AN EIGHTEEN-MINUTE SUBMAXIMAL EXERCISE TEST TO ASSESS CARDIAC FITNESS IN RESPONSE TO AEROBIC TRAINING

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ABSTRACT

Romagnoli, M, Alis, R, Sanchis-Gomar, F, Lippi, G, and Arduini, A. An 18-minute submaximal exercise test to assess cardiac fitness in response to aerobic training. *J Strength Cond Res* 32(10): 2846–2852, 2018—We aimed to evaluate the utility of a submaximal heart rate recovery (HRR) test to monitor changes in cardiac fitness after aerobic training. Twenty healthy subjects were assigned to a control ($n = 10$) or a training ($n = 10$) group. Subjects in the training group performed 8 weeks of bicycle training, followed by 8 weeks of detraining. Heart rate recovery was assessed after exercises at 65% and 80% HR_{max}. The HRR test was performed at weeks 0 (W0), 4 (W4), 8 (W8), and 16 (W16) in the training group and at W0 and W8 in the control group. Heart rate recovery indices changed in response to training and detraining. Absolute HRR at 60, 120, and 180 seconds after exercise increased at both exercise intensities at W8 of training ($p < 0.01$, W8 vs. W0) and returned to the pretraining level after detraining ($p > 0.05$, W16 vs. W0). Time constants of fast HRR recovery (<1 minute) changed with training ($p < 0.05$–0.01, W8 vs. W0) and detraining ($p > 0.05$, W16 vs. W0) but only at 65% HR_{max}. At the end of the 3-minute recovery period, the predicted heart rate (HR) value (A_0) and the HR recovered (A_{max}) from the monoexponential analysis changed with training ($p < 0.05$–0.01, W8 vs. W0) and detraining ($p > 0.05$, W16 vs. W0). We conclude that this novel submaximal HRR test is highly sensitive for monitoring cardiac fitness during training and detraining in healthy people. Because this test is simple, inexpensive, and the data are reliable and easy to analyze, we hope that it may be of interest to the sports science community.

KEY WORDS heart rate recovery, cycle ergometer, monitoring, parasympathetic

INTRODUCTION

Heart rate is determined by the activity of the autonomous nervous system, composed of sympathetic and parasympathetic branches that operate in an inverse manner. During exercise, the increase in heart rate (HR) is caused by both the disappearance of vagal tone (parasympathetic branch) and the dominance of sympathetic tone. However, upon cessation of exercise, earlier heart rate recovery (HRR) can be explained mainly by parasympathetic reactivation. β-adrenergic blockade with propranolol has no effects on HRR in the first minute after exercise while selective parasympathetic blockade with atropine or double blockade with both agents blunt fast HRR recovery (11). Complete recovery to pre-exercise heart rate is, however, accomplished by both the modulation of parasympathetic activity and sympathetic tone withdrawal (16,18).

Exercise training is known to promote changes in cardiorespiratory fitness (4,7,12,21). Reviewing scientific literature about HRR and its association with cardiac fitness, cross-sectional analyses show that HRR is faster in trained than in untrained subjects and that training processes improve HRR (5). Imai et al. (8) found that HRR was faster in athletes and was blunted in patients with chronic heart failure. Sugawara et al. (21) showed that 8 weeks of training induced improvements in vagal reactivation that were lost after 4 weeks of detraining.

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Therefore, HRR reliably mirrors adaptation to exercise training and detraining. Similar responses in HRR have been found in healthy people (8,21,27) and in cardiac patients (10,20,24).

Despite recent efforts to assess the reliability of specific HRR protocols (1,12), the validation of these tools for testing purposes is still an issue, and this is a major drawback for exercise testing and prescription. Evaluation of the beneficial effects of exercise on cardiac fitness by HRR measurements can provide inconsistent results (5). These adaptations may be obscured by exercise intensity (maximal vs. submaximal), mode (cycle vs. treadmill ergometer), type of recovery (active vs. passive), recovery time (1–10 minutes), or position (supine, standing, sitting). Our goal was to establish an easy sensitive method to assess changes in cardiac fitness in response to aerobic training.

Use of maximal exercises clearly limits the development of exercise testing procedures for the general population. Submaximal exercises may overcome problems related to reproducibility of maximal efforts (28); individuals do not always reach a real maximum because of volitional processes, pathology, pain, or technical difficulties. In addition, concerns about safety and special equipment arise when maximal exercises are used. For these reasons, we decided to establish an exercise test (HRR test) that uses submaximal exercise loads.

