Original article

Reliability of heart rate recovery indexes after maximal incremental tests

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Received: 12/04/2019
Accepted: 21/08/2019

Summary

Introduction: The relationship between heart rate (HR) recovery (HRR) and cardiovascular diseases (CAD) is well stablished, being that slower HRR is associated with an increased risk of sudden death and overall death, and it has been demonstrated to be independent predictor for both healthy and cardiac diseases individuals. However, it is not clear about which indexes from fast and slow phase of HRR have greater reliability after maximal exercise. This study aimed to verified which of the HRR indexes (T30 and ΔHR60s for fast phase of recovery; ΔHR300s and HR off-kinetics for slow phase) have better reliability in adults after maximal exercise test.

Material and method: Twelve healthy and moderate physical active young men without heart diseases performed three maximal treadmill tests with an interval of at least 48 h. Treadmill test started with speed of 4 $km.h^{-1}$, with increase of 1 $km.h^{-1}$ every minute until exhaustion. Beat-to-beat HR was recorded during exercise and 5 min of seated recovery to verify relative and absolute reliability of the T30, ΔHR60s, ΔHR300 and HR off-kinetics.

Results: It was found very high reproducibility in T30 (ICC = 0.91; SEM = 17.19s; CV = 13.51%), ΔHR60s (ICC = 0.91; SEM = 2.40 bpm; CV = 9.08%), ΔHR300s (ICC = 0.90; SEM = 2.69 bpm; CV = 5.42%) and HR off-kinetics parameters (ICC = 0.91-0.94; SEM = 2.43-3.63; CV = 4.06-8.10%), without difference for the variables among the tests ($p > 0.05$).

Conclusion: The ΔHR60s presented better reliability (higher ICC and lower CV) when compared to the T30, being both for fast phase of recovery. For slow phase, ΔHR300s and HR off-kinetics presented equivalent reliability.

Key words:
Cardiovascular diseases. Post-exercise recovery. Autonomic nervous system.

Reproducibilidad de los índices de recuperación de la frecuencia cardiaca después de las pruebas de esfuerzo máximas

Resumen

Introducción: La relación entre la recuperación de la frecuencia cardíaca (RFC) y las enfermedades cardiovasculares está bien establecida, siendo que la RFC más lenta se asocia con un mayor riesgo de muerte súbita y muerte en general, y se ha demostrado que es un factor predictivo independiente tanto para las personas sanas como para las personas con enfermedades cardíacas. Sin embargo, no está claro qué índices de la fase rápida y lenta de la RFC tienen mayor confiabilidad después del ejercicio máximo. Este estudio tuvo como objetivo verificar cuál de los índices de RFC (T30, ΔFC60s, ΔFC300s y cinética de FC) tienen mayor confiabilidad en adultos después de las pruebas máximas de ejercicio.

Material y método: Doce hombres con actividad física saludable y moderada sin enfermedades del corazón realizaron tres pruebas máximas en cinta rodante con un intervalo de al menos 48 h. La prueba en cinta rodante comenzó con una velocidad de 4 $km.h^{-1}$, con un aumento de 1 $km.h^{-1}$ cada minuto hasta el agotamiento. La FC de latido a latido se registró durante el ejercicio y 5 minutos de recuperación sentada para verificar la confiabilidad absoluta y relativa del T30, ΔFC60s, ΔFC300s y cinética de FC.

Resultados: Se encontró una reproducibilidad muy alta en T30 (CCI = 0,91; SEM = 17,19 s; CV = 13,51%), ΔFC60s (CCI = 0,91; EEM = 2,40 lpm; CV = 9.08%), ΔHR300s (CCI = 0,90; EEM = 2.69 lpm; CV = 5.42%) y los parámetros de cinética de FC (CCI = 0,91-0,94; EEM = 2,43-3,63; CV = 4,06-8,10%).

Conclusión: Los ΔFC60s presentaron mejor confiabilidad (mayor ICC y menor CV) en comparación con el T30 para una rápida fase de recuperación. Para la fase lenta, ΔFC300s y la cinética de FC fueron equivalentes.

Palabras clave:
Enfermedades cardiovasculares. Recuperación post ejercicio. Sistema nervioso autónomo.

