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Maximum Heart Rate during exercise: Reliability of the 220-age and Tanaka formulas in healthy young people at a moderate elevation

Frecuencia cardíaca máxima en ejercicio: confiabilidad de las fórmulas de 220-edad y Tanaka en jóvenes saludables en altitud moderada

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| Summary |

Background. The formulas to predict maximum heart rate have been used for many years in different populations.

Objective. To verify the significance and the association of formulas of Tanaka and 220-age when compared to real maximum heart rate.

Materials and methods. 30 subjects –22 men, 8 women– between 18 and 30 years of age were evaluated on a cycle ergometer and their real MHR values were statistically compared with the values of formulas currently used to predict MHR.

Results. The results demonstrate that both Tanaka p=0.0026 and 220-age p=0.000003 do not predict real MHR, nor does a linear association exist between them.

Conclusions. Due to the overestimation with respect to real MHR value that these formulas make, we suggest a correction of 6 bpm to the final result. This value represents the median of the difference between the Tanaka value and the real MHR. Both Tanaka (r=0.272) and 220-age (r=0.276) are not adequate predictors of MHR during exercise at the elevation of Bogotá in subjects of 18 to 30 years of age, although more study with a larger sample size is suggested.

Keywords: Heart Rate, Reproducibility of Results, Motor Activity, Exercise, Exercise Test, Altitude (MeSH).

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Resumen

Introducción. Las fórmulas que predicen la Frecuencia Cardíaca Máxima (FCM) han sido utilizadas desde hace varios años en diferentes poblaciones.

Objetivo. Verificar la precisión de las fórmulas de Tanaka y 220-edad con respecto a la FCM real.

Materiales y métodos. Se evaluaron 30 sujetos –22 hombres y 8 mujeres– entre 18 y 30 años de edad en cicloergómetro y se compararon estadísticamente las fórmulas con la FCM real.

Resultados. Se demuestra que tanto Tanaka p=0,0026 como 220-edad p=0,000003 no predicen la FCM real ni existe una asociación lineal de estas.

Conclusiones. Debido a la sobreestimación que realizan dichas fórmulas con Tanaka se sugiere realizar una corrección de 6 lpm al resultado final. Este valor representa la mediana de la diferencia de Tanaka con respecto a la FCM real: tanto Tanaka r=0,272 como 220-edad r=0,276 no son predictores adecuados entre sujetos de 18 a 30 años de edad de la FCM durante el ejercicio en la altura de Bogotá, aunque se sugiere realizar más estudios con una muestra mayor.

Palabras clave: Frecuencia Cardiaca; Reproducibilidad de Resultados; Actividad Motora; Ejercicio; Prueba de Esfuerzo; Altitud (DeCS).

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Introduction

Doing exercise leads to an increase in the metabolic and energy demand of an organism. This is reflected in the increase in oxygen consumption (VO2). Taking into account the persistence of hemoglobin concentration, the heart is the organ that responds to increase the supply of oxygen to the active tissues. Consequently, determining VO2 requires instruments that are capable of measuring the oxygen content of arterial and venous blood, as well as some method for finding circulatory performance through the determination of cardiac output.

We have known for many years that the increase of the VO2 induces a parallel increase, and with the same rate of change, in cardiac output (1). Also, given that cardiac output is the product of stroke volume and heart rate (HR), in a particular situation, the change in stroke volume between rest and exercise is less. In other words, it saturates earlier, and the HR becomes that variable that the increase in cardiac output depends on in response to exercise (1).

The use of heart rate as a method of finding the VO2 without the need to use techniques or instruments that limit the exercise have been developed by authors like Karvonen et al, and, more recently, corrections have been made by Tanaka (7,10). These authors propose formulas for predicting heart rate that correspond to an intensity of the exercise in course. Through the predictions of maximum heart rate (MHR) and reserve heart rate (RHR), training intensities at the sport and therapeutic levels can be found.

Its formulas are very common in clinical and physiological evaluations (2). With these formulas, the decline in aerobic capacity is correlated in a linear fashion according to age (3). But, due to the variability of HR in relation to workloads, exercise prescriptions can be made based on incorrect data. Therefore, comparing these formulas to real measurements of real maximum heart rate (real MHR) is very important for improving its reliability and proposing corrections that increase its precision (4).