Exercise intensity selection is critical when designing an HRR test because distinct exercise loads may elicit rather different responses. On the one hand, cardiac nerve activation and inhibitory mechanisms are dependent on exercise intensity (19,22,25). On the other hand, the biological variability of the sympathetic and vagal components of HRR is greater after exercise at greater intensity (15). Given the higher signal-to-noise ratio, exercises at higher intensity seem advantageous when monitoring minor changes in physical fitness elicited by training or detraining. The selection of specific exercise intensity is essential in HRR assessment since cardiac nerves activation (19) and inhibitory mechanisms are dependent on exercise intensity (22,25). Nevertheless, this concept has never been applied to HRR testing protocols to monitor changes in cardiac fitness. Therefore, we designed a test to assess HRR after 2 different exercise intensities.

We have previously shown the reliability of this novel test to assess HRR after submaximal exercises at 65 and 80% HR_{max} on a cycle ergometer (1). In this study, however, we aimed to validate the ability of this submaximal HRR test to monitor changes in cardiac fitness in response to changes in physical fitness.

METHODS

Experimental Approach to the Problem

The participants were randomly assigned to the control or the training group. The participants in the training group performed a 1-hour cycling session 3 times a week for 8 weeks. Exercise intensity was set at 65% of their theoretical maximum heart rate (HR_{max}) (23) and was increased progressively to achieve an intensity of 80% HR_{max} in the last week of training. The subjects included in the control group were instructed to follow their regular habits for an identical period of time (8 weeks).

Subjects

Twenty college students and academic teachers (aged 24–47, 10 men, 10 women) were included in this study. They were not involved in regular physical activity, because involvement in sport teams or in regular training were identified as exclusion criteria. All the participants were informed of the purpose, protocol, and procedures before being enrolled, and the subjects provided written informed consent to participate in the study. The study was approved by the Ethical Committee of the Catholic University of Valencia (Valencia, Spain). Additional exclusion criteria included resting systolic and diastolic blood pressure higher than 140 and 90 mm Hg, respectively, use of chronotropic action drugs, and abnormal electrocardiogram (ECG) (at rest or during exercise). This study complies with the principles of the Declaration of Helsinki.

Procedures

Incremental Test. All the participants performed an incremental test on a cycle ergometer (SRM, Jülich, Germany) until exhaustion to determine maximal oxygen consumption ($\dot{V}O_2max$) at week 0 (W0) and W8 (Figure 1). Subjects were instructed not to exercise 24 hours before performing the trial. Before beginning the test, subjects were weighed, and their lean body mass and body fat mass were estimated by the bioelectrical impedance method (BC-418 body composition analyzer; Tanita Corporation, Tokyo, Japan). The participants performed a 3-minute warm-up at 80 W, followed by a 3-minute rest. The incremental exercise started at a load corresponding to 2 metabolic equivalents (METs) with load increments of 2 METs every third minute until exhaustion (9). Exhaustion was determined as the inability to maintain a constant cadence of 70 revolutions per minute, despite verbal encouragement. During the maximal test, ventilatory parameters were recorded through a respiratory valve and face mask (Hans Rudolph, Inc., Kansas City, MO, USA) using a gas analyzer (Oxycon; Jaeger, Würzburg, Germany) that was calibrated for volumes and gas exchange composition before each test. Heart activity was monitored during the maximal test by a continuous 12-lead ECG. Blood pressure was monitored at rest, immediately after maximal exercise, and also after the 1- and 3-minute recovery periods. Fingertip capillary blood lactate was measured at the end of exercising in both protocols by a portable blood lactate analyzer (Lactate Pro LT170; Arkray KDK, Shiga, Japan). The test was considered maximal when at least 2 of the following conditions were fulfilled: postexercise blood lactate >8 $mmol \cdot L^{-1}$; respiratory exchange ratio >1.2; maximal heart rate > maximal heart rate predicted (26). All trials met these criteria and were considered maximal.

