A Pedagogical Approach to the Issue of Focal Task Specific Dystonia of the Embouchure

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The Goals of this Presentation

- Define Focal Task Specific Dystonia. [illegible] cramp – musician's cramp
- Discuss medical research.
- Examine this disorder from a pedagogical standpoint:
  - Re-examine our understanding of the role of the teacher.
  - Gain a better understanding of how people learn to do things.
  - Gain a better understanding of brass physiology.
- Assist in educating brass teachers about FTSD.
- Determine possible causes for FTSD.
- Explore possible treatment for FTSD.
- Assist players diagnosed with FTSD in getting help and support.
- Aim to eradicate FTSD.

General Definitions

- Focal: Localized
- Task Specific: Occurs only during a specific activity
- Dystonia: "A syndrome of sustained muscle contractions, frequently causing twisting and repetitive movements, or abnormal postures". (Dystonia Medical Research Foundation)

Action Dystonia

- Action Dystonia implies an involuntary posturing (dystonia) superimposed on a voluntary movement.
- Task Specific Dystonias are a subset of action dystonias which occur exclusively when performing a specific task.
  - Usually highly repetitive movements
  - Requiring extreme motor precision with an interplay between conscious (feedback-related) modulation and a repetitively executed motor plan. (Uitti et al Handbook of Dystonia, 1995)

Characteristics of FTSD of the Embouchure

- Weakness in tone production ("dull sound")
- Air leakage
- Embouchure tremor
- Tongue Lock (time-extended hesitation)
  - Often misdiagnosed as lip lock
  - Inability to start notes
  - Tends to lead to further dysfunction
- Involuntary lip movements
  - Lateral pull (usually at initial sound)
  - Lip closure (gripping sensation while sustaining a note)
  - Lip Lock (lips close tight at initial sound)
- Jaw closure (Jaw clamps shut at initial sound)

Case History of a player diagnosed with FTSD

- "Natural" player/"Well-trained" player
- Something changes the "feel" – different instrument, injury, added stress...
- Notices a difference/problem KINESTHETIC LEARNER · LEARNS BY FEEL
- Focuses on the problem and increases practice regimen

– STAY OUT OF THE REGISTER THAT IS DYSTONIC
– GO TO ANOTHER REGISTER

- Tries to fix the problem using conventional understanding of brass physiology
- Visits "pedagogues" and reads pedagogical texts
- Fear, anxiety and stress increase
- Problem gets worse
- Embarrassment and self-consciousness increase
- Depression sets in, hope fades
- Problem continues to get worse until it becomes clinical

Onset and Prognosis: **As described by Dr. Steven J Frucht et al. in "The Natural History of Embouchure Dystonia" (2001)**

- The average age of onset tends to be in the fourth decade.
- Symptoms are often register-specific.
- Symptoms are often style-specific.
- Symptoms develop and progress.
- Symptoms may begin in one style or register, but then progress to the entire range.
- Certain types of "dystonia" are instrument-specific.
- Lateral Pull tends to be more prevalent in trumpet and horn players.
- Lip Lock tends to be more prevalent amongst low brass, trombone and tuba players.
- FTSD of the embouchure is normally specific to playing the instrument but has spread to other tasks.
- "The most effective treatment was retraining their embouchure. Many had already consulted brass pedagogues before coming to see us..."

Pedagogy vs. Brass Physiology

- Pedagogy: The art or science of teaching
    - Determining the role of the teacher
    - Understanding the learning process
    - Identifying appropriate curriculum
- Brass Physiology: How we play a brass instrument
    - How do we make a sound on a brass instrument?
    - How do we alter the sound on a brass instrument?

Physiology: How do we learn "to do?"

- Imitation: The mind has an image of the task to be accomplished.
- Trial and error: The body attempts to "match" what the brain has conceived.

Physiology: Why we play the way we do

- Concept: Auralization of the musical ideas that we intend to communicate
    - Great musicians have great ears!
- Practice: Utilization of the concept
- Individuality: Every person has a unique set of talents and abilities.
    - Intellectually - conception/auralization
    - Emotionally - openness to expression
    - Physically - relaxation, air flow, embouchure/body in a position to respond.

CHOOSE THE BEST ROLE MODEL! NOT JUST WHO YOU HEARD LAST.

Function vs. Dysfunction

- We must first understand embouchure function if we are to understand embouchure dysfunction.
- Doctors tend to look at sickness and try to describe the symptoms of what has gone wrong within the body.
- Brass players/teachers often teach the symptoms of what has occurred when they have played well.
    - *"The players/teachers do what they do; they tell the students what they think they do; the students then try to do what they think the teachers think they said about what they think they do". - Denis Wick*
    - *"By minutely varying the tension and size of the lip opening, brass players are able to control the frequency or "pitch" of each note." - Dr. Steven J. Frucht quoting Philip Farkas.*
- A description of symptoms is not a prescription for doing.

Healthy Embouchure Function

- Physical relaxation:
    - The player has good energy flow throughout the body.
- Good use of air:
    - The body is relaxed and the player takes in air and blows air past the lips.
    - The action is blowing (playing music), the reaction is the inhalation.
- Embouchure:
    - The lips are in the way of the air stream.
    - The embouchure is blown into position by the air.
    - The ear/concept/brain controls the pitch, volume, timbre & stylistic changes.

90% of Focal Dystonia have Tension

A Good Embouchure is symptoms of Good Air & Great Ears!

Motor vs. Sensory Neural Pathway (use in motor performance)

Motor	**Sensory**
DSL	Ordinary phone line
Accurate & Fast	Inaccurate & Slow
Einstein Olympian	Moe, Larry & Curly

Practice Makes Permanent

A Possible Cause of FTSD

Physical [illegible]

- *Change* causes a disruption of "natural" motor function.
- Player notices a problem in the "feel" and ease of production. Most
- Player increases utilization of sensory feedback.
    - Moe, Larry & Curly
- Stress and tension increase.
- Inefficient use of air: Demonstrating the symptoms of a good breath, rather than taking a good breath.
- Player systematically and diligently practices the problem utilizing a variety of faulty theories of brass physiology.
    - A description of the symptoms of good brass playing is not a prescription for good brass playing!
- Negative results cause further negative expectations.
- Dysfunction becomes "hardwired" in the brain as an aberrant neural pathway.