A well-known and much used formula is the 220-age. The origin of the formula is a superficial estimation based on the observation in a data set collected in 1968 (5). This formula is used, along with other formulas, to calculate MHR and, from this, an appropriate load for exercise training. However, this calculation gives a MHR from a formula that, it has been demonstrated, is not at all reliable. To set up an exercise heart rate (EHR), a determined percentage of the maximum oxygen consumption is used (VO2max). However, it can also be found by using the reserve heart rate (RHR) or by using Karvonen's formula (7).

The RHR is the difference between the MHR and the resting heart rate (HRrest) (8). Therefore, its formula is based on the calculation of the MHR, and prescribing exercise at a 50% intensity would be done in the following manner: 50% RHR = 0.5(220-age-HRrest)+HRrest (9).

The deficiency in the 220-age formula is due to the fact that it was found for individuals of more than 60 years of age that had chronic pathologies and high cardiovascular risk. That said, it has been one of the most used equations (10). Tanaka performed a meta-analysis in which he found that the MHR declines at the same rate in both men and women according to age (active, sedentary, heavy exercisers). Therefore, a strong association was found between these two variables (r=-90) and the regression equation of all the subjects was 208 — (0.7(age)). This is due to the fact that a regression performed by Stepwise revealed that age alone explains 80% of individual variance in terms of the MHR (10).

An increase in the elevation over sea level causes a reduction in barometric pressure and a resulting reduction in the partial pressure of oxygen. This leads to an environment of hypobaric hypoxia (11). Continued exposure to this environment puts pressure on a process of complex physiological adjustments named, together, acclimatization. Taking into account the fact that elevation puts stress on the heart and that modifications in the stroke volume and HRrest occur as a response to hypoxia (12), these changes can also influence the behavior of these two variables during exercise and, as a result, the MHR values obtained in exercise could be very different from those predicted by equations that were developed at sea level.

The present study intends to compare the 220-age formula and Tanaka's formula (208-[0.7(age)]) by determining the MHR during a maximal exercise at 2 600 meters above sea level (masl) in the city of Bogotá, Colombia, and, from the results, to evaluate if a modification that makes the estimation of MHR more reliable during higher elevation exercise can be found.

Materials and methods

Location and subjects

The measurements were made in the Calorimetry Room of the Faculty of Medicine of the Universidad Nacional de Colombia, in Bogotá, at 2 600 masl, with a mean ambient temperature of 23°C and a mean relative humidity of 50 to 60%. The tests were administered between 14:00 and 18:00. A group of 30 healthy subjects was selected. They were between 18 and 30 years of age, were residents of Bogotá for the previous three years or more, and participated in physical activity regularly (at least three sessions per week, 45 minutes or more per session). All of the subjects signed giving informed consent. The design and development of the study followed the ethical considerations of the Helsinki Declaration and Resolution No. 008430 of the Ministry of Health of Colombia.

With the methodology of the study, it was considered to have a medium level of risk, since it involved using data records and a high-effort intervention. A medical exam consisting of an interview and a physical exam was performed to rule out cardiovascular, endocrine or respiratory diseases. Also, the participants had to respond negatively to all of the questions of the Physical Activity Readiness Questionnaire (PAR-Q) (6) and could not be taking any medication.

Procedure

To determine the MHR, an incremental, tiered and maximal protocol using a cycle ergometer Monark Ergomedic 828e, manually calibrated according to factory instructions. The subjects had five minutes of warm-up time on the bicycle pedaling without a load and a rhythm of 60 rotations per minute. Later, three-minute-long stages with increases of 30 watts between each stage were initiated and continued until completing the criteria of the maximum. The HR was recorded continually with a wrist heart rate monitor and its chest band sensor (Polar F11-Kempele, Finlandia).

At the end of each stage, the subject was shown a cardboard 8.5x11 inch sign with a Börg scale adapted to scoring physical effort printed on it (4). The subject was considered to have reached MHR when a plateau in oxygen consumption (VO2max) was observed or when their score on the Börg scale reached 20 or when their respiratory quotient (RQ) was greater than 1.1.

For measuring oxygen consumption (VO2), the calorimeter Vyasis Health Care Vmax29 (USA) was used. It was turned on 1 hour before each test to ensure the thermal equilibrium of the sensors, and the calibration patterns were run daily according to the instructions of the management software. At the end of the test, the subject was given a 10-minute recovery period of pedaling with no load and a rhythm of 60 rotations per minute.