Heart Rate Recovery Test. In this test, we set exercise intensity by indirectly calculating HR_{max} (19); this procedure avoids

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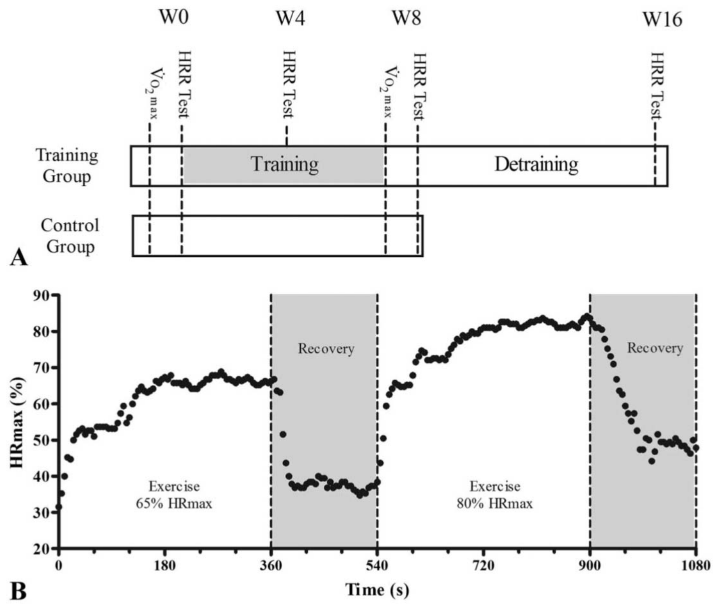

Figure 1. Graphical description of the experimental design (A) and the evolution of the 18-minute HRR test. One 6-minute exercise bout at 65% HR_{max} followed by a 3-minute recovery, and a second 6-minute exercise bout at 80% HR_{max} followed by a 3-minute recovery (B). HRR = heart rate recovery; HR = heart rate.

unnecessary costs and time-consuming tests to assess proper exercise loads. Importantly, intensities expressed as $\%HR_{max}$ are highly valuable in these settings because they elicit a specific internal load, which can be used for longitudinal comparisons (effect of training or detraining). Constant loads (fix power, mass, HR, speed) have to be adjusted according to the degree of training or detraining to elicit a similar response, so they are inappropriate for this purpose. The effect of recovery time and position may also influence the HRR results (14). We chose a sitting position for 3 reasons: (a) it is generally easier for a subject to rest on the bike instead of changing position, (b) it largely reduces variation in HRR caused by changes in position, and (c) it allows the analysis of the fast component of HRR, which is critical for assessing parasympathetic reactivation (1,8).

Heart rate recovery was assessed at W0, W4, W8, and W16 for the participants in the training group and at W0 and W8 for the participants in the control group (Figure 1). The HRR protocol consisted of 6 minutes of active pedaling on a cycle ergometer (Monark,

Table 1. Participants' characteristics and the incremental test data in both the control and the training groups, and their evolution over the training period.*†

	Control group ($n = 10$)		Training group ($n = 10$)	
	W0	W8	W0	W8
Male/Female	5/5		5/5	
Age (y)	32.30 (5.71)		29.70 (6.31)	
Body mass (kg)	69.87 (13.66)	69.61 (13.90)	67.56 (11.30)	68.14 (10.82)
BMI ($kg \cdot m^{-2}$)	23.66 (2.47)	23.64 (2.50)	23.23 (2.71)	23.43 (2.48)
Lean body mass (kg)	41.90 (8.20)	43.47 (3.22)	45.50 (2.17)	45.83 (1.99)
Fat body mass (%)	18.55 (6.72)	18.32 (2.12)	16.24 (3.22)	16.31 (3.02)
Maximal power output ($W \cdot kg^{-1}$)	2.63 (0.59)	2.58 (0.56)	2.60 (0.66)	3.40 (0.33)‡§
RER_{max}	1.30 (0.04)	1.25 (0.11)	1.26 (0.07)	1.26 (0.06)
$[La^{-}_{max}]$ ($mmol \cdot L^{-1}$)	11.15 (2.40)	11.16 (1.69)	9.79 (1.48)	11.45 (1.35)‖
Peak HR ($b \cdot min^{-1}$)	189.21 (11.33)	185.58 (10.72)	187.58 (4.96)	184.53 (4.41)
$\dot{V}O_2max$ ($ml \cdot min^{-1} \cdot kg^{-1}$)	33.20 (3.48)	34.30 (5.52)	35.37 (6.00)	43.08 (5.04)‡¶

*BMI = body mass index; RER = respiratory exchange ratio; $[La^{-}]$ = lactate concentration; HR = heart rate.
†Values are expressed as mean (*SD*).
‡$p < 0.01$ vs. the control group at the same week.
§$p < 0.01$ vs. W0 in the same group.
‖$p < 0.05$ vs. W0 in the same group.
¶$p < 0.001$ vs. W0 in the same group.