Medical Support

"The sensorimotor learning hypothesis of focal hand dystonia suggests that repetition of temporally related sensory inputs plays a role in triggering symptoms".

-Byl et al., "Learning-induced differentiation of the representation of the hand in the primary somatosensory cortex in adult monkeys", 1996.

Sensorimotor Dysfunction

"The results from this study provide evidence that abnormalities of sensorimotor as well as sensory processing exist in patients with focal hand dystonia".

-Lin et al. "Abnormalities of sensorimotor magnetic fields in focal hand dystonia.", 2004

Aberrant Learning?

The article "Focal Hand Dystonia May Result from Aberrant Neuroplasticity", by Nancy N. Byl, cites more than 10 theories from the medical community for possible causes of focal hand dystonia. She offers an additional possibility: "Aberrant learning is consistent with direct observations and self-reported patient histories highlighting (certain) behaviors..."

Some of the Practice Behaviors cited by Byl

- Precise motor control
- Sophisticated "feedback-related" modulation
- Spaced, intense practice behaviors carried out over long periods of time
- Goal orientation and attention
- Modification in instrumentation or strategies of performance

YES - PRIMARY PERSON MOTOR CONTROL - SHIFT ATTENTION

Focus of Attention

"Researchers found that, in the subjects paying attention to the (stimulus), activation in the somatosensory cortex region representing the fingertips increased 13 percent compared to activation in subjects receiving the identical stimulation but not paying attention".

-*The Mind and The Brain*, Jeffrey M. Schwartz, M.D.

Recovery

"How well people can pay attention just after a right-brain stroke predicts how well they can use their left hands two years later."

–Attributed to Ian Robertson, Trinity College Dublin by Jeffrey M. Schwartz M.D. from *The Mind and The Brain*

Assessment of a player diagnosed with FTSD

- Be clear about whether or not you can help.
- The more teachers/doctors that a player consults without success, the more hopeless and depressed they will become. They may also pick up further baggage, making them more resistant to retraining.
- Once you have decided that you may be able to help, be sure to suggest that the person visit a medical professional to rule out other possible medical issues.
- Request a complete written playing, personal and medical history including what has been done to work through the problem.
- Assess of the extent of the problem. (intellectual, emotional, physical)

The retraining of a player diagnosed with FTSD

- There is a difference between "Teaching" and "Retraining" (Rehabilitation).
- Once the player has noticed a problem, it instantly becomes intellectual, emotional and physical, and therefore the retraining must also be holistic. → ALL INCLUSIVE
- Educate the player about the disorder.
- Educate the player about brass physiology.
- Begin with total body relaxation/"release" and energy flow. Bones of Cont Rich
- The priority should be on building a sense of ease.
- Each step in the process must be successful before moving on, and each additional step must be incremental and based upon matching a portion of the previous step.
- Focus of Attention is the key component to rewiring the brain.
- Each step must become "issue free" before moving on - SAFE GROUND.
- I utilize scalar melodies to assist the player in keeping his focus on communication of sound. (flow is outward rather than perceptive.)
- Distract as much as possible from the kinesthetic feedback. (motor rather than sensory function)
- VERY slowly, the player retrains a more natural motor function.

Cause & Effect

"Maybe focal dystonias reflect use driven changes in cortical representations degrading the fine-grained cortical maps like the colors of a Mondrian bleeding into each other after the rain."

-*The Mind and the Brain* by Jeffrey M. Schwartz, MD. Regan Books, Harper Court 2002. ISBN 0-06-039355-6

Eradication of FTSD?

- Incurable?
- Discouragement leads nowhere.
- We need to remain open-minded and hopeful.
- If even one person has been successful, there is hope.

10 *DOCUMENTED* WAYS TO IMPROVE YOUR BREATHING: RESEARCH FROM THE MEDICAL FIELD

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INTRODUCTION

Breathing misconceptions are common among musicians. While many of the breathing ideas and exercises created by musicians are beneficial, others may be a waste of time, or even detrimental to performance. The unique approach of this article is the attempt to summarize only points that have been tested and documented to affect measurable lung capacity, function, or mechanics. A deliberate effort has been made to document thoroughly, using only medical sources.

A brief note about terminology: In the medical profession, the term *inspiration* is synonymous with inhalation, and *expiration* with exhalation. *Lung volume* is divided into several categories, but *vital capacity* (the maximum amount of air a person can voluntarily exhale after a maximal inhalation), is the most applicable to musicians. *Lung function* refers to how well a person is able to use their lung volume. Although there are many different measures of lung function, the most common is *forced expiratory volume in one second*, or FEV1, the amount of air a person can exhale in one second. *Spirometry* is the practice of taking specific measurements of lung volume and lung function. *Ventilation*, which is probably a more exact term than *breathing* for the way air is used by musicians, is simply the movement of air in and out of the lungs (without respect to oxygenation of the blood, gas exchange, etc.).

1) Practice deep breaths.

It has been shown that the respiratory muscles, like other skeletal muscles, can be strengthened through training.[1] There is a whole subfield of respiratory therapy, called "incentive spirometry," that is at least partially based on this idea as it applies to the respiratory system. Incentive spirometry involves, essentially, training respiratory muscles using various "mechanical aides" that offer "visual or other positive feedback."[2] Practicing with these mechanical aides normally involves inspiration or expiration against varying degrees of resistance. Medical studies have shown that subjects practicing incentive spirometry on a daily basis for five to six weeks significantly improve both lung capacity and lung function, including vital capacity,[3] total lung capacity,[4] maximal dynamic pressure,[5] maximal expiratory pressure,[6] maximal inspiratory pressure,[7] and general inspiratory muscle performance.[8]

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[1] M.J. Belman and G.C. Sieck, "The Ventilatory Muscles: Fatigue, Endurance and Training," *Chest* 82 (1982): 761-66; D.E. Leith and M. Bradley, "Ventilatory Muscle Strength and Endurance Training." *Journal of Applied Physiology* 41(4) (1976): 508-16; C.H. Roussos and P.T. Macklem, "The Respiratory Muscles," *New England Journal of Medicine* 307 (1982): 786-97.

[2] "American Association for Respiratory Care Clinical Practice Guidelines," *Respiratory Care* 36 (1991): 1402-1405.

[3] Leith.

[4] Ibid.

[5] G.E. Tzelepis, "Inspiratory Muscle Adaptations Following Pressure or Flow Training in Humans," *European Journal of Applied Physiology* 79(6) (May 1999): 467-71.

