White Paper:

The One-Size-Fits-All Age Adjusted Maximum Heart Rate Equation Fits No One

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Position Statement

The 220-minus-age equation regularly used to estimate an individual's maximum heart rate (MHR) is invalid[1] for this purpose. The equation, first published in 1970 from data with large variance, disregards the range of individual differences. MHR in healthy adult individuals can be as low as 150 beats-per-minute (BPM) and as high as 230 BPM. Because of this large variance, group data averaged to a mean cannot be used to predict the MHR of individuals with reasonable accuracy. Such use is inappropriate, inaccurate and can be dangerous if used to derive exercise prescriptions. There is no equation that accurately estimates an individual's MHR or any other human biomarker, including blood pressure or cholesterol levels. Rather, exercise experts that I work with recommend individual assessments using a sub-max field test to estimate individual MHRs. We further argue that models based on population averages usually lead to inaccurate estimates and therefore the MHR equals 220-minus-age equation should not be used.

Discussion:

By definition, MHR is the highest number of times per minute the heart can contract. It's the heart rate at the point of exhaustion in an all-out short effort. An individual maybe

HEART ZONES

[1] GELLISH, RONALD L.; GOSLIN, BRIAN R.; OLSON, RONALD E.; McDONALD, AUDRY; RUSSI, GARY D.; MOUDGIL, VIRINDER K. Longitudinal Modeling of the Relationship between Age and Maximal Heart Rate. Medicine & Science in Sports & Exercise. 39(5):822-829, May 2007. " Although the HRmax-prediction model of 220 - age has become well established in the medical literature and is used widely in clinical and fitness settings, its validity is uncertain." http://www.ncbi.nlm.nih.gov/pubmed/1746858

be able to continue briefly to increase effort or speed when the actual MHR number is reached, but the heart simply won't beat any faster. Most scientists think individual MHR is a genetically determined number and not based on body size.[2] Rather, MHR is a self-protecting mechanism. If the heart beats too fast, it doesn't have enough time between beats to fill the chambers adequately in order to fully contract and effectively pump the volume of blood demanded by the effort.

The 220 BPM minus an individual's age equation for calculating the MHR almost accidentally became the standard in cardiology and in fitness programs, used in medical, sports and research. Indeed, an entire industry has grown around the use of this equation, especially the wearable and exercise equipment-enabled heart rate monitors sold to individuals and by cardio equipment manufacturers. Though inappropriate, as it is an average and not an individual number, the MHR 220-minus-age equation continues to be popular today because it is easy and seems commonsensical. Many exercise gurus, equipment handbooks, and coaches recite the equation. When learning to use most cardio-exercise equipment like a treadmill or indoor cycle, often there is a series of questions and one of this is "How old are you?". No matter how much science discredits the MHR 220-minus-age equation, no matter how many research studies invalidate it, too many professionals and exercise equipment manufacturers continue to believe that one size fits all – that everyone of the same age has the same MHR. This is false. Every child, every adolescent, and every adult has her or his own specific MHR, which is unique. That MHR number is genetically not mathematically determined.

The MHR 220-minus-age equation can lead to potentially dangerous outcomes. Carl Foster, Ph.D. and the past president of the American College of Sports Medicine, knows this from personal experience. When Dr. Foster, now professor of Exercise Science at the University of Wisconsin-La Crosse, was 20 and running collegiate cross country, his coach demanded that he run near his MHR. The cross country coach used the MHR 220-minus-age equation - Carl's age, 20, which predicted an MHR of 200 BPM as the goal he should achieve. But when Dr. Foster tested himself – after all, he was an exercise science major – in an all out sprint, the highest number that he could ever achieve was160 BPM. He was humiliated, ridiculed by the running coach in front of his teammates. But in fact, at an all

2 Batterham, A. M.; George, K. P.; Mullineaux, D. R. RELATIONSHIP BETWEEN HEART SIZE AND BODY DIMENSIONS: AN ALLOMETRIC SCALING APPROACH: 886. Medicine & Science in Sports & Exercise: May 1995 - Volume 27 - Issue 5 - ppg S158

out sprint, Dr. Foster's genetically determined MHR was within a few heartbeats of 160 BPM. The MHR 220-minus-age equation had a 40 BPM error for Dr. Foster, an egregious error. Training at too high a heart rate for too long a period, resulting in overtraining, can lead to hormonal, nutritional, mental, emotional, muscular, neurological and other imbalances.