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Introduction

Heart rate (HR) recovery (HRR) is a non-invasive tool to evaluate fast and slow phase of cardiac autonomic control after exercise[1]. The autonomic imbalance[2-5] is associated with increased risk of cardiovascular disease (CAD), sudden death and all-cause mortality[2,4-7]. At onset of exercise occurs vagal withdrawal and sympathetic increase activity, enhancing HR. After exercise, occurs fast parasympathetic reactivation, followed by sympathetic activity withdrawal, making a decreased of HR[8-10]. Previous studies have proposed different indexes with the purpose to monitor the HRR in different populations, and training effect[8,11,12].

Slower HRR is associated with an increased risk of CAD[1,4,13] and it has been demonstrated to be independent predictor for both healthy and cardiac diseases individuals[2,4,5,6,12]. For evaluation of HRR after maximal exercise, the main indexes used are T30, the difference between HR registered at the end of exercise and after sixty seconds (ΔHR60s) and after three hundred seconds (ΔHR300s) and nonlinear regression on the first 300s of the recovery phase (HR off-kinetics). T30 and ΔHR60s are indexes that evaluate fast recovery phase, determined by vagal reactivation, while Δ300s and HR off-kinetics covers both fast and slow recovery phase, determined by vagal reactivation and sympathetic withdrawal[7,8].

Some studies have demonstrated divergent results about HRR reliability using different indexes. This inconsistence may be due the different experimental protocols, such as: type of effort (maximum or submaximal)[14,15], type of recovery (active, passive or mixed)[16-18], interval between each test[19,20] and level of physical activity (sedentary, physically active or athletes)[17,21-23]. In this manner, this study aimed to verified which fast and slow HRR indexes (T30 and ΔHR60s for fast phase of recovery; ΔHR300s and HR off-kinetics for slow phase) have stronger reliability in young adults after maximal incremental tests.

Material and method

Subjects

Twelve healthy and moderate physical active young men (age = 24.6 ± 5.2 yr) without heart diseases took part of this study. The procedures were approved by the local Human Research Ethics Committees and all participants were informed about the aim and study protocols and signed an informed consent form.

Experimental design

In first session, the participants were submitted to anthropometric, body composition and blood pressure assessment. Later, they performed three maximal treadmill incremental tests with an interval between each other for at least 48 h. Participants were instructed to avoid caffeine and alcohol intake and strenuous exercise in the 24 h before the tests.

Anthropometric and blood pressure measurements

Weight (kg) was evaluated in digital scale (Tanita, UM-080) and height (cm) was measured with a stadiometer and, posteriorly, body mass index (BMI) was calculated according to equation (kg/m^2). The body fat (%) was assessed by tetrapolar bioelectric impedance analysis device (Maltron, BF906).

Blood pressure (mmHg) was measured by automatic device (Omron, HEM-7113), with standard cuff for adults, being considered the mean between two consecutive measurements with maximum differs of 4 mmHg, with two minutes interval between each other.

Exercise testing

Maximal exercise test started with speed of 4 km.h^{-1}, with increase of 1 km.h^{-1} every minute until exhaustion and fixed treadmill slope of 1% throughout the test. Rating of perceived exertion (RPE) was measured at final of each stage (last 10 seconds of each minute) from the incremental test using Borg scale 6-20. The test was considered maximal when the following variables were reached: 95% of HRmax predicted for age (220-age), rating of perceived exertion (RPE) ≥19 and voluntary exhaustion. Immediately after test, the subjects sat on a chair during 5 minutes of passive recovery and minimum movement. Beat-to-beat HR was recorded during exercise and recovery period by Polar V800 HR monitor to evaluate T30, ΔHR60s, ΔHR300s e HR kinetics.

HR data analysis

T30 was the negative reciprocal of the slope of the regression line between the natural logarithm of heart rate and elapsed time from the 10th to 40th second of exercise[24]. ΔHR60s was obtained through of numerical difference between HR immediately at the end of exercise and HR one minute after the end of test[2] and ΔHR300s after five minutes of end-test[25]. HR off-kinetics was adjusted by the following monoexponential function[26]:

$$HR = HRmin + A_{off} * \exp[-(time- \tau)/T]$$

Where HRmin is the asymptotic value of HR; A_{off} is the amplitude of the HR response; T is the time of the recovery onset; and τ is the time constant to reach 63% of the HR decline.

Statistical analysis

Data are present as mean and standard deviation (SD). Normality of distribution was checked with the Shapiro-Wilk test. Three tests were compared by repeated measures ANOVA for normally distributed data and Friedman test for non-normally distributed. Relative reliability was assessed with intraclass correlation coefficient (ICC) and absolute reliability with the standard error of measurement (SEM) and the coefficient of variation (CV). Significance level was set at $p < 0.05$.