Studies have also shown that measurable improvement can result from practicing full breaths against little or no resistance. This can be done with or without mechanical aides. In one study, a group of 16 healthy volunteers increased their vital capacity by an average of 200 ml by completing a daily six-week routine of 20 maximal inhalations, held each time for ten seconds with the glottis open.[9] Similar studies, including both slow and fast breaths, as well as yoga-style breathing, have shown improvement in maximal inspiratory flow[10] and peak expiratory flow rate.[11] Generally speaking, it would appear that practicing breathing against resistance improves ability to exert respiratory pressures, while practicing breathing without resistance (or against minimal resistance) increases the ability of the respiratory system to generate high flow rates.[12] Both types of practicing appear to benefit lung capacity (see above).

2) Eat fruit and vegetables.

Multiple medical studies have found that intake of fresh fruit and vegetables directly improves breathing, including general lung function,[13] lung capacity,[14] FEV1 (forced expiratory volume in one second),[15] and FVC (forced vital capacity).[16] It has also been shown to have a protective effect on respiratory function from decline due to age.[17] Apples (which contain high levels of the antioxidant *quercetin*) and vitamin E appear to have a particularly strong positive effect on lung function.[18] Researchers speculate that the benefits of fruit and vegetables result from their antioxidant action on the lung.[19]

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[6] Hiroaki Nomori et al., "Preoperative Respiratory Muscle Training," *Chest* 105 (1994): 1782-88; Do Hyun Nam et al., "Specially Programmed Respiratory Muscle Training for Singers by Using Respiratory Muscle Training Device (Ultrabreathe®)," *Yonsei Medical Journal* 45(5) (2004): 810-817.

[7] N. Hart et al., "Evaluation of an Inspiratory Muscle Trainer in Healthy Humans," *Respiratory Medicine* 95(6) (2000): 526-31; Nomori et al.; Do Hyun Nam et al.

[8] "American Association for Respiratory Care Clinical Practice Guidelines," *Respiratory Care* 36 (1991): 1402-1405.

[9] C.H. Fanta, D.E. Leith, and R. Brown, "Maximal Shortening of Inspiratory Muscles: Effect of Training," *Journal of Applied Physiology* 54(6) (June 1983): 1618-23.

[10] G.E. Tzelepis et al., "Pressure-flow Specificity of Inspiratory Muscle Training," *Journal of Applied Physiology* 77(2) (August 1994): 795-801.

[11] L.N. Joshi and V.D. Joshi, "Effect of Forced Breathing on Ventilatory Functions of the Lung." *Journal of Postgraduate Medicine* 44(3) (1998): 67-9; H.R. Nagendra and R. Nagarathna, "An Integrated Approach of Yoga Therapy for Bronchial Asthma: a 3-54-month Prospective Study," *Journal of Asthma* 23(3) (1986): 123-37.

[12] G.E. Tzelepis, V. Kasas, and F.D. McCool, "Inspiratory Muscle Adaptations Following Pressure or Flow Training in Humans," *European Journal of Physiology* 79(6) (May 1999): 467-71; Joseph A. O'Kroy and J. Richard Coast, "Effects of Flow and Resistive Training on Respiratory Muscle Endurance and Strength," *Respiration* 60 (1993): 279-83.

[13] Linda Grievink et al., "Dietary Intake of Antioxidant (Pro)-vitamins, Respiratory Symptoms and Pulmonary Function: The MORGEN Study," *Thorax* 53 (1998): 166-171; J. R. Britton et al. "Dietary Antioxidant Vitamin Intake and Lung Function in the General Population," *American Journal of Respiratory Critical Care Medicine* 151(5) (May 1995): 1383-1387.

[14] Grievink.

[15] Grievink; Britton; Barbara K. Butland et al., "Diet, Lung Function, and Lung Function Decline in a Cohort of 2512 Middle Aged Men," *Thorax* 55 (2000): 102-108; Cora Tabak et al., "Dietary Factors and Pulmonary Function: A Cross Sectional Study in Middle Aged Men from Three European Countries," *Thorax* 54 (1999): 1021-1026; Cora Tabak et al., "Chronic Obstructive Pulmonary Disease and Intake of Catechins, Flavonols, and Flavones: The MORGEN Study," *American Journal of Respiratory and Critical Care Medicine* 164 (2001): 61-64.

[16] Grievink; Britton.

[17] Grievink.

[18] Butland; Cora Tabak et al., "Chronic Obstructive Pulmonary Disease and Intake of Catechins, Flavonols, and Flavones: The MORGEN Study." *American Journal of Respiratory and Critical Care Medicine* 164 (2001): 61-64; Holger J. Schünemann et al., "The Relation of Serum Levels of Antioxidant Vitamins C and E, Retinol and Carotenoids with Pulmonary Function in the General Population," *American Journal of Respiratory and Critical Care Medicine* 163 (2001): 1246-1255.

[19] Fomieu; D. P. Strachan et al., "Ventilatory Function and Winter Fresh Fruit Consumption in a Random Sample of British Adults," *Thorax* 46: 624-629.

3) Don't smoke.

Besides causing lung cancer, of course, smoking negatively affects nearly every measurable aspect of lung function, including FVC (forced vital capacity),[20] FEV1 (forced expiratory volume in one second),[21] and MEF 50% (maximal expiratory flow at 50% of vital capacity).[22] This applies not only for tobacco, but for cannabis as well.[23] The effects of smoking are cumulative, as measured by duration and pack years, although they are at least partially reversible upon cessation.[24]

4) Stay (or become) physically fit.

Studies of the pulmonary effects of aerobic activities such as swimming and running have shown marked improvement in both lung capacity and lung function, including vital capacity, inspiratory muscle strength, maximum expiratory pressure, maximal voluntary ventilation, and maximum sustainable ventilatory capacity.[25]

It should be noted that, at least in some cases, the *direct* effects of exercise on lung function are somewhat controversial in the medical field;[26] however, it is widely agreed that weight loss and increase in body muscle (*indirect* results of exercise) have a direct correlation with lung function, as shown by multiple studies.