Physician and consultant to U.S. soccer team, Dr. Donald Kirkendall, Duke University Medical Center Sports Medicine Section, is another of the professionals who challenge the seemingly etched-in-stone belief in the 220 minus age equation. In one of his first experiences analyzing the data from a heart rate monitor was testing a member of the U. S. rowing team, he told The New York Times. Dr. Kirkendall asked the athlete for an all-out effort for six minutes. One rower, in his mid-20s, had an estimated maximum heart rate of 195 BPM (220 minutes his age of 25 years or 195 BPM. "His pulse rate hit 200 at 90 seconds into the test,'' Dr. Kirkendall said. ''And he held it there for the rest of the test'', a much longer time than would be possible even if his MHR was actually 200, which it wasn't – it was substantially higher. A local cardiologist, looking on in astonishment, told Dr. Kirkendall, ''You know, there's not a textbook in the world that says a person could have done that.'' The purpose of this White Paper is to support rewriting the textbooks on the 220 minus age equation.

So, why is it important that we know an individual's MHR? Who created the MHR 220-minus-age equation and made it a belief so strong that even scientific rigor has not yet corrected it? Why if it is known that the prediction model is inaccurate hasn't the scientific community corrected it? And, given the enormous range in MHRs between individuals of the same age and fitness, why would anyone use the 220 minus age equation today?

Why Do We Need to know Individual MHR?

The 220 minus age MHR prediction is based on group averages of individuals of the same age. It says that all 10-year olds have the same MHR of 220 minus 10, or an MHR of 210 BPM, and all 50-year olds have the same MHR of 170 BPM or 220 - 50 years. According to this and most MHR formulas[3], as you get older, your MHR declines one BPM per year.

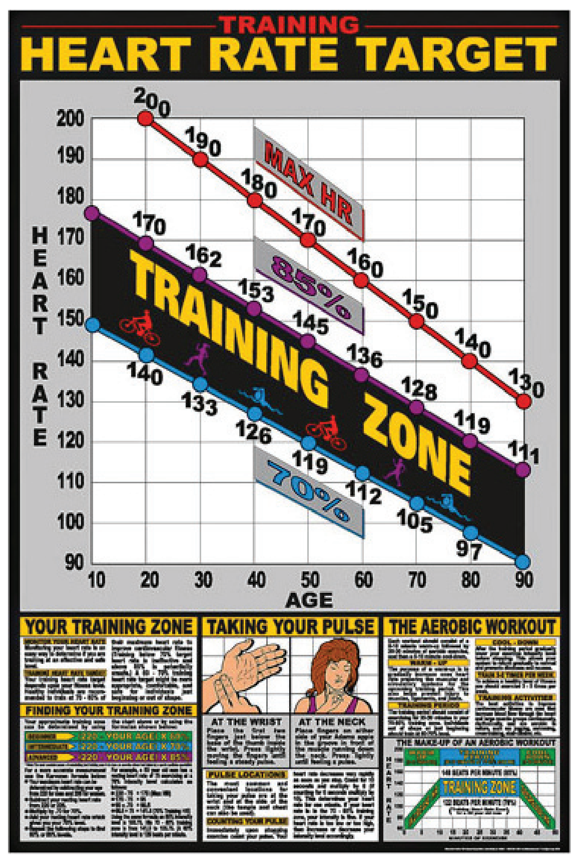
[3] Robergs, Robert A. and Landwehr, Roberto. Prediction of Maximal Heart Rate. Journal of Exercise Physiology. Volume 5 Number 2 May 2002.

This simply is not true.

In medical, research and exercise applications, an accurate measure of MHR is important as it is used for exercise testing and prescriptions for some of the following reasons:

- Determining the intensity of the exercise during a workout is often expressed as a percentage of MHR. For example, the average target heart rate for the workout might be only 72% of maximum effort.
- It is used to assess the fitness level. For example, an individual is becoming fitter because he or she is achieving a higher percentage of MHR for a longer period of exercise time.
- It becomes a criterion for achieving maximal exertion: For example, the individual's MHR is 180 BPM and in a high intensity interval training session (HIIT) the individual reached 170 BPM three times.
- For prescribing individual training zones for safe exercise activities in both the healthy and unhealthy population.

