CRITICAL VS ESTIMATED HEART RATE IN ELDERLY SUBJECTS

FREQUÊNCIA CARDÍACA CRÍTICA X ESTIMADA EM INDÍVIDUOS IDOSOS

FRECUENCIA CARDÍACA CRÍTICA X ESTIMADA EN INDIVIDUOS DE LA TERCERA EDAD

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ABSTRACT

Introduction: Heart rate (HR) has been a simple and easy-to-use physiological parameter widely used to determine exercise intensity. The critical power fatigue limit model, known as the critical heart rate (CHR), can be extrapolated to HR. However, an estimate for a CHR mathematical model has not yet been extrapolated for upper limb exercise in the elderly. Objective: To compare the mathematical model previously used to estimate CHR with the heart rate values at the critical power (CP) during arm-ergometer exercises in elderly subjects. Methods: After an initial maximum-incremental exercise test on a cycle arm-ergometer, seven elderly people performed four high-intensity constant-load tests to the limit of tolerance (T_{lim}), to determine CP and critical heart rate (CHR). For each power output, the heart rate of the last five seconds (HR_{lim}) and total time to exhaustion (in minutes) were obtained. The slope coefficients of the regression lines between HR_{lim} and T_{lim} were defined as CHR, and between W_{lim} and T_{lim} as CP. A square-wave test was performed on a different day, in the power determined as equivalent to CP, and the heart rate at CP (CP_{HR}) was assessed. Results: The HR-T_{lim} relationship was found to be hyperbolic in all subjects, who were able to sustain upper-limb exercise at CP for 20 min. CP attained 66.8±9.4% of peak work rate in the ramp test. The real average HR measured in the CP test was strikingly similar to the CHR calculated by the mathematical model of PC (137.6±16.9 versus 139.7±13.3bpm, respectively, *p*=0.53). There was strong correlation between the real and the estimated CHR. Conclusion: This study indicated that the maximal sustainable exercise intensity can be based on a physiological variable such as HR, and the CHR test can define exercise endurance, which can be useful in performance assessment and training prescription. ***Level of evidence II; Diagnostic studies – Investigating a diagnostic test.***

Keywords: Heart rate; Exercise tolerance; Upper extremity.

RESUMO

*Introdução: A frequência cardíaca (FC) tem sido um parâmetro fisiológico fácil de usar, amplamente empregado para determinar a intensidade de exercício. O modelo de limiar de fadiga pela potência crítica pode ser extrapolado para a FC, conhecido como frequência cardíaca crítica (FCC). Entretanto, a estimativa para um modelo matemático da FCC ainda não foi extrapolada para o exercício de membros superiores em idosos. Objetivo: Comparar o modelo matemático para estimar a FCC usado anteriormente com os valores da frequência cardíaca na potência crítica (PC) durante exercícios com ergômetro de braço em idosos. Métodos: Depois de exercício inicial máximo incremental em um ciclo de ergômetro de braço, sete idosos realizaram quatro testes de carga constante até o limite de tolerância (T_{lim}) (para determinar a PC e a frequência cardíaca crítica (FCC). Para cada potência, foram obtidas a frequência cardíaca dos últimos cinco segundos (FC_{lim}) e o tempo total de exaustão (em minutos). Os coeficientes de declive das linhas de regressão entre FC_{lim} e T_{lim} foram definidos como FCC e entre CT_{lim} e T_{lim} como PC. Um teste de onda quadrada foi realizado em um dia diferente, na potência que se determinou equivalente à PC, e a frequência cardíaca na PC (PC_{FC}) foi avaliada. Resultados: Verificou-se que a relação FC-T_{lim} era hiperbólica em todos os indivíduos, que foram capazes de manter o exercício do membro superior na PC por 20 minutos. A PC atingiu 66,8 ± 9,4% da taxa de pico de trabalho no teste de rampa. A FC média real medida no teste de PC foi notavelmente semelhante à FCC calculada pelo modelo matemático de PC (137,6 ± 16,9 versus 139,7 ± 13,3 bpm, respectivamente, p = 0,53). Houve forte correlação entre FCC real e a estimado. Conclusão: Este estudo indicou que a intensidade máxima de exercício sustentável pode basear-se em uma variável fisiológica, como a FC, e que o teste de FCC pode definir a resistência ao exercício, o que pode ser útil para a avaliação do desempenho e para a prescrição do treinamento. **Nível de evidência II; Estudos diagnósticos - Investigação de um exame para diagnóstico**.*

