

The Measurement and Prediction of Maximum Heart Rate

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Introduction

Heart rate (HR) is arguably one of the most often measured physiological responses in relation to physical fitness or health. HR measured at rest, during submaximal exercise, at maximal exercise and during recovery can provide some level of assessment of fitness and health. In the past, HR was most often measured from manual palpitation of a pulse (palpation), using a stethoscope (auscultation) or an electrocardiograph. The latter measurement device is thought to be the gold standard for heart rate measurement. Today HR is likely to be measured using a myriad of HR monitors available to anyone. HR is also commonly used to prescribe aerobic endurance intensity. In this respect, HR training intensities are selected based on actual measured HR responses or predicted HR responses from a variety of formulas, many of which use a calculated maximum HR (predicted HR_{max}). Obviously, there is much variability and error associated with predicted HR_{max} values and actual measured HR_{max} is most valid. However, the measurement of actual HR_{max} requires an individual to be able to sustain a maximum exercise to elicit such a response that is not also possible or safe. Finally, heart rate responds very well to aerobic endurance training. For example, resting and submaximal heart rate is reduced and maximum heart rate is either unchanged or only slightly reduced.

How does the heart beat?

The heart is unique in that it has the ability to maintain a contractile rhythm without external nervous system innervation. This is generally referred to as pacemaker activity. There are specially cells and groups of cells in the heart that are involved in this inherent property but all heart tissue has pacemaker activity. These heart cells are specialized in that they are “leaky” to sodium ions that produces a less negative resting membrane potential that moves toward the threshold for depolarization (≈ -40 mV) that is required to initiate the heart muscle to contract. For comparison, other muscle such as skeletal muscle has a resting membrane potential of ≈ -85 mV, and requires a “stimulus” from a nerve (motoneuron) to its membrane to initiate voluntary muscle contraction. One specialized group of cardiac muscle cell fibers, termed the sinoatrial node (S-A node), is located in the wall of the right atrium and extends into the left atrium. The resting membrane potential of the SA node is ≈ -55 mV because of the sodium ion leakage, and results in a depolarization rate of 60 contractions or more per minute. Since the SA node fires at a rate faster than other cardiac tissue, it has been termed the pacemaker of the heart.

When the depolarization of the SA nodal tissue spreads throughout the right and left atria, it also flows down other specialized tissues in the heart called internodal tracts that conduct the impulse faster than through the cardiac muscle cells. These tracts lead to another special group of cells called the atrioventricular node (A-V node). The A-V node also has its own intrinsic ability to depolarize its membrane but at a lower rate (<60 per minute) compared to the SA node. The purpose of the A-V node is to slightly delay (by ≈ 0.10 s) the conduction of the faster impulses that originated from the SA node and through the internodal tracts to allow the blood from the contracting atria to completely fill the ventricles before the ventricles begin to contract. The A-V node terminates out into

another set of specialized cell fibers called the Bundle of His that further sub divides into left and right branches that terminate into the Purkinje fibers of the left and right ventricles. The combination of these unique cells to conduct impulses at different rates from the cardiac muscle cells and their location at key areas of the cardiac muscle allows for a highly coordinated spread of depolarization throughout the cardiac muscle. The result is a contraction of the atria to force blood into the ventricles, which then contract to force blood through the body and pulmonary system.

The exchange of ions that occurs across the heart muscle membranes generates an electrical signal. This activity (voltage) can be detected by electrodes that are placed on the upper body in particular positions (e.g. a 12 lead ECG). The electrical signal is relayed to an amplifier (the electrocardiograph) to enhance it. The signal can then be visualized on an oscilloscope or on a paper chart recorder connected to the electrocardiograph. This is what is termed the electrocardiogram and what is meant by the abbreviation, ECG. The changes in electrical activity that occur throughout the heart in one cycle produce some characteristic deflections in the recording that are shown in Figure 1. As the electrical activity of the heart is tracked toward a positive skin electrode, an upward (positive) deflection on the ECG occurs and when it moves away from a positive skin electrode, it produces a downward (negative) deflection on the ECG. The characteristic deflections have all been defined. The P wave is a result of the electrical activity associated with depolarization of the atria. The QRS deflections (complex) are due to ventricle depolarization. The T wave occurs during initiation of ventricle repolarization followed by the U wave (not always observed) that is generated during the final stages of ventricle repolarization. The interval between two R points of the QRS complex is what is measured to determine one heart beat. HR is the number of heartbeats per minute.