In exercise and fitness applications, MHR is used in both training and racing. One of the most important reasons to assess one's MHR accurately and individually is to use that number as an anchor to set training zones. The chart in Figure 1, while based on an individual's 220 minus age equation estimated MHR, can be used once the MHR is determined by ignoring the age axis. Simply use the MHR for the individual. Using heart rate training zones allows the fitness enthusiast a way to easily determine relative, working heart rate zones or workout zones using a wearable heart rate monitor. By using a zone training method, an individual can work out simply using percentages of the MHR number.

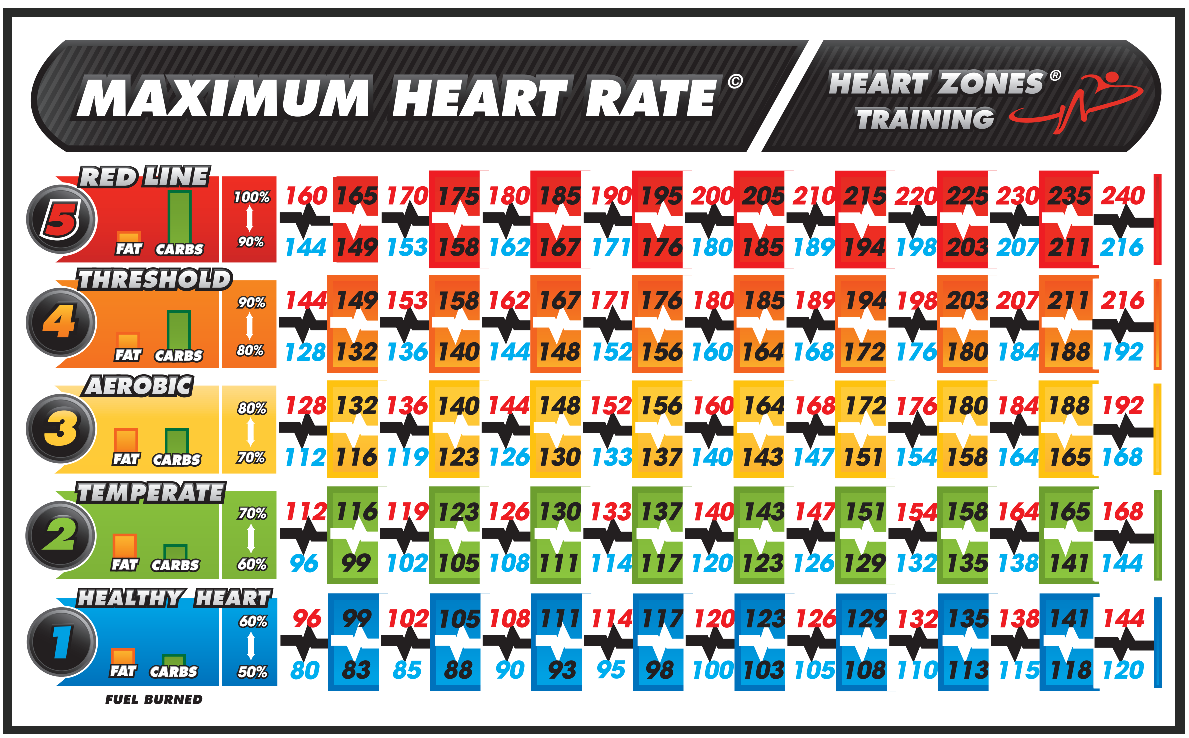


Figures 1. Using MHR To Set Training Zones Based On MHR Equation 220 Minus Age. (©FITNUSPOSTERS)

Over the last quarter century, dozens of scientists have tried to demonstrate that there is a more accurate measure of MHR by adding more than just age as a variable in the equation. There now are MHR equations based on ethnicity, gender, fitness levels, weight and other factors.[4] And yet, there simply is no way to mathematically determine something that needs to be measured individually.[5] Among practitioners who agree is exercise medicine researcher Mark Sarzynski's, PhD, Assistant Professor of Exercise Science, University of South Carolina. "Our findings show that based on the standard error of estimates, the prevailing age-based, estimated HR max equations do not precisely predict an individual's measured MHR." [6]

How is Maximum Heart Rate Determined?