Weight loss positively correlates with VC (vital capacity), FVC (forced vital capacity), TLC (total lung capacity), FEV (forced expiratory volume), FEV1 (forced expiratory volume in one second), and virtually every other traditional measurement of lung function.[27]

General muscle strength has been found to have a positive correlation with lung function.[28] Studies of localized, targeted muscle strengthening have been conducted, with mixed results. For example, healthy subjects in a recent study who performed sit-ups and biceps curls three to four days a week for 16 weeks significantly increased diaphragm thickness, maximal transdiaphragmatic pressure, maximaum inspiratory pressure, and maximum expiratory pressure.[29] Another study measured FVC (forced vital capacity) and FEV1 (forced expiratory volume in one second) in 16 healthy subjects who participated

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[20] J. W. Twisk et al., "Tracking of Lung Function Parameters and the Longitudinal Relationship with Lifestyle," *European Respiratory Journal* 12(3) (Sept 1998): 627-34; S. C. Yang, "Relationship Between Smoking Habits and Lung Function Changes with Conventional Spirometry." *Journal of the Formosan Medical Association* 92 Suppl 4 (Dec 1993): S225-31.

[21] Twisk; Yang; G. J. Beck, C. A. Doyle, and E. N. Schachter, "Smoking and Lung Function," *American Review of Respiratory Disease* 123(2) (Feb 1981): 149-55.

[22] Beck.

[23] D. R. Taylor et al. *Addiction* 97(8) (Aug 2002): 1055-61.

[24] Beck; D. W. Dockery et al., "Cumulative and Reversible Effects of Lifetime Smoking on Simple Tests of Lung Function in Adults," *American Review of Respiratory Disease* 137(2) (February 1988): 286-92.

[25] T.L. Clanton et al., "Effects of Swim Training on Lung Volumes and Inspiratory Muscle Conditioning," *Journal of Applied Physiology* 62(1) (January 1987): 39-46; E.P. Robinson and J.M. Kjeldgaard, "Improvement in Ventilatory Muscle Function with Running," *Journal of Applied Physiology* 52(6) (June 1982): 1400-6.

[26] Christopher J. Womack et al., "Weight loss, Not Aerobic Exercise, Improves Pulmonary Function in Older Obese Men," *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences* 55:MM453-M457 (2000).

[27] Womack; Antonino De Lorenzo et al., "Body Composition Analysis and Changes in Airways Function in Obese Adults After Hypocaloric Diet," *Chest* 119 (2001): 1409-1415; F. Zerah et al., "Effects of Obesity on Respiratory Resistance," *Chest* 103: 1470-1476.

[28] A. M. Hall et al., "Lung Function in Healthy British Women," *Thorax* 34: 359-395; R. Lazarus et al., "Effects of Body Composition and Fat Distribution on Ventilatory Function in Adults," *American Journal of Clinical Nutrition* 68(1) (July 1998): 35-41; T. Ringqvist, "The Ventilatory Capacity in Healthy Subjects," *Scandinavian Journal of Clinical and Laboratory Investigation* 18(suppl. 88) (1966): 98-99; J.B. Schoenberg, G.J. Beck, and A. Bouhuys, "Growth and Decay of Pulmonary Function in Healthy Blacks and Whites," *Respiratory Physiology* 33(3) (June 1978): 367-93; J. Bande, J. Clement, and K.P. Van de Woestijne, "The influence of Smoking Habits and Body Weight on Vital Capacity and FEV1 in Male Air Force Personnel: A Longitudinal and Cross-sectional Analysis," *American Review of Respiratory Disease* 122(5) (November 1980): 781-790; Vincent Madama, *Pulmonary Function Testing and Cardiopulmonary Stress Testing* (New York: Delmar Publishers, 1998), 153.

[29] V.A. DePalo et al., "Respiratory Muscle Strength Training with Nonrespiratory Maneuvers," *Journal of Applied Physiology* 96(2) (February 2004): 731-4.

in a 12-session training program designed to increase abdominal strength. Although abdominal muscle strength was shown to improve, there was no improvement in either FVC or FEV1.

Obesity has dramatic negative effects on lung capacity and function. Although some musicians have the idea that being overweight improves lung capacity or lung function, this is clearly a misconception in several measurable ways. First, there is a clear negative correlation with the spirometric measurements that are linked positively with weight loss (above), including both lung function and lung capacity. In addition, obesity leads to greater respiratory resistance, requiring greater energy to perform even the most basic respiratory tasks; specifically, obesity causes "mechanical impairment" through mass loading of the respiratory system[30] as well as "congestion of bronchial vessels in the airway submucosa, thickening of the airway wall, and decrease in airway size."[31]

5) Allow full expansion.

It is a common piece of workaday knowledge among physiologists that the bellows of the human respiratory system consists of two parts: the diaphragm and the rib cage.[32]

Using only the diaphragm, as is sometimes advocated by musicians,[33] eliminates approximately one third of the vital capacity.[34] Other studies indicate that this amount could even be higher.[35] There are clearly many cases in which musicians require a full vital capacity breath, not just two thirds of capacity. Since maximum expiratory flow is possible only near total lung capacity and decreases progressively as lung volume decreases, this matter obviously affects lung function as well as lung volume.[36]

Movement of the rib cage portion of the bellows occurs mechanically through what physiologists call the "bucket handle" motion of the rib cage, wherein the rib cage moves upward and outward upon inhalation, downward and inward on exhalation. If the rib cage remains fixed (whether in an upward or a downward position), its mechanical purpose is obviously thwarted. That is to say, the rib cage must move up and down, in and out, in order to work as a bellows.[37]

If rib cage motion is inhibited and only the diaphragm is used, the efficiency of the entire respiratory system is compromised. Respiratory physiologists have shown that the respiratory system works best as a whole, not through isolation of individual muscles like the diaphragm (hence the term respiratory *system*). Studies demonstrate, for example, that the respiratory muscles other than the diaphragm do not simply offer mechanical assistance to the diaphragm. Rather, these muscles actually "coordinate so as to *optimize* diaphragmatic function"[38] (emphasis added), with "substantial coupling" between the

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30 F. Zerah et al., "Effects of Obesity on Respiratory Resistance," *Chest* 103(5) (May 1993): 1470-6.

31 De Lorenzo.

32 Charles E. Tobin. *Basic Human Anatomy* (New York: McGraw-Hill, 1973); Leonard R. Johnson, ed. *Essential Medical Physiology*, 2nd ed. (New York: Lippincott-Raven, 1998), 256.

