Journal of Science and Medicine in Sport 22 (2019) 607–610

Contents lists available at ScienceDirect

Journal of Science and Medicine in Sport

journal homepage: www.elsevier.com/locate/jsams

Original research

The relationship between maximum heart rate in a cardiorespiratory fitness test and in a maximum heart rate test

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ARTICLE INFO

Article history:
Received 8 February 2018
Received in revised form
10 September 2018
Accepted 20 November 2018
Available online 28 November 2018

Keywords:
Exercise
Sex
Physical exertion
Exercise physiology

ABSTRACT

Objectives: It is suggested that individuals will not reach their heart rate maximum (HRmax) at an incremental cardiorespiratory fitness (CRF) test and commonly five beats per minute (bpm) are added to the highest heart rate (HR) reached. To our knowledge, there is not sufficient data justifying such estimation. Our aim was to assess whether individuals reached HRmax in an incremental CRF test to exhaustion.
Design and methods: Fifty-one males and 57 females (aged 22–70 years) completed both an incremental CRF test (gradual increase in speed and/or inclination until volitional exhaustion) and a test designed to reach HRmax (with repeated work bouts at high intensity before maximal exertion) ≥48 h apart. We investigated the relationship between the highest HR in the two tests using hierarchical linear regression analysis, with HRmax from the HRmax test as a dependent variable, and the highest HR reached at the CRF test (HRcrf), whether maximum oxygen uptake was reached on the CRF test, CRF, sex and age as independent variables.
Results: HRmax was 2.2 (95% confidence interval, 1.5–2.9) bpm higher in the test designed to reach HRmax than in the CRF test ($p < 0.001$). Only HRcrf significantly predicted HRmax, with no contribution of the other variables in the model. HRmax was predicted from the highest HR reached in an incremental CRF test by multiplying HRcrf with 0.967, and adding 8.197 (HRmax = 8.197 + [0.967 × HRcrf]) beats/min.
Conclusion: Non-athletes reached close to HRmax in a standard CRF test.

1. Introduction

Heart rate (HR) is often used to set exercise intensity in endurance training, both during traditional endurance exercise and even more so during high intensity interval training (HIT). Commonly, the intensity during HIT is set at 85–95% of HRmax,[1] and the percentage of HRmax reached during HIT is important for improving cardiorespiratory fitness (CRF).[2] For HR to be a valid measure of exercise intensity, we need to know the HRmax of the individual. In clinical practice, HR is often reported as a percentage of age-predicted HRmax. The traditional formula for age-predicted HRmax is 220 – age,[3] although later studies suggest that HRmax declines by around 0.7 beats/min (bpm) per year.[4,5] Such formulas, although perhaps correct in finding an average HRmax for a large group of people, will not predict an individual's HRmax correctly due to the large inter-individual variability in HRmax.[4] Due to this large individual variation, we often use the highest HR obtained on a standard, incremental CRF test and add five beats to estimate an individual's HRmax. This calculation is, to our knowledge, based on a single study in young, well-trained athletes,[6] and we are unaware of studies assessing how well the highest HR reached in a CRF test estimates HRmax in non-athletes. Although established that HRmax decreases with age,[5,7,8] the effect of sex and CRF on HRmax is still controversial. Some studies have indicated no difference in HRmax between sexes,[4,5,8] one study found higher HRmax in females compared to males,[9] and yet another demonstrated the opposite.[10] Furthermore, physically active individuals were found to have lower HRmax compared to sedentary individuals in some investigations,[9–11] while others observed no association between physical activity level and HRmax.[4,8,12] Our aim was to assess whether individuals reached HRmax in an incremental CRF test to exhaustion. We also investigated whether age, sex or CRF would affect the relationship between the highest HRs in these two tests, as well as whether HRmax differed between males and females and between those with high versus low CRF.

