.54.28 to 1.52.85 s. In addition,

bicarbonate had a significant effect on resting blood pH. Researchers concluded that the ingestion of sodium bicarbonate in youth athletes is an effective buffer during high-intensity interval swimming and suggested that such a procedure may be used in youth athletes to increase training intensity and swimming performance in competition at distances from 50 to 200 m. Zajac A, Cholewa J, Poprzecki S, Waskiewicz Z, Langfort J. Effects of sodium bicarbonate ingestion on swim performance in youth athletes. *J Sports Sci Med*. 2009 Mar 1;8(1):45–50.

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Another study tested whether repeated breath holds by elite breath-hold divers to reduce oxygen pressure in the blood could result in reduced blood acidosis and oxidative stress. Trained divers with seven to ten years of experience in breath hold diving, and with an ability to hold their breath for up to 440 seconds during rest, were compared with a second group of non-divers who had at most a 145 second breath-hold time.

Both groups performed a breath hold during rest, followed by 2 minutes of forearm exercises during which the diver group performed a breath hold and the second group breathed as normal. Interestingly, the group who breathed as normal showed an increase in blood lactic acid concentration and oxidative stress. In the diver group, the changes in both lactic acid and oxidative stress were markedly reduced after both breath holds and exercise. The paper concluded that humans who are involved in a long-term training program of breath-hold diving have reduced blood acidosis and oxidative stress following breath holds and exercise. Joulia, Steinberg, Wolff, Gavarry, Jammes 2002, 121–30.

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Appendix

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apnea. Ivancev et al. tested the hypothesis that repeated breath holds, which are an integral part of breath-hold diving, blunt cerebrovascular reactivity to hypercapnia. Two groups of seven elite breath-hold divers and seven non-divers were involved in the test. The study noted that breath-hold divers had a greater tolerance to carbon dioxide, largely the result of lower breathing frequency. The findings of the study were "that the regulation of the cerebral circulation in response to hypercapnia is intact in elite breath-hold divers, potentially as a protective mechanism against the chronic intermittent cerebral hypoxia and/or hypercapnia that occurs during breath-hold diving." Therefore, regular breath-hold practice does not impair cerebrovascular reactivity to high carbon dioxide pressure. Ivancev V, Palada I, Valic Z, et al. Cerebrovascular reactivity to hypercapnia is unimpaired in breath-hold divers. *J Physiol*. 2007 Jul 15;582(Pt 2):723–30.

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Epilogue

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