33 Medical studies have shown that musicians are often wrong in both details and generalities when giving physiological descriptions of their own activities. See, for example, Peter J. Watson and Thomas J. Hixon, "Respiratory Kinematics in Classical (Opera) Singers," *Journal of Speech and Hearing Research* 28(1) (March 1985): 104-22.

34 D. M. Sebei et al., *Respiration: The Breath of Life* (New York: Torstar Books, 1987), 28.

35 Edward H. Bergofsky, "Relative Contributions of the Rib Cage and the Diaphragm to Ventilation in Man," *Journal of Applied Physiology* 19(4) (1964): 698-706.

36 Leonard R. Johnson, ed. *Essential Medical Physiology*, 2nd ed. (New York: Lippincott-Raven, 1998), 263.

37 Ibid.

38 Michael D. Goldman and Jere Mead, "Mechanical Interaction Between the Diaphragm and Rib Cage," *Journal of Applied Physiology* 35(2) (1973): 197-204.

muscles of the rib cage and the diaphragm.[39] In other words, the diaphragm does not work as efficiently by itself as it does in combination with the other respiratory muscles.

Finally, there is no physiological evidence that rib cage motion causes tension in any way, contrary to what musicians sometimes claim. In point of fact, motion more often *relieves* tension than causes tension. Think of the last time your neck was stiff—did you relieve the tension by keeping it as fixed as possible? If your arms are tense do you relax them by holding them as still as possible?

6) Don't wear restrictive clothing.

Breathing, of course, involves work by the respiratory muscles. A major portion of this work is done against the mechanical resistance of the abdomen and rib cage.[40] Clothing that restricts movement of either the abdomen or the rib cage increases this resistance, creating what physiologists call *external loading* of the respiratory system. This can significantly inhibit breathing, including decreasing vital capacity, FEV1, and forced vital capacity.[41] Among the clinical practice guidelines recommended by the American Association of Respiratory Care for taking breathing measurements is the following: "Breathing movements should not be restricted by clothing."[42] Specifically, experts recommend loosening anything tight across the abdomen, chest, or neck, including neckties and belts, before taking breathing measurements.[43] By way of comparison, tight clothing around the abdominal wall actually compromises the respiratory system in a way similar to obesity and pregnancy, by "impeding the effectiveness of the diaphragm" to displace the abdominal viscera.[44] Although the general point might seem self-evident, a surprising number of musicians, particularly in performance situations, wear clothing that clearly restricts outward movement of the abdomen or chest.

7) Don't eat a lot before performing.

Presence of a large amount of undigested food in the abdomen makes displacement of abdominal contents by the diaphragm mechanically more difficult. The American Association for Respiratory Care recommends the following in its clinical guidelines for taking breathing measurements: "The patient should not have had a large meal shortly before testing."[45] In other words, avoid that big pasta dinner right before the concert. For what it's worth, experts in the field of exercise physiology, who analyze such things in detail, recommend eating approximately 2 ½ hours before performing, for an optimal balance of factors such as breathing, digestion, and energy.[46]

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[39] B. R. Boynton et al., "Mechanical Coupling of the Rib Cage, Abdomen, and Diaphragm Through Their Area of Apposition," *Journal of Applied Physiology* 70(3) (1991): 1235-44.

[40] Andrew Davies et al. *Human Physiology* (London: Churchill Livingstone, 2001).

[41] Anthony F. DiMarco et al., "Effects on Breathing of Selective Restriction of Movement of the Rib Cage and Abdomen," *Journal of Applied Physiology* 50(2) (1981): 412-420; S. Bygrave et al., "Effect of Backpack Fit on Lung Function," *Ergonomics* 47(3) (February 2004): 324-9.

[42] "American Association for Respiratory Care Clinical Practice Guidelines," *Respiratory Care* 39(8) (1994): 830-836.

[43] Jack Wagner, *Pulmonary Function Testing: A Practical Approach* (Philadelphia: Williams & Wilkins, 1992), 25.

[44] Rodney A. Rhoades and George A. Tanner, eds. *Medical Physiology* (Philadelphia: Lippincott Williams & Wilkins, 2003), 312.

[45] "American Association for Respiratory Care Clinical Practice Guidelines."

[46] W.D. McArdle et al., *Exercise Physiology: Energy, Nutrition, and Human Performance* (5th ed.) (Philadelphia: Lea & Febiger, 2001).

8) Relax.

Tension in either the abdominal muscles or the expiratory muscles of the rib cage (intercostals) during inhalation limits the respiratory system's ability to expand, and thus decreases lung efficiency and lung volume.[47] Both general tension (e.g., tension resulting from performance anxiety or poor practice habits) and local tension (e.g., tension resulting from attempts to hold individual parts of the respiratory system in a fixed position) are clearly counterproductive to ventilation.

In addition, studies of professional wind instrumentalists and vocalists have shown that, although their performance results are very similar, their specific breathing patterns are remarkaby varied.[48] Research has shown that the specifics of breathing, including the ratio of diaphragm to rib cage use, sequence of muscle recruitment, and the visual manifestations of breathing, vary significantly according to individual build and body type.[49] Studies have also demonstrated that, regardless of claims sometimes made to the contrary, professional musicians have very little control over the individual muscles of the respiratory system, particularly the diaphragm,[50] and very inaccurate physiological awareness of what is actually occurring when they breathe.[51] Research would seem to indicate that it is more efficient for musicians to relax and allow natural forces to take place according to each person's unique build and body type, rather than exerting unnecessary energy trying to change what is largely an involuntary process.

Finally, the benefits of yoga on lung function (see studies listed under "Practice deep breaths," above) are presumably at least partly related to relaxation.

9) Maintain good posture.

For various physiological reasons, lung capacity decreases by about 2 percent from standing to sitting, then about 15 percent from sitting to supine (lying on your back).[52] Reclining ("semi-supine") is significantly less efficient than sitting.[53] Lung *function* is also best when standing; both FVC and FEV1 are "slightly but significantly higher" when standing than when sitting.[54] The difference is important enough that the American Thoracic Society recommends documenting which posture is used during spirometry (breathing measurements).[55] In short, it makes sense to stand if you can while performing; if you cannot stand, sit up straight.

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[47] John F. Murray, ed. *Textbook of Respiratory Medicine* (New York: W.B. Saunders, 2000), 106; Goldman.