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https://doi.org/10.1016/j.jsams.2018.11.018

2. Methods

The study was carried out at the Norwegian University of Science and Technology (NTNU). The Regional Ethical Committee for Health Research (REK-midt) concluded that there was no need for approval as the study implied no prevention, diagnosis or treatment of illness. The study was reported to the Norwegian Centre for Research Data (NSD). All participants were informed about the study and signed a written informed consent prior to participation. They were free to withdraw from the study at any time. The participants met in the laboratory (NextMove Core Facilities, St. Olavs Hospital, Trondheim, Norway) on two occasions, separated by at least 48 h. They were instructed to withstand from heavy exercise 48 h prior to each test and to meet well rested and hydrated, as well as to have a light meal 2–3 h before the tests. On the first test day, the participants underwent a CRF test and on the second day, they did a specially designed HRmax test, as detailed below.

Participants were recruited through social media, advertisements in public places, and word of mouth. Inclusion criteria were (1) aged 20–79 years, (2) no known heart disease, (3) no use of medications that affect HR and, (4) being able to walk or run on a treadmill. Participants were excluded if they were pregnant or had conditions or injuries that could limit performance.

All exercise tests were undertaken on a calibrated treadmill (Woodway, Germany) with the participants wearing a HR monitor (Polar RS100, Polar, Finland). After warming up for 10 min at light-to-moderate intensity, the participants were fitted with a mask (V2, Hans Rudolph Inc., USA) and started an incremental exercise test with direct measurements of expired gases (Oxycon Pro, Jaeger, Germany). We used an individual ramp protocol that started at an intensity of about 70% of HRmax (estimated by rating of perceived exertion of 11–13 on a 6–20 scale) for the initial three minutes and increased the speed by 0.5–1.0 km/h each 1–2 min if the participant was able to run (n = 102). For participants who were walking (n = 5), the speed was held constant and the inclination was increased 1–2% every 1–2 min.[13] The test was continued until volitional fatigue and the participants were orally encouraged throughout the whole test to ensure they reached exhaustion. Participants were not allowed to grasp the treadmill handrails until the end of the test. The highest HR obtained during the CRF test was recorded as HRcrf. We calculated maximal or peak oxygen uptake (VO_2max/VO_2peak) as the average of the three highest consecutive 10 s measurements. For participants with a respiratory exchange ratio (RER) ≥ 1.05 and a levelling off of oxygen uptake despite increased workload, we report this as the VO_2max.[14] For participants who did not fulfil the criteria for VO_2max the average of the three highest consecutive 10 s measurements is reported as VO_2peak.

There exists no gold standard method to measure HRmax. Our protocol was developed based on one previous study testing HRmax in athletes.[6] Typically, the individual undergoes a test with repeated near-maximum workloads before a final repetition with maximum effort.[6] Our test specially designed for HRmax started with a minimum of 15 minutes warm-up at 60–70% of HRcrf. The inclination of the treadmill was 3% or more for all participants. Directly following the warm-up, the participant walked or ran for four minutes at an intensity corresponding to ∼90% of HRcrf. This was repeated three times, interspersed with two minutes of moderate intensity (60–70% of HRcrf) running or walking. In the last of the high intensity work bouts, the participants held the intensity corresponding of 90–95% of HRcrf for the first two minutes, before the speed or inclination of the treadmill was increased every 30 s, by 0.5–1 km/h or 1–2%, respectively, until volitional fatigue. Participants were orally encouraged throughout the test, particularly during the final stage to ensure they reached exhaustion. The highest HR during the test was recorded and is reported as HRmax. We calculated the study sample size based on the observed difference in HRmax in a CRF test and HRmax in a test specially designed to reach HRmax in athletes.[6] We selected the sample size to provide a statistical power of 80%, with a 0.05 alpha level (two-tailed), to detect a difference between the two tests of 5.76 bpm, with a standard deviation of 2.81.[6] This gave a minimum sample size of 5 participants. To be able to investigate the potential differences between sex, age and fitness level, we aimed at including 120 participants (10 males and 10 females in each age stratum).