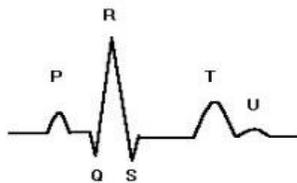


Figure 1. Typical ECG recording.

A heart monitor can be thought of as working in a similar way. The strap around the chest has an electrode portion on each side of the strap that straddles the sternum. These electrodes detect the electrical activity of the heart and telemetrically transmit the

signal to the watch receiver or receiver located in the exercise machine (treadmill, cycle ergometer, rowing machine, etc.) if it is equipped with such a mechanism. If the exercise device requires the individual to grasp a bar before a HR appears on a display, this device is measuring a pulse rate not a HR. The pulse is the wave of pressure primarily within the arterial vessels generated with each heartbeat that can be felt at particular locations on the body (e.g. radial pulse). Unfortunately these pressure waves can be distorted and misread when manually determined producing a lot of error in measurement. Ideally, the pulse count should equal the HR but because of the error and variability in pulse counts, it is more accurate to measure HR with a monitor that is actually making its measurement based on the electrical activity of the heart.

What causes the heart to beat?

The heart is innervated by various nerves of the autonomic nervous system that is further subdivided into the sympathetic and parasympathetic systems. The sympathetic response is excitatory, meaning that its function is to increase HR and the parasympathetic response is inhibitory or to decrease HR. The cardiovascular control center is located in the medulla oblongata of the brain stem. This network of nerves function to coordinate the beating of the heart and to process other information that modifies the HR. Factors that can increase HR include release of catecholamines (epinephrine and norepinephrine) from the adrenal medulla gland of the kidney; increases in partial pressure of carbon dioxide (PCO_2), hydrogen ion (H^+), potassium (K^+) sensed by chemoreceptors; decrease in partial pressure of oxygen (PO_2) also sensed from chemoreceptors; and, increases in peripheral neural activity that occur from at least the mechanical (mechanoreceptors) or via respiratory muscle stimulation. HR is decreased as a result of interpretation of neural activity from increased blood pressure (via the baroreceptors) or increased blood volume (stretch receptors).

What determines HR at rest, submaximal and maximal exercise?

Resting HR is primarily under parasympathetic nervous system control and, to a lesser extent, the sympathetic system that keeps the heart rate at a rate of approximately 65-75 beats per min (b/min). HR at rest is usually higher in children (80 to 100 b/min) due to a relatively lower stroke volume output of the heart, increases as we grow older as a result of a variety of aging effects, can be elevated to an assorted variety of cardiopulmonary disorders. As well, resting HR is influence by a variety of medications/drugs, sleep, stress and certain nutritional products. Resting HR is also elevated due to the anticipation of exercise. During submaximal exercise, there is an increased stimulation to the heart to increase its rate to deliver more oxygen and remove metabolic by-products such as carbon dioxide. There is a systematic and almost linear increase in heart rate with each increase in exercise power output until the intensity of exercise that elicits the anaerobic threshold after which there is a mismatch between the increase in intensity and the change in heart rate (Conconi et al. 1982) until a maximum heart rate is achieved when no further change in HR occurs. All the factors described previously that determine the rate at which the heart beats are responsible for the change in heart rate during exercise.

HRmax varies between individuals of the same age and this thought to be determined at birth or, in other words, by genetics. To illustrate this, two 20 year-old athletes in our lab with a similar training background differed in their HRmax's by 28 b/min (184 vs. 212 b/min). This is not an uncommon finding among individuals, athletes

or non-athletes. One thing that is certain is that regardless of what an individual's actual HRmax is, it will decline with age, less in people who remain active versus those that remain inactive, as they grow old. It should also be pointed out that there is a myth in the general population and interestingly enough in some athletes, that a high HRmax indicates a high fitness level. However, this is simply not true. HRmax is an individual and genetically determined factor and does not indicate a particular fitness. On the other hand a low resting and low HR response to submaximal exercise is certainly related to good aerobic fitness levels but not HRmax. If anything, HRmax might actually decrease by a few beats per minute with intense endurance training as discussed in the next section.