[48] Isabelle Cossette, Pawel Sliwinski, and Peter T. Macklem, "Respiratory Parameters During Professional Flute Playing," *Respiration Physiology* 121 (2000): 33-44; Scott A. Nelson, "Respiratory Physiology of the Wind Instrumentalist," D.M.A. diss., University of Cincinnati, 1989; Monica Thomasson and Johan Sundberg, "Consistency of Inhalatory Breathing Patterns in Professional Operatic Singers," *Journal of Voice* 15(3) (2001): 373-83; Peter J. Watson et al., "Abdominal Muscle Activity During Classical Singing," *Journal of Voice* 3(1) (1989): 24-31.

[49] J. Hoit and T. Hixon,"Body Type and Speech Breathing," *Journal of Speech and Hearing Research* 29 (1986): 313-24; O.L. Wade, "Movements of the Thoracic Cage and Diaphragm in Respiration," *Journal of Physiology* 124 (1954): 193-212.

[50] O.L. Wade, "Movements of the Thoracic Cage and Diaphragm in Respiration," *Journal of Physiology* 124 (1954): 193-212. After testing three trained physiologists and a teacher of singing, all of whom claimed they could control the diaphragm during inspiration, Wade concludes, "There is no evidence that the diaphragm is under any direct voluntary control; the extent of its movement seems to be determined entirely by the depth of breath that is taken… "

[51] Peter J. Watson and Thomas J. Hixon, "Respiratory Kinematics in Classical (Opera) Singers," *Journal of Speech and Hearing Research* 28(1) (March 1985): 104-22; Wade.

[52] E. J. M. Campbell and J. Newsom Davis, *The Respiratory Muscles: Mechanics and Neural Control* (Philadelphia: W.B. Saunders Company, 1970), 20.

[53] N. Koulouris et al., "The Effect of Posture and Abdominal Binding on Respiratory Pressures," *European Respiratory Journal* 2(10) (November 1989): 961-5.

[54] M. C. Townsend, "Spirometric Forced Expiratory Volumes Measured in the Standing Versus the Sitting Position," *American Review of Respiratory Disease* 103 (1984): 123-124.

[55] American Thoracic Society, "Standardization of Spirometry: 1994 update," *American Journal of Respiratory Critical Care Medicine* 152 (1995): 1107-1136.

SUMMARY

Following is a summary of how each of the above items has been documented to affect breathing:

To improve *lung capacity* (how much air you have at your disposal):

- •practice deep breaths
- •eat fruit and vegetables
- •stay (or become) physically fit
- •allow full expansion
- •don't wear restrictive clothing
- •relax
- •maintain good posture

To improve *lung function* (how well you use the air at your disposal):

- •practice deep breaths
- •eat fruit and vegetables
- •don't smoke
- •stay (or become) physically fit
- •allow full expansion
- •don't wear restricitve clothing
- •relax
- •maintain good posture
- •take big breaths (even when you don't think you need them)

BREATHING TOOLS

Buhl Pocket Spirometer
Description: Spirometer that measures vital capacity
Distributor: www.medmarketplace.com/1-888-501-2800
Approx cost: 190.00 (don't buy the extra mouthpieces—it comes with plenty)

Micropeak Flow Meter
Description: Measures peak flow—how fast you can move air on exhalation
Distributor: www.hometestmed.com/1-800-298-4515
Approx cost: 15.00

Powerlung Trainer
Description: Trainer for inhaling/exhaling against resistance. 3 different models for different difficulty levels—middle one ("Trainer" model) seems to provide plenty of resistance for musicians.
Distributor: Woodwind and Brasswind (www.wwbw.com)
Approx cost: 80.00

Breath Builder
Description: Plastic tube with ping pong ball. Ball goes to top on both inhalation and exhalation. Good for eliminating Valsalva.
Distributor: Hickey's Music (www.hickeysmusic.com/1-800-HICKEYS)
Approx cost: 19.00

Hudson RCI Voldyne 5000
Description: "Volumetric Exerciser"—a type of incentive spirometer. Gives general measurement for air inhaled. Piston moves up on inhalation.
Distributor: Hickey's Music. Item #37940.
Approx cost: 18.00

Portex Inspiron
Description: Incentive spirometer. Ball moves to top on inhalation. For exhalation, turn chamber upside-down. May also adapt for mouthpiece buzzing (especially trombone shank).
Distributor: Hickey's Music. Item #37939
Approx cost: 17.00

Airlife AirX Incentive Spirometer
Description: Incentive spirometer. Ball moves to top on inhalation. For exhalation, move hose to opposite side. May also adapt for mouthpiece buzzing (especially tuba).
Distributor: www.medicalsupplygroup.com/1-800-278-0227. Item #BAX001900.
Approx cost: 4.50

Rusch Air Bag
Description: 6 liter or 5 liter air bag. Visual feedback for exhalation. Also makes multiple rapid vital capacity breaths possible (without passing out).
Distributor: Hickey's Music. Item #37947 (6 liter) or #37945 (5 liter)
Approx cost: 37.00