The data obtained was automatically recorded by the ergospirometry software and organized in an Excel data table. The HR at the end of each step was manually recorded in this table.

Data management

After finishing the physical tests, the difference between the MHRs observed during the exercise protocol and the heart rates predicted by the formulas (220-age) and (208-[0.7(age)]) were found.

The statistical analysis was done with the software R version 3.1.0 (http://www.r-project.org/) (13). A comparison of the results of the 220-age and Tanaka (208-[0.7(age)]) formulas with respect to the "gold standard" —the MHR found in the tests (real MHR)— was made (14). The difference between these were determined and hypothesis t-tests were performed to verify if the differences were significant when $p<0.05$ (15).

The density was estimated using Kernel estimators (16) and a Pearson correlation coefficient was found between the t-formulas and the real MHR value (17). Finally, an adjustment was proposed for correcting one of the formulas for predicting MHR.

Results

Demographics

The subjects of the study were mostly male (73%). There were not significant differences in the age of the males and the females ($p=0.21$). With respect to weight, the males had significantly more body mass than the females ($p=0.0003$). Also, the height of the males was significantly greater than that of the females (p=0.0000007). The body mass index (BMI) was not significantly different between the males and the females (p=0.24). Neither the time of residence in Bogotá nor the exercise time (minutes) was different between the two sexes (Table 1).

Table 1. Characteristics of population groups 1 and 2.

Variable	Range	Males (mean±SD)	Females
Age (years)	18 – 30	23.18 ± 3,4	21.5 ± 2,5
Weight (Kg)*	51.5 – 78	66.33 ± 6.9	55.67 ± 4.8
Height (cm)*	153 – 182	171 ± 5.6	160 ± 6
BMI (Kg/m2)	19 – 26	22.7 ± 2	21.8 ± 1,6
Time of residence in Bogotá (years)	13 – 29	21.5 ± 4.1	21.5 ± 2.5
Daily exercise time (min)	45 -120	69.5 ± 25.6	69.4 ± 17.8

Note: (N=30); Males n=22; Females n=8. BMI = Body Mass Index. *=Significantly different (P <0.05).

MHR

A difference was observed with respect to the mean and median between real MHR and the formulas of Tanaka and 220-age, as can be seen in Table 2. This indicates that, on average, both Tanaka and 200-age do not approximate the true value, as will be explained below (Figures 1 and 2).

Table 2. Real MHR and differences when compared to Tanaka and 200-age formulas for the whole group.

	Mean	Standard Deviation	Median	First quartile (25%)	Third quartile (75%)
Real MHR	18 – 30	23.18 ± 3,4	21.5 ± 2,5	21.5 ± 2,5	21.5 ± 2,5
Tanaka prediction	51.5 – 78	66.33 ± 6.9	55.67 ± 4.8	55.67 ± 4.8	55.67 ± 4.8
220-age prediction	153 – 182	171 ± 5.6	160 ± 6	160 ± 6	160 ± 6
Difference (220-age) -(real MHR)	19 – 26	22.7 ± 2	21.8 ± 1,6	21.8 ± 1,6	21.8 ± 1,6
Difference Tanaka –real MHR	13 – 29	21.5 ± 4.1	21.5 ± 2.5	21.5 ± 2.5	21.5 ± 2.5

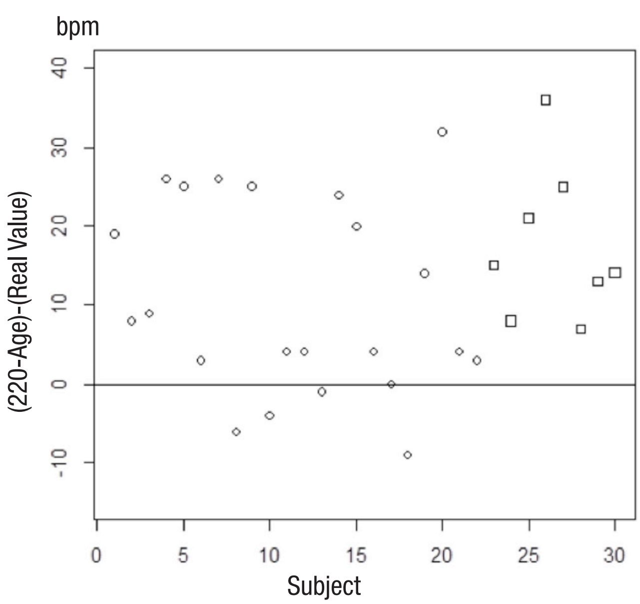

Figure 1. Individual differences between 220-age and real MHR.