To compare the difference between HRmax and HRcrf we used a two-sided, paired sampled *t*-test. We used stepwise hierarchical multiple linear regression analysis to investigate the association between HRmax and HRcrf, whether the participant fulfilled the criteria for VO_2max, CRF, age and sex. CRF was categorized as low or high for age and sex, according to a reference material of 4631 healthy Norwegian men and women.[15] Age was entered as a continuous variable. The continuous variables were checked for normality, homogeneity of variance and heteroscedasticity of residuals, and all assumptions for linear regression were met. We also did a separate analysis including only those who reached VO_2max on the CRF test. Additionally, to assess whether HRmax differed between males and females or between those with high versus low CRF, and to assess if there was an interaction between sex and CRF, we performed an age-adjusted two-way ANOVA (sex × CRF). Descriptive statistics are reported as mean, with standard deviation. Regression data is reported as unstandardized coefficients beta (B), standard error (SE_B) and standardized coefficient beta (β). Only R^2 is reported here as there was no shrinkage (i.e. loss of predictive power) between R^2 and adjusted R^2.[16] The difference between the HRmax and HRcrf and differences between factors in the ANOVA are reported as mean with 95% confidence interval (CI). Statistical significance was considered as $p < 0.05$. All analysis were performed using IBM SPSS Statistics version 24.

3. Results

We included 107 participants. Table 1 shows descriptive statistics for the participants and results from the two exercise tests. The HRmax was 2.2 (95% CI, 1.5, 2.9) bpm higher than HRcrf ($p < 0.001$). When including only those who reached VO_2max (n = 96) in the analysis, HRmax was 2.2 (95% CI, 1.4, 2.9) bpm higher than HRcrf ($p < 0.001$). 30.2% of the participants were classified as having low CRF, i.e. with a VO_2max lower than the average for their age and sex.[15]

HRcrf was the only variable that significantly predicted HRmax and accounted for 90.5% of the variance in HRmax (Table 2). HRmax was predicted by the equation: HRmax = 8.197 + [0.967 × HRcrf] when including all participants. When including only those who fulfilled the criteria for VO_2max, HRmax was predicted by the equation: HRmax = 6.674 + [0.976 × HRcrf]. The addition of the non-significant independent variables to the model did not strengthen the prediction of HRmax (Table 2). Fig. 1 shows the individual HRmax and HRcrf for all participants. We observed an effect ($p = 0.005$) of CRF on HRmax. Individuals with low CRF had on average 5.8 (95% CI, 1.8–9.9) bpm higher HRmax than individuals with high CRF, estimated at an average age of 39.5 years. There was no effect of sex ($p = 0.38$) and no interaction between CRF and sex ($p = 0.13$) on HRmax.

4. Discussion

Our main finding was that HRmax was on average two beats per minute higher than the highest HR reached in a CRF test in males and females aged 20–70 years. The highest HR reached during the CRF test explained ∼90% of the HRmax and we observed no evi-

Table 1
Descriptive data for the total population and according to sex and cardiorespiratory fitness level (CRF). CRF is categorized as high and low in those who had peak/maximum oxygen uptake above and below the average for age and sex, respectively. Values are mean ± SD.

	Total	Females		Males	
		High CRF (n = 42)	Low CRF (n = 15)	High CRF (n = 36)	Low CRF (n = 15)
Age, years[a]	39 ± 12	40 ± 13	35 ± 10	39 ± 12	41 ± 14
BMI, kg/m^2	24.4 ± 2.9	22.7 ± 2.0	25.8 ± 4.5	25.1 ± 2.3	25.8 ± 1.6
Cardiorespiratory fitness test					
VO_2peak, mL/kg/min	47.7 ± 8.4	46.2 ± 6.0	36.2 ± 5.1	55.0 ± 6.1	46.2 ± 4.8
HRcrf, bpm	186 ± 12	183 ± 12	194 ± 10	184 ± 12	187 ± 9
RPE	17.7 ± 1.1	17.9 ± 1.2	17.3 ± 0.9	17.7 ± 1.1	17.5 ± 1.1
RER	1.12 ± 0.1	1.10 ± 0.1	1.13 ± 0.1	1.12 ± 0.1	1.15 ± 0.1
Heart rate maximum test					
HRmax, bpm	188 ± 12	185 ± 12	197 ± 8.3	187 ± 12	189 ± 9
RPE	17.9 ± 0.9	17.7 ± 1.0	18.3 ± 0.8	18.1 ± 0.8	17.5 ± 1.0