Descritores: *Frequência cardíaca; Tolerância ao exercício; Extremidade superior.*

RESUMEN

Introducción: La frecuencia cardíaca (FC) ha sido un parámetro fisiológico fácil de usar, ampliamente empleado para determinar la intensidad de ejercicio. El modelo de umbral de fatiga por la potencia crítica puede ser extrapolado para la FC, conocido como frecuencia cardíaca crítica (FCC). Entretanto, la estimativa para un modelo matemático de la FCC aún no fue extrapolada para el ejercicio de miembros superiores en personas de la tercera edad. Objetivo: Comparar el modelo matemático para estimar la FCC usado anteriormente con los valores de la frecuencia cardíaca en la potencia crítica (PC) durante ejercicios con ergómetro de brazo en personas de la tercera edad. Métodos: Después de ejercicio inicial máximo incremental en un ciclo de ergómetro de brazo, siete ancianos realizaron cuatro tests

*de carga constante hasta el límite de tolerancia (T_{lim}) para determinar la PC y la frecuencia cardíaca crítica (FCC). Para cada potencia, fueron obtenidas la frecuencia cardíaca de los últimos cinco segundos (FC_{lim}) y el tiempo total de agotamiento (en minutos). Los coeficientes de declive de las líneas de regresión entre FC_{lim} y T_{lim} fueron definidos como FCC y entre CT_{lim} y T_{lim} como PC. Un test de onda cuadrada fue realizado en un día diferente, en la potencia que se determinó equivalente a la PC, y fue evaluada la frecuencia cardíaca en la PC (PC_{FC}). Resultados: Se verificó que la relación FC-T_{lim} era hiperbólica en todos los individuos, que fueron capaces de mantener el ejercicio del miembro superior en la PC por 20 minutos. La PC alcanzó 66,8 ± 9,4% de la tasa de pico de trabajo en el test de rampa. La FC promedio real medida en el test de PC fue notablemente semejante a la FCC calculada por el modelo matemático de PC (137,6 ± 16,9 versus 139,7 ± 13,3 bpm, respectivamente, p = 0,53). Hubo fuerte correlación entre FCC real y la estimada. Conclusión: Este estudio indicó que la intensidad máxima de ejercicio sostenible puede basarse en una variable fisiológica, como la FC, y que el test de FCC puede definir la resistencia al ejercicio, lo que puede ser útil para la evaluación del desempeño y para la prescripción del entrenamiento. **Nivel de evidencia II; Estudios diagnósticos - Investigación de un examen para diagnóstico**.*

Descriptores: *Frecuencia cardíaca; Tolerancia al ejercicio; Extremidad superior.*

INTRODUCTION

The critical power (CP) is the highest power that can be sustained without fatigue and can be defined as a relationship between the power applied and the time to exhaustion.[1] CP establishes the border between intense and very intense exercises, i.e. the threshold of fatigue, as a good endurance capacity index in long-term activities.[2] This model of CP has been applied in different exercise modes involving a single muscle or large muscle groups; in addition, different muscles such as the heart, respiratory muscles, and peripheral muscles have different thresholds of fatigue, with specific percentages of one's maximum capacity of work.[3,4]

The mathematical model for determination of CP has undergone numerous adaptations to meet the most varied forms of exercises.[5] An example of variation of this concept is the critical velocity determined in running athletes.[6,7] Although many of the modalities of the exercise using CP as a form of training have been directed to the lower limbs (LL), some studies have extrapolated this concept for activities that involve the upper limbs (UL), such as swimming, rowing, kayaking, and training in arm-ergometer by paraplegic subjects.[8-11]

Consistent with this, a study has demonstrated a new adaptation to the mathematical model of CP, using the physiological parameter of heart rate to estimate the critical heart rate (CHR) in the ergometer cycle exercise of lower limbs.[12] It is well known that training intensity based on percentage of maximum heart rate or cardiac reserve is widely used in aerobic training in rehabilitation programs, resulting in improving cardiovascular conditioning. Interestingly, the model of CHR is based on a physiological variable; it can be an alternative that is simple, safe, and more practical in determining the intensity of aerobic exercise.