Note: each point represents the difference for each individual subject between predicted HR and observed HR (real value). Circles=males, squares=females. Bpm = beats per minute.

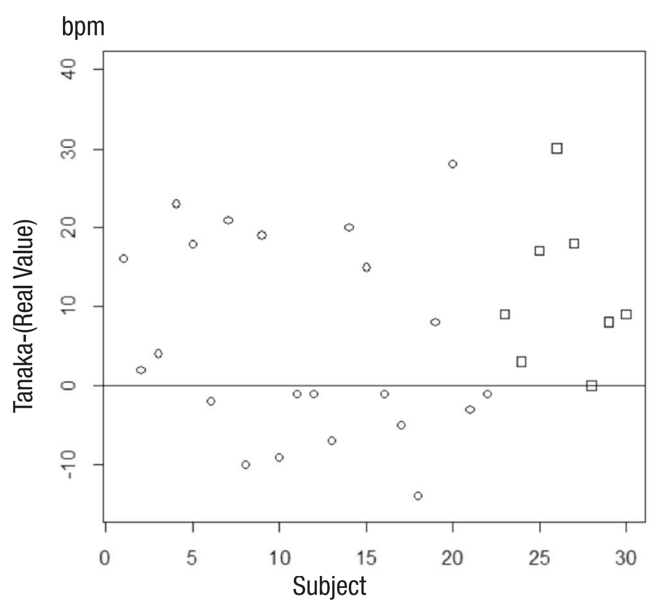

Figure 2. Individual differences between Tanaka predictions and real MHR.

Note: each point represents the difference for each subject between predicted HR and observed HR (real value). Circles=males, squares=females. Bpm = beats per minute.

In Student's t-test, the null hypothesis was rejected with a p-value of <0.05 between the MHR predicting formulas and real MHR. This indicates that the Tanaka and 220-age formulas do not adequately predict real MHR since the p-value for the Tanaka formula with respect to real MHR is p=0.0026, and the p-value for 220-age with respect to real MHR is p=0.000003 (3.604e-06). With this, it can be said that the Tanaka formula has a smaller difference with real HR than 220-age does. Also, the 220-age value overestimates real MHR significantly.

The difference between 220-age and real MHR can be seen in Table 2 and in Figure 1, where it can be seen how, in the majority of the cases, 220-age overestimates that real value —so much than in many cases it is 20 bpm over the real value. Also, in Figure 2, it is see how Tanaka also overestimates the results, though the bias is less.

Upon performing Student's t-test on Tanaka and 220-age, a significant difference can also be seen with p=2.2e-16. The reliability of these formulas is checked by examining the averaged distance of each point from its real MHR value: in the case of 220-age, the average distance was 13.63 bpm and for Tanaka, it was 10.73 bpm.

An estimate of the densities of the three variables based on the sample information was made through the used of Kernel estimators. The difference between the dispersion of real MHR and EHR in comparison to the dispersion of Tanaka and 220-age values can be clearly seen (Figure 3).

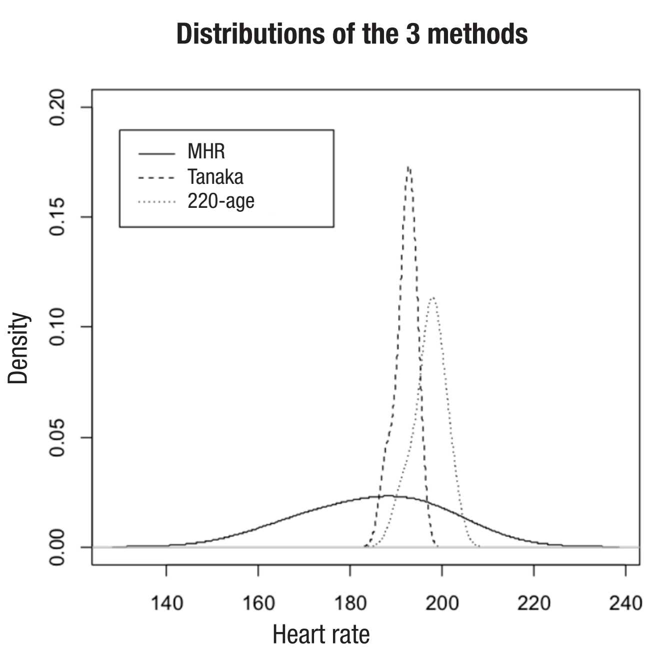

Figure 3. Distribution of densities of real MHR, Tanaka values, and 220-age values.