	20	25	30	35	40	45	50	55	60	65	70	75	80
4'	1.8	1.8	1.7	1.7	1.6	1.5	1.5	1.4	1.3	1.2	1.1	1.0	0.9
4' 1"	1.9	1.8	1.8	1.7	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.0
4' 2"	2.0	1.9	1.9	1.8	1.7	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.0
4' 3"	2.1	2.0	1.9	1.9	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.1	1.0
4' 4"	2.1	2.1	2.0	1.9	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1
4' 5"	2.2	2.2	2.1	2.0	1.9	1.9	1.8	1.7	1.6	1.5	1.4	1.2	1.1
4' 6"	2.3	2.2	2.2	2.1	2.0	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2
4' 7"	2.4	2.3	2.3	2.2	2.1	2.0	1.9	1.8	1.7	1.6	1.5	1.3	1.2
4' 8"	2.5	2.4	2.3	2.3	2.2	2.1	2.0	1.9	1.8	1.6	1.5	1.4	1.2
4' 9"	2.6	2.5	2.4	2.3	2.2	2.1	2.0	1.9	1.8	1.7	1.6	1.4	1.3
4' 10"	2.7	2.6	2.5	2.4	2.3	2.2	2.1	2.0	1.9	1.8	1.6	1.5	1.3
4' 11"	2.8	2.7	2.6	2.5	2.4	2.3	2.2	2.1	1.9	1.8	1.7	1.5	1.4
5'	2.8	2.8	2.7	2.6	2.5	2.4	2.3	2.1	2.0	1.9	1.7	1.6	1.4
5' 1"	2.9	2.9	2.8	2.7	2.6	2.5	2.3	2.2	2.1	1.9	1.8	1.6	1.5
5' 2"	3.0	3.0	2.9	2.8	2.7	2.5	2.4	2.3	2.2	2.0	1.9	1.7	1.5
5' 3"	3.1	3.1	3.0	2.9	2.7	2.6	2.5	2.4	2.2	2.1	1.9	1.7	1.6
5' 4"	3.2	3.2	3.1	2.9	2.8	2.7	2.6	2.4	2.3	2.1	2.0	1.8	1.6
5' 5"	3.3	3.2	3.1	3.0	2.9	2.8	2.7	2.5	2.4	2.2	2.0	1.9	1.7
5' 6"	3.4	3.4	3.2	3.1	3.0	2.9	2.7	2.6	2.4	2.3	2.1	1.9	1.7
5' 7"	3.6	3.5	3.3	3.2	3.1	3.0	2.8	2.7	2.5	2.3	2.2	2.0	1.8
5' 8"	3.7	3.6	3.4	3.3	3.2	3.1	2.9	2.8	2.6	2.4	2.2	2.0	1.8
5' 9"	3.8	3.7	3.5	3.4	3.3	3.1	3.0	2.8	2.7	2.5	2.3	2.1	1.9
5' 10"	3.9	3.8	3.7	3.5	3.4	3.2	3.1	2.9	2.7	2.6	2.4	2.2	1.9
5' 11"	4.0	3.9	3.8	3.6	3.5	3.3	3.2	3.0	2.8	2.6	2.4	2.2	2.0
6'	4.1	4.0	3.9	3.7	3.6	3.4	3.3	3.1	2.9	2.7	2.5	2.3	2.1
6' 1"	4.2	4.1	4.0	3.8	3.7	3.5	3.4	3.2	3.0	2.8	2.6	2.3	2.1
6' 2"	4.3	4.2	4.1	3.9	3.8	3.6	3.4	3.3	3.1	2.9	2.6	2.4	2.2
6' 3"	4.5	4.3	4.2	4.0	3.9	3.7	3.5	3.3	3.1	2.9	2.7	2.5	2.2
6' 4"	4.6	4.4	4.3	4.2	4.0	3.8	3.6	3.4	3.2	3.0	2.8	2.5	2.3
6' 5"	4.7	4.6	4.4	4.3	4.1	3.9	3.7	3.5	3.3	3.1	2.9	2.6	2.3
6' 6"	4.8	4.7	4.5	4.4	4.2	4.0	3.8	3.6	3.4	3.2	2.9	2.7	2.4
6' 7"	4.9	4.8	4.7	4.5	4.3	4.1	3.9	3.7	3.5	3.3	3.0	2.7	2.5
6' 8"	5.1	4.9	4.8	4.6	4.4	4.2	4.0	3.8	3.6	3.3	3.1	2.8	2.5
6' 9"	5.2	5.0	4.9	4.7	4.5	4.3	4.1	3.9	3.7	3.4	3.2	2.9	2.6
6' 10"	5.3	5.2	5.0	4.8	4.6	4.4	4.2	4.0	3.8	3.5	3.2	3.0	2.7
6' 11"	5.5	5.3	5.1	5.0	4.8	4.6	4.3	4.1	3.9	3.6	3.3	3.0	2.7
7"	5.6	5.4	5.3	5.1	4.9	4.7	4.4	4.2	3.9	3.7	3.4	3.1	2.8
7' 1"	5.7	5.6	5.4	5.2	5.0	4.8	4.5	4.3	4.0	3.8	3.5	3.2	2.9
7' 2"	5.9	5.7	5.5	5.3	5.1	4.9	4.7	4.4	4.1	3.9	3.6	3.3	2.9

*Estimated vital capacities for **females** in liters. Follow height (in left column) and age (at top, in five year increments). Based on a formula from the American Thoracic Society*