There are two common ways to measure the individual MHR. The first way is to estimate MHR in either an all out effort or with sub-max testing protocols. The second but erroneous way to assess MHR for the individual is to use one of the many formulas from population averages. Once the MHR is determined, that number in BPM can then be used as an



Figures 2. Heart Zones Calculated On 10% Of Measured Maximum Heart Rate (©Heart Zones, Inc)

[4] J Am Coll Cardiol. 2001;37(1):153-156. doi:10.1016/S0735-1097(00)01054-8

[5] M.A. SARZYNSKI,1, T. RANKINEN,1 C.P. EARNEST,2 A.S. LEON,3 D.C. RAO,4 J.S. SKINNER,5 and C. BOUCHARD1. Measured Maximal Heart Rates Compared to Commonly Used Age-Based Prediction Equations in the Heritage Family StudyAm J Hum Biol. 2013 Sep-Oct; 25(5): 695–701.

[6] http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3935487/

anchor point or value to calculate individual heart rate training zones, which are typically marked in 10% intervals of the MHR number.

The Maximum Heart Rate chart herein[7] shows five training zones each based on 10 per cent intervals of one's individual MHR.[8] First published in 1993, _The Heart Rate Monitor Book_[9], this chart removes all factors used in the earlier equations such as age or gender. By anchoring training zones on one's actual individual MHR and setting goals based on percentages of a valid MHR number, a person or trainer can more accurately assess the appropriate amount of time to allot to each zone, arguably providing improved health and fitness benefits.

Where did the MHR equals 220-minus-age equation originate?

In 1927 Harvard University created the prestigious Harvard Fatigue Lab[10] dedicated to promoting scientific and collaborative research in exercise physiology. Then doctoral candidate Sid Robinson, who later became a professor at University of Indiana, published a paper that showed the MHR of different age groups. This is called cross-sectional versus longitudinal research. Robinson compared a group of 20-year olds with a group of 30-year olds and so forth. The fitness levels were not measured nor were individuals screened for medication usage or health issues. Robinson's results appeared like a splattergram of dots because the individual differences (i.e., variance) in MHR are so immense.[11] He and researchers who followed took the average of each age group regardless of fitness level, plotted it and drew a regression line that showed that MHR drops by 1 BPM

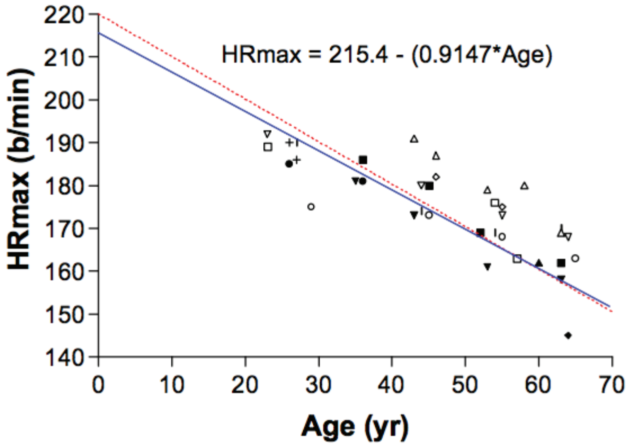


Figure 3. Splattergram of red dots are individual MHRs. The blue line is the regression line for the one-size-fits all equation. (Roberg)

[7] Heart Zones Inc copyright 1993

[8] Carl Foster, The Bloodless Lactate Profile. Medicine and Science in Sports and Exercise, pp 927-933, 1995.

[9] S. Edwards. The Heart Rate Monitor Book. Polar Electro Oy, 1993.

[10] http://www.humankinetics.com/excerpts/excerpts/harvard-fatigue-laboratory-influential-in-promoting-exercise-physiology-research

[11] Robergs, Robert A. and Landwehr, Roberto. Prediction of Maximal Heart Rate. Journal of Exercise Physiology. Volume 5 Number 2 May 2002.

per year. Today, longitudinal research does show that measured MHR may drop by age, especially in those who become unfit, but the rate of decline of MHR is individualistic, and that in large part as fitness declines the ability to reach MHR declines. That is the individual being tested may not have the strength or the stamina to reach their true MHR in a testing situation. Indeed, this decline in individual MHR may be the result of their individual inability to reach MHR rather than the MHR actually declining. There is currently no known research to assess this decline in MHR-testing capacity in the older population.