The analyses of the Pearson correlations between real MHR and the predictions from the 220-age and Tanaka formulas show values of r=0.27 for both MHR predicting formulas. This indicates a low linear association between the two ways of estimating MHR and real MHR at the elevation of Bogotá (Table 3).

Table 3. Pearson correlation coefficients between real MHR at 2 600 masl and the MHRs predicted by the 220-age and Tanaka (208-[0.7(age)]) formulas.

	Real MHR	220-age	Tanaka
Real MHR	1.0000000	0.2767570	0.2767570
220-age	0.2767570	1.0000000	0.99083
Tanaka	0.2726997	0.9908345	1.0000000

However, the Pearson correlation coefficient between the Tanaka formula and the 220-age formula is r=0.99, indicating an almost perfect linear association. This is due to the bases of the construction of these indicators.

Discussion

One of the main findings of this study is that the predictions of the Tanaka and 220-age formulas are significantly different from the real MHR values found in this group of subjects at the elevation of the city of Bogotá. This is different from the findings of Camarda et al. (33). Although the Tanaka formula has less bias than the 220-age formula, both overestimate maximum heart rate, something which can affect the objectives sport and therapeutic exercise at this elevation.

Several publications have proposed the need to estimate MHR in adults in a more appropriate way, since the real results do not coincide with the traditional 220-age formula (18,19), as the present study demonstrated. Because of this need, Tanaka performed a meta-analysis to find which factors most influenced HR. He found that the greatest correlation was with age (20,21). Similar observations have been published in other studies (22,23).

Furthermore, it is known that other factors can affect MHR prediction, including the pharmaceuticals that the subject is consuming —beta-blockers, for example (24)—, the anatomical characteristics of the heart —such as the presence of hypertrophies due to concurrent diseases (25)—, and diverse endocrine factors —such as the levels of adinopectin and leptin in post-menopausal women (26)—. As a secondary result, Tanaka proposed the regression equation MHR=[208-(0.7(age)], since the 220-age equation overestimates the results (10).

Other studies agree with the present study in that the Tanaka and 220-age formulas are not reliable formulas for the prediction of MHR (27,28), and less so in conditions of moderate elevation as is the case in the city of Bogotá, as can be seen in Figures 1-3.

This study proposes a correction of the Tanaka formula, since it was slightly closer to the real result (real MHR). Neither the mean nor the average distances from real MHR are subtracted so that extreme values do not affect the final result. Instead, we propose subtracting the median of the differences between the Tanaka predicted value and the real MHR from the Tanaka predicted formula. Therefore, the corrected formula would be written as follows:

$$MHR=[208-(0.7\ (age)]-6$$

This equation more reliably approximates the true value.

Conclusions

The results found in this study agree with the majority of the studies performed up to this time, in which a low linear association between the Tanaka predicted values and the real MHR is found (but an almost perfect correlation between Tanaka and 220-age is described). It is important to take into account that this study was done on a population of 18 to 30-year-olds. Other studies confirm that the Tanaka and 220-age formulas do not predict the real MHR value in young people, adults, obese individuals, people of color, white people, or in women and men. However, all studies agree that these equations overestimate the MHR value (18,19, 27-32). It is noteworthy that a study in Brazil with a sample size of 2 047 subjects with an age range of 12-69 years of age showed an r= 0.72 for both the 220-age value and the Tanaka value when compared to real MHR taken in a maximal exercise test (33). The high correlation coefficient between real MHR and the prediction equations in this particular study could be the result of its design. They selected a very wide age range, which supports the natural tendency of the reduction of real MHR with age.

Both the Tanaka and 220-age formulas do not significantly predict real MHR for individuals between the ages of 18 and 30 residing at an elevation of 2 600 masl. To approximate the average real MHR values with the Tanaka formula, an adjustment should be made by subtracting 6 bpm from the final result. These 6 bpm correspond to the median of the differences between Tanaka and real MHR. The realization of further studies with larger sample sizes is suggested.

Conflict of interest

None declared by the authors

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