Results

Participants characteristics are presents in Table 1 (mean ± SD) (Table 1).

The maximum speed, duration of the tests, HRmax (bpm), HRmax (%) and RPE in three treadmill incremental tests were not significant different ($p > 0.05$). Table 2 shows the data of each test (Table 2).

Table 3 shows data of T30, ΔHR60s, ΔHR300s and HR kinetics of each test and the reliability values. High reliability was found in T30 (ICC =

Table 1. Characteristics of the subjects (n=12).

Characteristics	Values
Age (years)	24.6 ± 5.2
Weight (kg)	75.7 ± 14.0
Height (cm)	174.2 ± 6.9
BMI (kg/m²)	25.0 ± 4.3
Body fat (%)	23.0 ± 8.7
SBP (mmHg)	121.0 ± 9.4
DBP (mmHg)	65.6 ± 7.8

Values in mean ± standard deviation. BMI: body mass index; SBP: systolic blood pressure; DBP: diastolic blood pressure.

Table 2. Maximal treadmill test data.

Variable	Test 1	Test 2	Test 3
Maximum speed (km.h^{-1})	15.9 ± 1.7	15.9 ± 1.4	15.8 ± 1.5
Duration (s)	793.8 ± 86.3	787.6 ± 78.0	783.9 ± 82.6
HRmax (bpm)	192.5 ± 6.3	193.4 ± 7.9	191.6 ± 7.7
HRmax (%)	104.0 ± 3.7	104.5 ± 5.0	103.5 ± 3.9
RPE (a.u.)	19.3 ± 1.2	19.1 ± 1.2	19.2 ± 1.3

Values in mean ± standard deviation. Duration: incremental test duration; HRmax: maximum heart rate; RPE: rating of perceived exertion.

Table 3. Reliability of HRR indexes after maximal treadmill test.

	Test 1	Test 2	Test 3	ICC	SEM	CV (%)
T30 (s)	232.0 ± 56.6	214.1 ± 60.4	220.1 ± 73.9	0.91	17.19	13.51
ΔHR60s (bpm)	44.3 ± 8.9	43.6 ± 9.2	47.7 ± 12.2	0.91	2.40	9.08
ΔHR300s (bpm)	85.03 ± 9.81	85.30 ± 9.54	86.16 ± 11.79	0.90	2.69	5.42
HRmin (bpm)*	104.1 ± 9.2	104.2 ± 11.8	101.5 ± 12.3	0.91	2.43	4.06
Aoff (bpm)*	89.6 ± 15.5	91.0 ± 14.2	90.1 ± 12.2	0.92	3.39	6.44
τ (s)*	77.6 ± 13.4	79.2 ± 18.8	77.0 ± 21.3	0.94	3.63	8.10

Values in mean ± standard deviation. ICC: intraclass correlation coefficient; SEM: standard error of measurement; CV: coefficient of variation; T30: time constant of fast stage of HRR; ΔHR60s: difference between maximum and minimum heart rate one minute post exercise; ΔHR300s: difference between maximum and minimum heart rate five minutes post exercise; HRmin: minimum heart rate after five minutes of recovery; A_{off} : amplitude of heart rate; τ: time constant. *HR kinetics indexes.

0.91; SEM = 17.19 s; CV = 13.51%) and ΔHR60s (ICC = 0.91; SEM = 2.40 bpm; CV = 9.08%). Both variables evaluate fast recovery phase, where there is mainly vagal reactivation.

ΔHR300s (ICC = 0.90; SEM = 2.69 bpm; CV = 5.42%) and HR kinetics (ICC = 0.91-0.94; SEM = 2.43-3.63; CV = 4.06-8.10%) also presented high reliability. They evaluate both fast and slow recovery phase, with vagal reactivation and sympathetic withdrawal.

Discussion

This study aimed verify the reliability of HRR indexes after maximal treadmill tests in adults. The indexes evaluated were T30 and ΔFC60s for vagal reactivation (fast recovery phase) and ΔFC300s and HR kinetics for vagal reactivation and sympathetic withdrawal (fast and slow recovery phase together)[7,8].

ICC is a classical measure of relative reliability which permits estimation of the percentage of the observed score variance that is attributable to the true score variance[14,16,27], being the higher value, greater the relative reliability. SEM provides an index of the expected trial-to-trial noise in the data, and CV is a measure of the discrepancy and expresses error as a percentage of the mean[14,16,21,27], with the lower value considered greater absolute reliability.