But, where did the one-size-fits all equation, the MHR 220-minus-age, originate? In 1970, three exercise medicine specialists in the Public Health Service, Fox, Naughton, and Haskell first derived and published it as a solution to a problem.[12] At the time, Dr. Samuel Fox was leading a program on heart health and was mentoring Dr. William Haskell. Together, with researcher J.P. Naughton, they were in search for a way to prescribe safe exercise intensities for cardiac patients.

But, according to Robert A. Robergs and Roberto Landwehr in the Journal of Exercise Physiology, "Surprisingly, there is no published record of research for this equation." It was not the Fox team's intention to create something that would become the foundation of aerobic exercise intensity levels, they simply sought a quick way to establish levels of effort in order to prescribe safe exercise. They were working with sick patients, not kids, fitness-seekers, or athletes and they needed to provide these patients with safe exercise prescriptions. Today there are a number of different equations[13] [14] and the argument continues concerning which is the best equation with the least amount of error. In fact, all such equations to mathematically calculate MHR are equally useless. ''I've kind of laughed about it over the years,'' Dr. William Haskell told The New York Times in 2001. The equation, he said, ''was never supposed to be an absolute guide to rule people's training.'' (For a more complete story about how the MHR equal 220 minus age equation became "perceived wisdom" read the entire New York Times article.[15])

Why Do Some Individuals have a Higher MHR than Others of the Same Age?

Given identical age, fitness level, gender and all other factors, how can non-smokers

[12] Fox SM, III, Naughton JP, Haskell WL. Physical activity and the prevention of coronary heart disease. Ann Clin Res. 1971;3:404–432. [

[13] Robergs RA, Landwehr R. The surprising history of the "HRmax=220 minus age" equation. J Exerc Physiol online. 2002;5:1–10.

[14] Nes BM1, Janszky I, Wisløff U, Støylen A, Karlsen T. Age-predicted maximal heart rate in healthy subjects: The HUNT fitness study. Scand J Med Sci Sports. 2013 Dec;23(6):697-704. 2012 Feb 29.

[15] http://www.nytimes.com/2001/04/24/health/maximum-heart-rate-theory-is-challenged.html?pagewanted=all

who are disease and medication-free individuals have as high as an 80 BPM difference in their tested MHRs. A perhaps whimsical answer lies in the differences between the heart rate of a hummingbird versus that of a blue whale.

First, let's take the hummingbird's heart beat frequency - more than 20 times each second - or as high as 1,260 beats per minute. A hummingbird's heart is tiny, smaller than the size of an aspirin. Next, compare a hummingbird's heart to the world's largest heart - that of the seven-ton blue whale. A blue whale's heart can be as big as a room. The cardiac frequency of hummers and whales varies from individual to individual just like humans, but in general, larger animals have a slower heat rate than smaller animals. The average heart rate of large whales is from about 10 BPM to a MHR of 30 BPM.

But, a more technical answer to the question why there is such an enormous range in MHR between two individuals of the same weight, size, and other factors has to do with heart mass. The bigger the dimensions, the size and weight of your heart, the lower your MHR – you are a blue whale. And conversely, the smaller your heart mass is as compared to your body size, the higher your MHR – you are a hummingbird.

What Can Be Done to change the Practice of Using the MHR Equals 220-Minus-Age Equation?

There is a better way to estimate MHR than erroneously using a one-size fits all equation, which recent research has shown is especially inappropriate for women[16] and children[17]. Our recommendation is to estimate an individuals MHR using a safe and time-efficient sub-max field test. A field test or field experiment is different from a lab test. The field test is conducted in the same use environment or conditions of normal exercise instead of in a controlled environment like a laboratory.

There are several different sub-max tests and when done in combination, these field tests are almost as accurate as an all-out MHR test.[18] See the example of one of the "Easy-Moderate-Hard Sub-Max" field tests presented here in Figure 3.

Let's use the Easy-Moderate-Hard Sub Max Test as an example. After an adequate

16 Circulation. 2010 Jul 13;122(2):130-7. doi: 10.1161/CIRCULATIONAHA.110.939249. 2010 Jun 28. Heart rate response to exercise stress testing in asymptomatic women: the st. James women take heart project. Gulati M1, Shaw LJ, Thisted RA, Black HR, Bairey Merz CN, Arnsdorf MF.