What happens to HR with aerobic endurance training?

There are important changes to the heart with regular aerobic endurance training. These include a decrease in resting HR thought to be primarily due to an increase in stroke volume output at rest. Anecdotal reports of elite athletes with resting HR's under 30 b/min can be found in the popular press. The same HR response is true for submaximal exercise. There is a decrease in heart rate at each submaximal exercise power output after aerobic endurance training thought, again, to be primarily due to an increase in stroke volume output but also due to a decrease of other cardiac accelerants such as catecholamines, PCO₂, H⁺, K⁺, and peripheral neural activity. An increase in mechanical efficiency during exercise can also produce a drop in submaximal heart rate. The effect of aerobic endurance training on HRmax is more controversial with some research showing no change but other research showing a slight decrease. A review by Zavorsky (2000), suggests that if HRmax declines after aerobic endurance training, it is possibly due to at least a plasma volume expansion, enhanced baroreceptor function and an alteration in autonomic neural responses. This training-induced drop in HRmax is lost when training stops resulting in a return of HRmax to pre-training levels. It should also be noted by fitness appraisers that if HRmax drops by more than this (>5 b/min) it could mean that the client did not achieve a true HRmax during the test and a retest or supramax confirmation of the maximum value would be recommended if HRmax is an important variable being assessed.

Predicting maximum heart rate.

Predicting any type of variable from a formula relies on valid and reliable research that commonly measures the actual variable along with one or more other variables that are thought to be predictors of the actual variable or influence it in some fashion. These variables are analyzed in such a way (regression, multiple regression, etc.) so that a formula can be derived allowing the input of the related variables other than the actual one thereby producing a predicted variable or score. It is also important to control for age, gender, race, geographic location, training status, nutrition, and many other factors depending on the variable when creating prediction formulas. There should also be a sufficient sample size used in this type of research. A small number of subjects used in studies deriving prediction equations leads to greater variability and therefore more error in the prediction of the variable. As well, in exercise studies, choice of exercise mode (treadmill running, cycle ergometry, rowing, etc.) is known to cause a variation in heart rate response is very important. It is important for the fitness appraiser and counselor, to pay attention to as many of these factors as possible when selecting and using prediction formulas to ensure these factors are matched to the clientele as close as possible.

There are also some very good reasons for using prediction formulas. For example, predicting % body fat is often done because the actual measurement of body fat is impossible to do without sacrificing the individual and dissecting all of the fat off the cadaver...gruesome! Predicting a 1 RM strength score from a 10 RM strength test eliminates the stress and risk associated with 1 RM strength testing especially in an untrained individual. Similarly, the benefits of predicting HRmax using a formula that relies on age is simple to do, convenient, does not require sophisticated equipment and is safe since it does not require an individual to maximally exercise. There are many examples in the fitness assessment world and these types of predictions allow fitness professionals and appraisers more tools to provide important information to the client. However, caution should be exercised when using predictive values due to the variability and error associate with such variables. This needs to be understood by the appraiser and adequately explained to the client.

The most common and popular prediction formula for HRmax is $220 - \text{age}$ in years (Fox et al., 1971). However as pointed out by Robergs and Landwehr (2002), there is little research support for this formula and much variability associated with it. In fact, it might actually be quite a coincidence if this prediction formula does result in the same value as known or actual HRmax of an individual measured on an ECG! In their excellent review, Robergs and Landwehr (2002) have categorized all published and referenced prediction equations for HRmax that they could find yielding a total of 43 different formulae. You will note from Table 3 in their paper, these formulas vary by sample size, population (including gender, health status, training status, exercise mode) and resulting formula. The first number used in the reviewed prediction equations range from a low of "189" to a high of "226". Secondly, many of these types of formulas include a "modifier" of age in the equation. These modifiers range from "0.41" to "1.07". Thus, there would be a great range in the predicted HRmax depending on the formula used. The bottom line is that there is large error if age is the only modifier in the HRmax prediction formula leading to > 11 b/minute error in HR. There also seems to be an effect of exercise mode on the HRmax prediction formulas that is often ignored (Robergs & Landwehr, 2002).