Based on this, we hypothesized that the mathematical model for CP determination could be extrapolated to determine the critical heart rate for exercise of UL in healthy elderly people. As such, the aim of this study was to verify whether the previously-applied model of CHR in LL exercise could be used for dynamic exercise of the UL in healthy elderly people. In addition, HCR was tested and compared to the heart rate achieved in charge of the critical power in the UL exercise, as well as to the heart rate at ventilatory threshold (VT_{HR}) level and respiratory compensation point (RCP_{HR}).

METHODS

This was a cross-sectional study involving elderly subjects. The protocol consisted of six visits. During the first visit, the subjects underwent clinical evaluation, anthropometric measures, and maximal cardiopulmonary exercise testing of UL. On four separate days (at 48-hour intervals), each subject underwent four continuous workouts to exhaustion at different power outputs, to determine the CP_{HR} and CHR. In addition, a square-wave test was performed on a different day, at the subsequently-determined power equivalent to fatigue threshold or critical power with target duration of 20 min. In all exercise tests, HR values were measured to exhaustion to determine the CHR and CP_{HR}. CHR was then statistically compared to CP_{HR}, as well as to VT_{HR} and RCP_{HR}.

This study included seven healthy elderly with ages of 55-80 years that have undergone a supervised physical activity program at our service and were considered who underwent in a sedentary according to the physical activity questionnaire[13] and therefore not involved in regular physical activity in the last year. Smokers were excluded, and subjects with diagnosis of cardiorespiratory or neurological disorders, orthopedic or other comorbidities that could restrain conduct in the evaluations. Institutional research ethics committee approved the study (nº 346549), and all participants signed an informed consent form prior to the investigation.

All subjects underwent previously clinical evaluations and anthropometric.

Arm Exercise Incremental Maximal Cardiopulmonary Test for Upper Limbs

The rapidly-incrementing maximal cardiopulmonary exercise test for upper limbs was performed on an arm cyclergometer Angio® (Lode BV – Groningen, Netherlands), and the data were directed to the CardiO₂ System⁰ (MGC). All procedures for this test were performed in accordance with the Statement.[14]

For all tests, subjects were seated and the arm crank height was adjusted so that the fulcrum of the pedals was at the level of the gleno-humeral joint. After a period of familiarization of the participants, test started with a warm-up period of 2 minutes with free-load, while maintaining a fixed rotation between 55-60 rpm. After heating, workloads were increased by 7-12 watts, until the exercise stopped due to exhaustion or to inability to maintain the minimal rotations required.

During the test, the following variables were obtained: metabolic variables - oxygen consumption (VO_2, mL.min⁻¹), carbon dioxide production (VCO_2, mL.min⁻¹), and respiratory exchange ratio; ventilatory variables - minute ventilation, respiratory frequency, ventilatory equivalents for O_2 and CO_2 (VE/VO_2 and VE/VCO_2), and VE/MVV ratio; cardiovascular variables: 12-derivation electrocardiogram, resting heart rate, and arterial pressure;

and gas exchange variables: peripheral oxygen saturation. Perception of dyspnoea and fatigue in the upper limbs were evaluated by means of Borg's modified scale at rest, at exercise peak, and recovery.[15]

The anaerobic threshold was determined by method V-slope. Ventilatory equivalents were also used to confirm the RCP, by increases in VE/VO_2 with no increases in VE/VCO_2 and by departure from the linearity of VE, whereas RCP corresponded to an increase in both VE/VO_2 and VE/VCO_2. Two experienced exercise physiologists carried out these observations.