BMI: body mass index.
VO_2peak: maximum/peak oxygen uptake.
HRcrf: maximum heart rate at the cardiorespiratory fitness test.
Bpm: beats per minute.
RPE: rate of perceived exertion, on a 6–20 scale.
HRmax: maximum heart rate.

[a] Number of participants in each age group: aged 20–29 years, n = 30 (18 females and 12 males; 12 females with high fitness, 8 males with high fitness), aged 30–39 years, n = 28 (15 females and 13 males; 8 females with high fitness, 12 males with high fitness), aged 40–49 years, n = 27 (11 females and 16 males; 9 females with high fitness, 11 males with high fitness), aged 50–59 years, n = 12 (6 females and 6 males; 6 females with high fitness, 3 males with high fitness), aged 60–69 years, n = 9 (6 females and 3 males; 5 females with high fitness, 2 males with high fitness), 70–79 years, n = 1 (1 male with high fitness).

Table 2
Summary of hierarchical linear regression analysis for variables from predicting heart rate maximum.

	B	SE_B	β	p-Value
With only HRcrf as variable in the model				
Intercept	8.197	5.688		
HRcrf	0.967	0.031	0.951	< 0.001
R	0.951			
R^2	0.905			
SEE	3.671			
With HRcrf, VO_2max/VO_2peak, fitness, sex and age as variables in the model				
Intercept	8.107	8.693		
HRcrf	0.966	0.041	0.950	<0.001
VO_2max/VO_2peak	0.330	1.235	0.008	0.790
Fitness, low/high	0.112	0.849	0.004	0.896
Age, years	-0.002	0.037	-0.002	0.952
Sex, female/male	0.213	0.728	0.009	0.771
R	0.951			
R^2	0.901			
SEE	3.740			

HRcrf = heart rate maximum during a cardiorespiratory fitness test, B = unstandardized coefficient beta, SE_B = standard error of the unstandardized coefficient beta, β = standardized coefficient beta, R = linear regression coefficient, R^2 = coefficient of determination, SEE = standard error of the estimate, VO_2max/VO_2peak = whether the participant reached maximum or peak oxygen uptake at the cardiorespiratory fitness test.

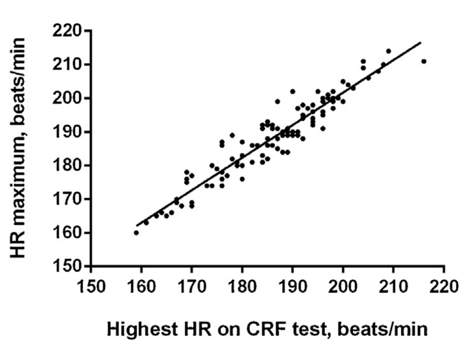

Fig. 1. Heart rate (HR) maximum from a test designed to reach HR maximum and the highest HR reached during a cardioreapiratory fitness (CRF) test. Each dot represents one individual.

dence for an effect of age, sex or CRF, or whether the participants fulfilled the criteria for VO_2max on this relationship. We observed lower HRmax in individuals who had VO_2max/peak higher than the average for their age and sex, compared to individuals with below-average CRF, but no difference in HRmax between males and females. Our findings indicate that most non-athletes reach close to their HRmax at the end of a standard CRF test and that the common practice of adding 5 bpm to the HRcrf to estimate HRmax might be excessive for many individuals. However, the difference between HRmax and the highest HR reached in the CRF test ranged from −5 to 12 bpm, which could lead to inaccurate intensity zones if using the prediction equation reported here. For an individual, on either end of this range, HRmax can be over- or underestimated, potentially causing suboptimal training effect.[17] Thus, for accurate HRmax measurements a maximum HR test should be performed.