Why should a fitness appraiser and counselor be concerned about the error in HRmax prediction?

The most often used application of predicting HRmax is for use in predicting fitness levels (e.g. aerobic fitness or VO_2max) or for setting aerobic endurance training intensities. If the predicted HRmax were not accurate, the result of this would be providing false information to a client about their aerobic fitness levels. The other problem is using an inaccurate predicted HRmax in formulas that are used to calculate HR training intensities such as the heart rate reserve (HRR) method of Karvonen et al. (1957). Again an over or under prediction of HRmax can lead to errors in establishing HR training intensities that may be unachievable by clients if set too high or lead to less than optimal change in fitness if set too low.

So what should the fitness appraiser and counselor do?

1. Avoid predicting HRmax in the general population and choose fitness prediction tests that do not rely on predicted HRmax.

2. Avoid prescribing HR training ranges based on predicted HRmax in the general population. Alternatively, perform a safe submaximal exercise test of increasing intensity and measure HR. Use these HR responses to prescribe the training HR intensities for submaximal aerobic training sessions.
3. For athletes, recommend a lab-based maximum aerobic fitness test such as a VO₂max for the greatest accuracy of determining HRmax and use this test result to prescribe HR training intensities. Additionally, there are a number of lab and field test protocols that can be done with an accurate and inexpensive HR monitor for athletes to determine actual HRmax and various submaximal HR responses such as the Conconi HR method of determining anaerobic threshold (Conconi et al., 1982).
4. If a prediction HRmax formula is to be used pick one that best represents the age, gender, and population you are working with. Robergs and Lanwehr (2002) suggest the formula of Inbar et al. (1994): $HR_{max} = 205.8 - 0.685(\text{age})$ while another recent popular formula of Tanaka et al. (2001) is: $HR_{max} = 208 - 0.7(\text{age})$. For me, the original predicted HR formula of 220-age produces a HRmax of 173 b/min; Inbar formula = 174 b/min; and, the Tanaka formula produces a HRmax of 175 b/min. All are out by at least 10 b/min since my actual measured HRmax is 185 b/min. For HR training intensities based on predicted HRmax, it is recommended to use ranges of heart rates (e.g. a 10 b/min range) for the client to maintain during exercise. That way if the HR is predicted too low, the client can work at the upper end of the HR range and vice versa.

Conclusion

There is no one accurate mathematical equation for predicting maximum heart rate. But, this does not mean fitness appraisers and counselors should abandon such use. Provided there is an understanding provided to a client regarding the error associated with any predicted fitness value used and if a range of values is reported that represents the common error associated with the particular fitness variable, then there is some usefulness in using predictive formulas for the general population. Similarly if HR training ranges based on predicted HR maximums are provided with a range in values that represents a reasonable amount of error associated with the prediction formulas, then this would be reasonable for most clients.

These ongoing exams are offered to Alberta CSEP Health & Fitness Program PFLCs in each edition of the 'Fitness Informer' or can be downloaded from the web site at provincialfitnessunit.ca, as an opportunity to gain Professional Development Credits. A passing mark of 80% is required to attain credit. Worth: 0.5 PDCs. **Submission Deadline: January 31, 2005.**

Name: _____

Address: _____

True or False .

1. An individual that has a lower maximum heart rate than another individual of the same age has a higher aerobic fitness.
2. Heart rate can be measured by counting the number of R-R intervals on a ECG in one minute.
3. Pacemaker activity of the heart only exists within the SA node.
4. Predicting maximum heart rate is most accurately done using the formula: $220 - \text{age in years}$.
5. Different maximum heart rate prediction formulas will provide the same HRmax value in the same individual.
6. A heart rate monitor that consists of a strap that is placed around the chest combined with a receiving unit is actually recording the electrical activity of the heart.
7. HRmax can decline slightly with aerobic endurance training in some individuals.
8. Individuals of the same age have the same actual maximum heart rates.
9. Using pulse rate by palpitation is more variable than using the auscultation for determining heart rate.
10. Aerobic endurance training produces higher resting, submaximal and maximum heart rate.