17 Dev Med Child Neurol. 2011 Sep;53(9):861-4. doi: 10.1111/j.1469-8749.2011.03989.x. Epub 2011 May 13.Maximum heart rate for children: The 220-age equation does not predict maximum heart rate in children and adolescents. http://www.ncbi.nlm.nih.gov/pubmed/21569015

18 Ten different Sub-Max tests are available in the Heart Rate Monitor Guidebook by Edwards. Heart Zones publishing 2010 available at www.HeartZones.com

EASY-MODERATE-HARD Sub Max Test©

"Sub" means below and max means "maximum" so together sub-max means below your maximum heart rate.

STEP 1 Warm up adequately for 5-10 minutes.

STEP 2 EASY: Select any cardiovascular activity that you enjoy such as walk-jog-run. Do that activity for 2-minutes or one lap around a track at a easy to moderate effort or with a Rating of Perceived Exertion (RPE) of 1-3. Record your peak heart rate at the end of 2-minutes.

STEP 3 MODERATE: Do the same activity for the next 2-minutes or one lap and increase your effort to a level that feels "moderate to somewhat hard" RPE of 4-6. Record your peak heart rate at the end of 2-minutes.

STEP 4 HARD: Do the same activity for 2-minutes or one lap and increase your effort to an intensity level that feels "HARD" to "Very Hard!", an RPE of 6-7. Record your peak heart rate at the end of 2-minutes.

STEP 5 Estimate your maximum heart rate by adding the appropriate math factors to your peak heart rates.

EASY-MODERATE-HARD Sub Max Test©

Using the table below, add the number that best corresponds to your current fitness level.

RPE*	DESCRIPTION OF FEELING OF EFFORT
0	Rest
1	Really Easy
2	Easy
3	Moderate
4	Sort of Hard
5	Hard
6	HARD
7	Very Hard!
8	At My Limit!
9	Past My Limit!
10	Destroyed

CURRENT EFFORT LEVEL	EASY	MODERATE	HARD
ADD THE MATH FACTOR	60 BPM	40 BPM	20 BPM
YOUR PEAK HEART RATE	+ ____ BPM	+ ____ BPM	+ ____ BPM
ESTIMATED MAXIMUM HEART RATE	BPM	BPM	BPM

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warm-up, the participant begins the first of three stages of an activity of their choice at an effort level that matches a feeling of effort best described as "Easy". After two minutes the participant records the number of beats-per-minute (BPM) that matches the feeling of Easy. Using the RPE, Rating of Perceived Exertion scale of 0 being no effort and 10 representing a feeling of all-out effort, the Easy level of intensity is a rating of 2. The second stage of the test is to immediately increase the intensity of the same activity to a moderate level that would be best represented on the RPE between a 4 to a 6 rating effort level. Again, after two minutes of moderate effort, the participant record their BPM for Moderate. The final 2-minute stage is at a hard to very hard level of intensity equal to a 6-7 on the scale of perceived exertion. Taking the BPM from all three stages of the Sub-Max Field Test the resulting estimate of MHR for this participant would be as185 BPM. See Table 1.

Table 1. Calculating MHR from the Easy-Moderate-Hard Sub-Max Field Test

Current Effort Level:	Easy	Moderate	Hard	
	120 BPM	145 BPM	170 BPM	
Add the Math Factor: Estimated MHR from Field Test:	+60 180 BPM	+40 185 BPM	+20 190 BPM	**MHR: 185 BPM**

Convert from MHR to Threshold Heart Rate

There is another way to anchor individual training zones which is not based on maximum heart rate. This method is called the threshold heart rate method. Many exercise scientists and researchers today recommend this method of assessing for threshold heart rates because as your fitness level changes so does your threshold heart rate numbers. Threshold heart rate numbers are dynamic while the MHR number does not change with fitness.

Threshold biomarkers are measured when there is a shift in the energy requirements, the carbohydrates and fats, that are burned during an exercise session. The most accurate way to assess the threshold biomarkers is in an exercise laboratory while field tests for the threshold heart rate have been scientifically validated.[19] There are two different threshold

[19] Giancarlo Condello,1, Ezekiel Reynolds,2, Carl Foster,2,3,Jos J. de Koning,2,3, Erika Casolino,1, Megan Knutson,2, and John P. Porcari2, A Simplified Approach for Estimating the Ventilatory and Respiratory Compensation Thresholds J Sports Sci Med. 2014 May; 13(2): 309–314. 2014 May 1.

exercise intensities called the first threshold (T1) or the low threshold. The second threshold (T2) or the high threshold is commonly called the ventilatory or lactate threshold and formerly known as the anaerobic threshold. By doing a field test for T1 and T2, dynamic heart rate zones can be set as shown in Figure 5. Threshold Training System.