Constant-load Arm Exercise Tests

On separate days each subject undertook a series of four different constant-load arm exercise tests to the limit of tolerance. The WRs were randomly applied, in order to induce exhaustion in more than 1 and less than 20 min. Relative to the peak values obtained at maximum-incremental exercise (%peak WR), these workloads corresponded in control subjects and patients to 100–120% (WRA), 90% (WRB), 80% (WRC) and fourth test (WRD), which will have their load at 5-20% above the CP estimated by three previous loads, individually chosen in an attempt to provide an even point distribution along the 1/time axis.

Critical Power Test

The work load corresponding critical power was determined from the linear regression of x intensity multiplied by 1/Tlim of constant load tests (WA, WB, WC, WD), corresponding to the value of the y-intercept, that is, when the line touches the y-axis.

In order to test the tolerability of the power output equivalent to fatigue threshold, a square-wave test was performed on a different day, at the subsequently-determined power output equivalent to CP with target duration of 20 min.

Time to fatigue (*t*) was taken as the interval between the sudden imposition of work rate and the point at which the subject could no longer maintain the required pedaling rate (55 rpm), despite active encouragement from the observer.[2,16]

For the calculation of critical heart rate (CHR), it was necessary to obtain the total number of heartbeats by time period (HR_{lim}) of each of the tests of constant load. Thus, this calculation used the following equation:[12]

$$HR_{lim} = HR \times time$$

Being that the heart rate (HR) corresponds to the average heart rate of the last five seconds, and the time expressed in seconds corresponds the time of tolerance at critical power test.

After determining the CHR, these values were compared to the final HR (average of the last five seconds) measured at the CP test, with the aim of testing its validity.

Statistical analysis

Statistical analysis was performed using SPSS software (version 13.0). Data were presented as mean and standard deviation (SD). Relationship between the W and the 1/tempo, representing the y-intercept-y (CP) and relationship between the HRlim and the time of tolerance, were analyzed by linear regression.

For direct data comparison and measurement of CHR and HR at CP test, the paired student's *t*-test was used. The analysis of agreement between CHR estimated and HR at limit of CP test (CHR determined) was made by the intraclass correlation coefficient (ICC), and the confidence interval of 95 was calculated. The ICC values were established as: excellent agreement from 0.80 to 1.0; good agreement from 0.60 to 0.79; and poor agreement below 0.60. ICCs are deemed to be clinically acceptable if the values are greater than 0.80.[16] The agreement limits of the CHR and HR at limit of CP test were investigated by plotting the individual differences against their means (Bland-Altman analysis).[17]

RESULTS

Table 1 shows the anthropometric characteristics of the sample evaluated in the study.

The variables of interest at peak WR attained in the incremental exercise test and in the critical power test are shown in Table 2. The intensity of the constant-load at the critical power corresponded to 66% of peak WR.

The average HR peak at the end of the incremental test and at the end of the CP test corresponded to approximately 91.7% and 88.9% of the prediction for age, respectively. All subjects could sustain exercise for 20 min at the level CP with stable VO_2 and VE, with near-maximum cardiovascular and ventilatory stress but without progressive discomfort.

Figures 1A and 1B show representations of the HR-t relationships in response to HR at four progressively-intense exercise tests in a subject. (A) A hyperbolic relationship was found in the subjects: reductions in the asymptote (critical heart rate) and the area under the curve (anaerobic work capacity). (B) The subject's linearized response as a function of the number of heartbeat and time presented intercept (critical heart rate).

The estimated critical heart rate was not different when compared to the average of the heart rate at the end of the test performed at critical power load (139.7±13.3 *vs* 137.6±16.9bpm, *p*=0.53). In addition, excellent agreement was observed between CHR estimated and the CHR measure (intraclass correlation coefficient 0.93 (0.62-0.99); *p*= 0.002). The individual values of HR at anaerobic threshold level, HR at respiratory compensation point, CHR measure, and CHR estimated are shown in Table 3.

Table 3 includes the individual values for HR at anaerobic threshold, HR at respiratory compensation point, CHR measure, and CHR estimated. The mean CHR real (137.6± 6.9bpm) was not significantly different from the CHR estimated (139.7±13.3bpm), but was higher (p=0.03) than HR at AT (103±11.5bpm) and (*p*=0.05) HR at RCP (121.3±9.3bpm).