Most previous studies reporting HRmax have undertaken a standard, incremental CRF test by use of various protocols.[8,11,18] Due to different protocols and the uncertainty of reached maximal exhaustion in previous studies, it has been questioned whether the true HRmax has been reached in these tests.[8] However, when comparing three common CRF test protocols (the Bruce, Balke and Taylor protocols) Froelicher et al.[19] reported no significant difference in HRmax between protocols. It can be speculated that fit individuals are better at pushing themselves to exhaustion compared to unfit individuals. We observed the same difference between HRmax and HRcrf for participants who reached VO_2max and VO_2peak, indicating that reaching VO_2max in a CRF test is not necessary to estimate HRmax based on the test. However, most of our participants reached VO_2max and a larger sample of individuals with VO_2peak measurements on CRF tests is required to establish the association also in those not reaching VO_2max. We observed lower HRmax in participants with a CRF higher than the average for their age and sex compared to their lower fit counterparts. This is in line with some previous studies.[10,11,20] The absolute difference in HRmax between those above and below the average VO_2max for age and sex in our study (6 bpm), was similar to the difference Whyte et al. observed when investigating elite athletes compared to sedentary individuals.[20] However, Tanaka et al. concluded in a meta-analysis of 351 studies involving more than 18,000 individuals that HRmax was independent of physical activity status. A major strength of our investigation in this regard, is that we divided the individuals based on CRF and not the habitual frequency or duration of physical activity, as the latter does not necessarily predict the former.[21] If indeed individuals with high CRF have a lower HRmax, the mechanism for this relationship has been suggested to be adaptations in stroke volume and a better distribution of blood to the working muscle leading to more efficient distribution of cardiac output, and thereby decreased chronotropic drive in trained individuals.[22] Additionally, chronic training can decrease the sympathetic nervous system responsiveness by alterations in β-adrenoreceptor density.[23] The studies that observed no effect of fitness on HRmax included relatively large numbers of participants of all ages.[4,7] It can be questioned whether older, unfit adults failed to reach maximum exhaustion and thereby a lower HRmax got recorded, compared to their fit counterparts, thereby masking an effect of fitness on HRmax for the whole study population.[8]

We found no effect of sex on HRmax, which is in accordance with some previous studies,[4,7,8] but in contrast to others.[9,10] The studies that found no effect of sex on HRmax had a larger sample, they included non-athletes and participants from a wide age range, similar to our study. In contrast, the studies that showed an effect of sex on HRmax had a younger and smaller sample.[9,10]

The major strength of our study is the inclusion of males and females over a large age span and at different CRF levels. Our study has some limitations. We had a limited number of participants and most of the participants had CRF above the average for sex and age. Thus, fitness could be a significant predictor of the relationship between HRmax and HRcrf in a more heterogeneous population. We were not able to recruit as many participants in the older age groups as we aimed to, therefore limiting the generalizability of our results in the older (>60 years) population. We did not control for the time of day the two tests were undertaken, thereby introducing a risk of bias due to the time of day variability. However, HRmax is minimally affected by time of day in non-athletes.[24]

5. Conclusion

The common practice of adding five bpm to the highest HR achieved during a CRF test may be excessive in non-athletes, and for this particular group a standard cardiorespiratory fitness test can give a good estimate of maximum heart rate.

Practical implications

- Non-athletes completed two different exercise test; one standard cardiorespiratory fitness test and one test designed to make the participants reach their heart rate maximum.
- On average, the participants' highest heart rate was 2 beats per minute higher in the heart rate maximum test.
- Standard cardiorespiratory fitness testing can therefore give a good estimate of heart rate maximum in non-athletes.

Acknowledgments

The equipment and lab facilities for the exercise testing were provided by NeXt Move, Norwegian University of Science and Technology (NTNU). NeXt Move is funded by the Faculty of Medicine and Health Sciences at NTNU and the Central Norway Regional Health Authority. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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