Considering T30, previous studies have showed low-to-moderate reliability (ICC = 0.12-0.56 s; SEM = 52.0-149.5 s; CV = 50.0-75.3%)[14,15,21]. This index presents limitations, such as: complex mathematical equation susceptible to artefact or arrythmias and required register HR on a beat-to-beat[8]. Another limitation is related to time frame used. Initially, the studies evaluated the first thirty seconds, but in the 10 initial seconds of recovery, the HR present a plateau or higher values compared to exercise HR. Thus, currently it has been encouraged to analyze the HR from 10th to the 40th seconds[8,12,14], which it present higher reliability (ICC = 0.12 to 0.56 vs 0.62 to 0.77, respectively). Conversely to other studies, this study showed high reliability of the T30 (ICC = 0.91; SEM = 17.19 s; CV = 13.51%). Our hypothesis is related to methods used, since the majority studies used submaximal tests[15,19]. However, Dupuy *et al.*[14] observed low reliability with method similar to the present study (maximum exercise), but with short period of the test, demonstrating that the effort duration may influence reliability values.

The present study showed high relative and absolute reliability of ΔHR60s (ICC = 0.91; SEM = 2.40 bpm and CV = 9.08%). Others studies have presented inconsistent reliability of ΔHR60s after submaximal exercise (ICC = 0.15-0.99; SEM = 1.6-11.4 bpm; CV = 0.9-25.7%)[14-17,19,20,22], but moderate to high reliability after maximum exercise tests (ICC = 0.58-0.92; SEM = 3.0-10.2 bpm; CV = 10.8-23.3%)[14,15,17,18,21], suggesting that ΔHR60s reliability may be exercise intensity dependent. Cole *et al.*[2] described that HRR, in active recovery, lower than 13 bpm in first minute after exercise is a powerful predictor of overall mortality. Later, Jouven *et al.*[4] showed in passive recovery that ΔHR60s less than 25 bpm is a predictor of sudden death. All subjects of the present study presented ΔHR60s > 25 bpm, indicating a good cardiovascular health.

As well as ΔHR60s, ΔHR300s also presented better reliability in maximal exercise tests in comparison to submaximal exercise. Several studies have found moderate to high relative (ICC = 0.71-0.93) and absolute (SEM = 3.4-5.6 bpm; CV = 7.0-8.6%) reliability after maximal exercise[16,17,20], while there were inconsistent results after submaximal exercise (ICC = 0.37-0.82; CV = 6.90-10.1%)[15,16,18]. Among men with diabetes, ΔHR300s is independently predictor of cardiovascular and all-cause death, with cut-off value <55 bpm[24].

HR kinetics also seems to present an association with effort intensity. Submaximal test showed low to moderate reliability (τ ICC = 0.36-0.64; SEM = 11.0-35.7 s; CV = 29.8-32.1%)[14,15,16,19,21] while, maximal treadmill tests presented moderate to high reliability (τ ICC = 0.71-0.84; CV = 11.5-13.3%)[14,16,20]. However, Al Haddad *et al.*[21] evaluated HR kinetics in cycle ergometer and obtained low reliability (τ CV = 24.3%), which it may suggest that this index can be influenced by the type of exercise.

In our study, despite the subjects were health and moderate physical active, they had different body mass index (eutrophic or overweight). Notwithstanding, Rezende *et al*.[28] evaluated young adults with normal weight and overweight and they did not find differences in vagal reactivation at short-term after a maximal incremental exercise test. In addition, the level of physical activity and interval between each test do not appear to be a determining factor in the variation of reliability. Previous studies[15,17] have showed large variation between the test periods (1-21 days) without any tendency to improve or worst reliability.

The main limitations of the study were small sample size and not breathing pattern recovery control. However, other studies have observed reliability of HR parameters with similar sample size and without breathing frequency control[19,21]. Additionally, this study was limited to healthy subjects, thus these results cannot be extrapolated to other populations.

Conclusion

All indexes of HRR showed high reliability after three maximal treadmill tests in adult men. However, for clinical practice, ΔHR60s is more recommended for evaluation of the fast recovery phase, because it presents higher relative and absolute reliability when compared to the T30. In addition, ΔHR60s has established prognostic values in previous studies. ΔHR300s and HR kinetics had similar reliability, and both can be used for clinical evaluation of both fast and slow recovery phase after maximal exercise.

Conflict of interest

The authors do not declare a conflict of interest.

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