The Bland-Altman plots (Figure 2) show the mean bias and limits of agreement intervals for the CHR measure and CHR estimated, which were -1.8±12.9bpm.

Table 1. Anthropometric characteristics of subjects.

Subjects	Age (years)	Weight (Kg)	Height (m)	BMI (Kg/m²)
1	62	93.2	1.59	36.9
2	63	72	1.60	28.1
3	56	72	1.55	30.0
4	65	80	1.75	26.1
5	64	62	1.60	24.2
6	77	67	1.63	25.2
7	67	83	1.78	26.2
Mean ± SD	64.8±6.3	75.6±10.5	1.64±0.09	28.1±4.3

Table 2. Exercise variables at peak ramp-incremental (peak) and at the last minute of the test at individual's critical power.

Variables	Incremental	Critical Power	CP (%max)
Workload (W)	62.7 ± 20.4	42.3 ± 16.7	66.8±9.4
Time (s)	420.6 ± 71.7	1200.0 ± 0	---
R	1.16 ± 0.17	0.97 ± 0.23	83.4 ± 15.1
HR$_{max}$ (bpm)	142.3 ± 12.9	137.6 ± 16.9	97.1 ± 12.9
VO$_2$/HR (ml/bpm)	8.1 ± 1.7	8.9 ± 1.9	110.9 ± 18.7
VE (L/min)	51.6 ± 17.6	46.9 ± 17.6	92.8 ± 30.7
VE/MVV (n=6)	0.45 ± 0.13	0.42 ± 0.17	94.0 ± 33.4
RR (rpm)	36.1 ± 7.6	34.0 ± 5.0	97.3 ± 22.9
VE/VO$_2$	44.4 ± 6.8	37.7 ± 9.7	84.8 ± 18.5
VE/VCO$_2$	37.8 ± 4.4	38.7 ± 4.8	103.1 ± 14.7
BORG UL	7 (3-10)	5 (4-9)	---
BORG dyspnea	5 (0-7)	1 (0-5)	---

W=Watts; s=seconds; R=respiratory quotient; bpm=beats per minute; rpm=respiration per minute; Ve= minute ventilation; MVV=maximum voluntary ventilation; RR=respiratory rate; HR=heart rate.
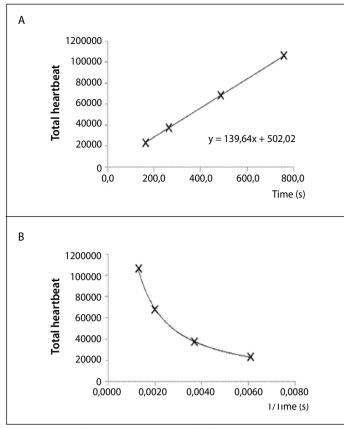
Figure 1. Linear relationship (A) and (B) hyperbolic between heart rate and time in seconds. The equation corresponds to the linear relationship between the average test time (in seconds) and the product of the time with HR final average for each of the four tests.

Table 3. Individual values of the HR at AT, RCP, and CHR measure and CHR estimated.

Subjects	HR AT (bpm)	HR RCP (bpm)	Measure CHR (bpm)	Estimated CHR (bpm)
1	91	114	109	112.3
2	113	125	122	137.6
3	92	121	153	146.1
4	121	133	151	149.5
5	106	128	132	136.2
6	93	105	148	142.5
7	105	123	148	152.0
Mean±SD	103±11.5	121.3±9.3	137.6±16.9	139.7±13.3

HR = heart rate; AT = anaerobic threshold; RCP= respiratory compensation point.
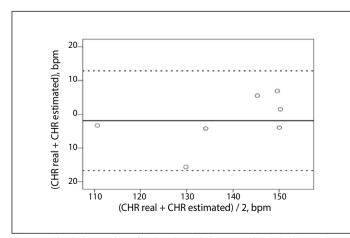

Figure 2. Bland-Altman plots of CHR real and CHR estimated. The solid line indicates the reference of mean difference, and the dashed lines represent the upper and lower limits of agreement.