HEART ZONES® TRAINING

The Threshold Training System®

ZONES CHART

CYCLING FUSION

Zone Number	Zone Name	Zone Description	Zone Calories Burned/minute	Zone Sustainable Workout Time	Training Load* Points/Minute	Zone Benefits
ZONE 5	Hard Zone	High, hot, hard effort "I don't want to and can't talk" Feels near max and unequivocally uncomfortable	> 15 calories	15 seconds - 40 minutes	6-8-10 points**	Get Fastest
T2 HIGH THRESHOLD						
ZONE 4	High Moderate Zone	Moderate and challenging effort "I can talk but becoming not comfortable" Feels like effort is becoming unsustainable	10-14 calories	40 minutes - 2 hours	4 points	Get Fast
ZONE 3	Low Moderate Zone	Moderate effort "I can talk conversationally" Feel the first shift in my breathing effort	7-9 calories	1-3 hours	3 points	Get Fitter
T1 LOW THRESHOLD						
ZONE 2	High Easy Zone	Easy effort "I can talk and it is comfortable." Feels comfortable-enjoyable	4-6 calories	Very, very long time	2 points	Get Fit
ZONE 1	Low Easy Zone	Very easy effort "I can talk and it is easy." Feels almost effortless	1-3 calories	Long-lasting	1 point	Get Healthy

*Training load is the amount of exercise stress or dosage measured using a point system; multiply the number of minutes in the zone by the training load points for that zone and this equals the total training load for that session. Load=Frequency x Zone Points x Minutes = Heart Zones Training Points or HZT Points.

** 6Points for the bottom of Zone 5, 8 Points for the middle of Zone 5, 10 Points for the top of Zone 5.

Conclusion

The MHR 220-minus-age equation – still in use in health clubs, schools, medical settings, and among many coaches today – has been proven to be outdated and inaccurate. Mark Sarzynski, PhD, a prolific researcher in personalized exercise medicine at the Arnold School of Public Health at the University of South Carolina's concluded, "Our results fail to validate the effectiveness of either of the two most widely used age-based HRmax prediction equations in sedentary, healthy adults. These results suggest that it may be very difficult, perhaps even impossible, to predict with a low standard estimate of error HRmax from age.[20]

That certainly has been the conclusion – and experience – of Carl Foster, the former collegiate cross country runner with the mere 160 BPM MHR who now is Professor of Exercise Science at the University of Wisconsin, La Crosse as well as the past editor of the International Journal of Sports Physiology and Performance. "There is not one equation that is meaningful or any better than any other equation," he wrote, "except for some very specific uses in medical practice, I think that the use of any predicted MHR should not be used in the exercise industry, in schools, and for other uses because it is useless at best, and dangerous at worst."

Using equations that predict MHR individually is a fruitless process because individuals simply have too much variance in MHR. Rather, an individual's MHR should be estimated using sub-max field tests with results used to derive training zones specific to the individual as well as help in the development of safe and appropriate exercise prescriptions for individuals.

There is no reason to continue using the 45-year old MHR 220-minus-age equation given what we know today.

[20] Ibid M.A. SARZYNSKI

Sally Edwards, MA, MBA, Physical Educator, is the CEO and founder of Heart Zones, Inc, the fitness technology company for Smart health and fitness. She is the author of 25 books on exercise, triathlon and running, and weight loss. She currently develops heart rate technology and programs for schools, health clubs, corporate wellness, sports teams, and rehabilitation centers.

Ms.Edwards has been an avid heart rate monitor user since she qualified and competed in the 1984 Olympic Trials guided by her Polar© heart rate monitor 32-years ago. Her oft-stated goal in life is to get America fit and one way is to use wearables like a heart rate monitor. She developed the Blink line of heart rate monitors and sensors for her program, Heart Zones Training™. A professional runner and triathlete, she first established the first five zone MHR system in 1992 in her first book on using a wearable for health and fitness The Heart Rate Monitor Book. She continues today to debunk the myth that MHR can be determined by any mathematical equation.

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