	20	25	30	35	40	45	50	55	60	65	70	75	80
4'	2.1	2.1	2.0	2.0	1.9	1.8	1.8	1.7	1.6	1.5	1.4	1.3	1.2
4' 1"	2.2	2.2	2.1	2.1	2.0	1.9	1.8	1.8	1.7	1.6	1.5	1.4	1.3
4' 2"	2.3	2.3	2.2	2.1	2.1	2.0	1.9	1.8	1.7	1.6	1.5	1.4	1.3
4'3"	2.4	2.4	2.3	2.2	2.1	2.1	2.0	1.9	1.8	1.7	1.6	1.5	1.4
4' 4"	2.5	2.4	2.4	2.3	2.2	2.2	2.1	2.0	1.9	1.8	1.7	1.6	1.4
4' 5"	2.6	2.5	2.5	2.4	2.3	2.2	2.1	2.1	2.0	1.8	1.7	1.5	1.4
4' 6"	2.7	2.6	2.6	2.5	2.4	2.3	2.2	2.1	2.0	1.9	1.8	1.7	1.5
4' 7"	2.8	2.7	2.7	2.6	2.5	2.4	2.3	2.2	2.1	2.0	1.9	1.7	1.6
4' 8"	2.9	2.8	2.8	2.7	2.6	2.5	2.4	2.3	2.2	2.1	1.9	1.8	1.7
4' 9"	3.0	2.9	2.9	2.8	2.7	2.6	2.5	2.4	2.3	2.1	2.0	1.9	1.7
4' 10"	3.1	3.0	3.0	2.9	2.8	2.7	2.6	2.5	2.3	2.2	2.1	1.9	1.8
4' 11"	3.2	3.1	3.1	3.0	2.9	2.8	2.7	2.5	2.4	2.3	2.1	2.0	1.8
5'	3.3	3.3	3.2	3.1	3.0	2.9	2.8	2.6	2.5	2.4	2.2	2.1	1.9
5' 1"	3.4	3.4	3.3	3.2	3.1	3.0	2.8	2.7	2.6	2.4	2.3	2.1	2.0
5' 2"	3.6	3.5	3.4	3.3	3.2	3.1	2.9	2.8	2.7	2.5	2.4	2.2	2.0
5' 3"	3.7	3.6	3.5	3.4	3.3	3.2	3.0	2.9	2.8	2.6	2.4	2.3	2.1
5' 4"	3.8	3.7	3.6	3.5	3.4	3.3	3.1	3.0	2.8	2.7	2.5	2.4	2.2
5' 5"	3.9	3.8	3.7	3.6	3.5	3.4	3.2	3.1	2.9	2.8	2.6	2.4	2.2
5' 6"	4.0	3.9	3.8	3.7	3.6	3.5	3.3	3.2	3.0	2.9	2.7	2.5	2.3
5' 7"	4.2	4.1	4.0	3.8	3.7	3.6	3.4	3.3	3.1	2.9	2.8	2.6	2.4
5' 8"	4.3	4.2	4.1	3.9	3.8	3.7	3.5	3.4	3.2	3.0	2.9	2.7	2.5
5' 9"	4.4	4.3	4.2	4.1	3.9	3.8	3.6	3.5	3.3	3.1	2.9	2.7	2.5
5' 10"	4.5	4.4	4.3	4.2	4.0	3.9	3.7	3.6	3.4	3.2	3.0	2.8	2.6
5' 11"	4.7	4.6	4.4	4.3	4.2	4.0	3.9	3.7	3.5	3.3	3.1	2.9	2.7
6'	4.8	4.7	4.6	4.4	4.3	4.1	4.0	3.8	3.6	3.4	3.2	3.0	2.8
6' 1"	4.9	4.8	4.7	4.6	4.4	4.2	4.1	3.9	3.7	3.5	3.3	3.1	2.8
6' 2"	5.1	5.0	4.8	4.7	4.5	4.4	4.2	4.0	3.8	3.6	3.4	3.1	2.9
6' 3"	5.2	5.1	4.9	4.8	4.6	4.5	4.3	4.1	3.9	3.7	3.5	3.2	3.0
6' 4"	5.3	5.2	5.1	4.9	4.8	4.6	4.4	4.2	4.0	3.8	3.6	3.3	3.1
6' 5"	5.5	5.4	5.2	5.1	4.9	4.7	4.5	4.3	4.1	3.9	3.7	3.4	3.1
6' 6"	5.6	5.5	5.4	5.2	5.0	4.8	4.6	4.4	4.2	4.0	3.8	3.5	3.2
6' 7"	5.8	5.6	5.5	5.3	5.2	5.0	4.8	4.6	4.3	4.1	3.8	3.6	3.3
6' 8"	5.9	5.8	5.6	5.5	5.3	5.1	4.9	4.7	4.4	4.2	3.9	3.7	3.4
6' 9"	6.1	5.9	5.8	5.6	5.4	5.2	5.0	4.8	4.6	4.3	4.0	3.8	3.5
6' 10"	6.2	6.1	5.9	5.7	5.6	5.4	5.1	4.9	4.7	4.4	4.1	3.9	3.6
6' 11"	6.4	6.2	6.1	5.9	5.7	5.5	5.3	5.0	4.8	4.5	4.2	4.0	3.7
7'	6.5	6.4	6.2	6.0	5.8	5.6	5.4	5.2	4.9	4.6	4.4	4.1	3.7
7' 1"	6.7	6.5	6.4	6.2	6.0	5.8	5.5	5.3	5.0	4.7	4.5	4.2	3.8
7' 2"	6.8	6.7	6.5	6.3	6.1	5.9	5.7	5.4	5.1	4.9	4.6	4.3	3.9
7' 3"	7.0	6.8	6.7	6.5	6.3	6.0	5.8	5.5	5.3	5.0	4.7	4.4	4.0
7' 4"	7.2	7.0	6.8	6.6	6.4	6.2	5.9	5.7	5.4	5.1	4.8	4.5	4.1
7' 5"	7.3	7.2	7.0	6.8	6.5	6.3	6.1	5.8	5.5	5.2	4.9	4.6	4.2
7' 6"	7.5	7.3	7.1	6.9	6.7	6.4	6.2	5.9	5.6	5.3	5.0	4.7	4.3

*Estimated vital capacities for **males** in liters. Follow height (in left column) and age (at top, in five year increments). Based on a formula from the American Thoracic Society*

Normal Predicted Average Peak Expiratory Flow (L/min)

The national Asthma Education and Prevention Program recommends that a patient's "personal best" be used as his/her baseline peak flow. "Personal best" is the maximum peak flow rate that the patient can obtain when his/her asthma is stable or under control. The following tables are intended as guidelines only.

Normal Males*

Age (Years)	Height (in) 60" / (cm) 152	65" / 165	70" / 178	75" / 191	80" / 203
20	554	575	594	611	626
25	580	603	622	640	656
30	594	617	637	655	672
35	599	622	643	661	677
40	597	620	641	659	675
45	591	613	633	651	668
50	580	602	622	640	656
55	566	588	608	625	640
60	551	572	591	607	622
65	533	554	572	588	603
70	515	535	552	568	582
75	496	515	532	547	560

Normal Females*

Age (Years)	Height (in) 55" / (cm) 140	60" / 152	65" / 165	70" / 178	75" / 191
20	444	460	474	486	497
25	455	471	485	497	509
30	458	475	489	502	513
35	458	474	488	501	512
40	453	469	483	496	507
45	446	462	476	488	499
50	437	453	466	478	489
55	427	442	455	467	477
60	415	430	443	454	464
65	403	417	430	441	451
70	390	404	416	427	436
75	377	391	402	413	422

Normal Children and Adolescents†

Height (In)	Height (Cm)	Males & Females	Height (In)	Height (Cm)	Males & Females
43	109	147	55	140	307
44	112	160	56	142	320
45	114	173	57	145	334
46	117	187	58	147	347
47	119	200	59	150	360
48	122	214	60	152	373
49	124	227	61	155	387
50	127	240	62	157	400
51	130	254	63	160	413
52	132	267	64	163	427
53	135	280	65	165	440
54	137	293	66	168	454

* Nunn AJH, Gregg I: Brit Med J 298:1068-70, 1989

†Polgar G, Promadhat V: Pulmonary Function Testing in Children: Techniques and Standards. Philadelphia. W.B. Saunders Company, 1971.

Note: All tables are averages and are based on tests with a large number of people. The peak flow rate of an individual can vary widely. Individuals at altitudes above sea level should be aware that peak flow readings may be lower than those at sea level, which are provided in the tables.