DISCUSSION

The main finding of this study is that the mathematical model of the CP extrapolated for a physiologic parameter (HR) provides accurate values of critical HR, and can be used as a new parameter of fatigue threshold for arm-ergometer exercise. Our results show that, as in the model of critical power, the HR-time model also presents a hyperbolic curve shape.

In the present study, work rates at the CP of upper limbs was similar (67% peak WR) to those found in other studies involving upper-limb exercise.[18,19] On the other hand, different studies have shown that work rate at CP of lower limbs is about 80% of peak work rate.[20,21] Neder et al.[20] evaluated the CP of lower limbs in a control group of healthy elderly subjects, which represented around 67% peak work rate and 80% of peak VO_2 in the incremental test. The CHR corresponded to 97% of peak HR attained in the incremental test, and up to 90% of the HR estimated for age. These values of CHR were superior to the heart rate values at respiratory compensation point and ventilatory threshold; in addition, CHR was also superior to those values of CP found for upper- and lower-limb skeletal muscles.

In 2000, Walsh[22] discussed the interpretation of physiological variables that contributed to fatigue and constant load exercise on the different levels of CP that more-varied muscle groups could present. The findings showed that the peripheral muscles had lower levels of CP as a percentage of the maximum, when compared to CP of the respiratory muscles and cardiac muscle. This can be explained by two mechanisms: (i) the distance diffusion capacity of oxygen, and (ii) the flow of oxygen into the cell. When comparing the heart muscle to skeletal muscles, we can notice a difference in these two mechanisms that favor the heart muscle, which presents a higher fatigue threshold. The main reason for this is the high mitochondrial density and large capillarization of the heart muscle, which increases the ability oxygen diffusion to the cells, allowing for a greater endurance capacity of this muscle than of respiratory and peripheral muscles. This process can be observed when a healthy subject performs a high-intensity exercise that is disrupted by fatigue in peripheral muscles, while the muscles responsible for maintenance of ventilation and for blood supply are not fatigued at the same threshold.[1,22]

Although our results give support to the CHR model proposed by Mielke, in the present study we show a smaller difference (2 bpm) between CHR estimated and CHR measure, as compared to 18bpm of difference in Mielke's study.[12] This difference can be attributed to the fact that these authors did not perform the test in charge of the CP, only estimating from linear regression analysis of HR data from the incremental test with constant load tests. In this way, as in fact the test was conducted in the load of the CP, the protocol adopted in our study was able to determine the validity of the CHR.

Other differences can be highlighted in relation to Mielke's study, including: I) The CHR was tested using the CP model in arm ergometer. This modality of upper-limb exercise may be useful for patients with osteoarthritis of the knees, as well as for athletes in kayaking, rowing, and other activities focused on exercising the upper limbs, as well as for subjects with paraplegia or lower-limb amputation. (II) Our sample consisted of elderly individuals, indicating that senescence was not a limiting factor in determining the CHR, and therefore broadening its applicability. The number of subjects evaluated was relatively small, due to the complexity of the protocol that included large numbers of tests of strenuous exercise, which required many visits to the laboratory. However, our sample size is similar to several other studies that investigated the critical power model in exercise.[8-11,23-25]

From a practical point of view, the CHR seems to be an interesting alternative in exercise prescription to the load on the CP, since both indicators

are associated with aerobic capacity. In this sense, the HR-time relationship can be used in the prescription of aerobic physical training, as well as in the assessment and monitoring of changes induced by physical training.

The main advantage of using the CHR consists of its simplicity and its low cost, since it is only necessary to use a heartbeat monitor and a stopwatch. Another important aspect is that the validity of CHR implies the addition of a physiological element to the traditional model of CP, impacting the notion of transition of effort domains.

In the present study, we conclude that the CHR model showed excellent agreement with the values of heart rate achieved in the CP load in healthy elderly people. Additionally, this study provides a simple and useful model to use in evaluation and in upper-limb endurance training in healthy subjects.

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