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Varberg, Sweden) at 65% HR_{max} and 3 minutes of rest sitting on the bike, followed by 6 minutes of pedaling at 80% of HR_{max} and 3 minutes of rest sitting on the bike (1). During the recovery phase, the subjects remained seated upright. They did not move, and they remained silent without interaction with the research staff. The subjects were instructed not to exercise 24 hours before performing the trial. The HR data were collected throughout the trial with an HR monitor (S810; Polar Electro, Kempele, Finland) and were interpolated to 1 second throughout the 3-minute recovery periods.

Heart Rate Recovery Analysis. Heart rate recovery was assessed by various models:

Absolute Heart Rate Recovery (Δ*HR).* Absolute HRR is the net difference between the mean value of the last 60 seconds of exercise and HR at 60 (ΔHR_{60}), 120 (ΔHR_{120}), and 180 (ΔHR_{180}) seconds of recovery.

T30 Slopes. The HR data of the first 60 seconds of recovery were transformed as their natural logarithm. Linear regression was performed against time in all the 30-second segments contained in the first minute of recovery. The negative reciprocal ($-1/\text{slope}$) of the rendered slope of the function in the first 30-second segment was interpreted as T30, as $T30_{10-40}$ in the segment between the 11th and 40th second, and the lowest single value in the first minute of recovery was interpreted as $T30_{min}$.

Heart Rate Recovery Kinetics. The data collected during the 3-minute recovery period were fitted to a monoexponential function $\left(y = A_0 + A_{max}\left[e^{\frac{-x}{T180}}\right]\right)$ (17). The first 10 seconds were excluded from the analysis to minimize the effect of HR abnormalities on the goodness of fit upon exercise cessation (1). A_0 represents the predicted HR value at the end of the 3-minute recovery period. A_{max} represents the HR recovered at the end of the 3-minute recovery period. T180 represents the decay constant of the fitted curve. Lesser values mean faster HRR.

Statistical Analyses

All the variables were analyzed for normality with the Shapiro–Wilk's test. Homogeneity of variance was assessed by Levene's test. To assess the differences between the training and control groups about HRR and incremental

TABLE 2. The baseline comparison of the HRR parameters between the control and the training groups.*†

	Control group ($n = 10$)	Training group ($n = 10$)	p
ΔHR_{60} ($b \cdot min^{-1}$)			
65%	23.68 (4.89)	21.44 (6.73)	0.405
80%	27.59 (7.13)	29.32 (10.00)	0.661
ΔHR_{120} ($b \cdot min^{-1}$)			
65%	30.40 (6.35)	25.71 (7.14)	0.138
80%	39.68 (5.01)	39.47 (6.37)	0.937
ΔHR_{180} ($b \cdot min^{-1}$)			
65%	33.18 (6.66)	28.74 (7.46)	0.177
80%	42.71 (5.60)	43.77 (6.307)	0.697
T30 (s)			
65%	271.70 (121.88)	214.97 (80.01)	0.234
80%	336.57 (183.04)	229.70 (85.54)	0.112
$T30_{10-40}$ (s)			
65%	259.25 (121.06)	239.72 (124.68)	0.726
80%	269.61 (131.96)	248.75 (69.74)	0.664
$T30_{min}$ (s)			
65%	198.53 (64.80)	201.47 (82.98)	0.931
80%	235.44 (85.73)	208.09 (63.77)	0.429
A_0 ($b \cdot min^{-1}$)			
65%	88.26 (10.84)	94.17 (8.84)	0.198
80%	103.39 (5.87)	102.22 (11.46)	0.777
A_{max} ($b \cdot min^{-1}$)			
65%	42.62 (7.57)	32.15 (11.12)	0.074
80%	58.12 (5.36)	49.43 (15.35)	0.119
T180 (s)			
65%	46.97 (20.97)	42.31 (24.26)	0.651
80%	55.68 (20.22)	68.38 (34.74)	0.331

*HRR = heart rate recovery.
†Values are expressed as mean (*SD*).

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test data at the baseline and after training (W0 and W8), both groups were separately analyzed at W0 and W8 using unpaired *t*-tests. In addition, paired *t*-tests were used to analyze the evolution of these variables from W0 to W8. The effects of training and detraining periods on the HRR variables in the training group were assessed by analysis of variance (ANOVA) with repeated measures (time points: W0, W4, W8, and W16). To identify the differences in HRR parameters at each time points between exercise intensities (65 and 80% HR_{max}), an ANOVA for repeated measures was used. Bonferroni's adjustment was performed for the post hoc comparisons. Significance was set at $p \leq 0.05$. All statistical analyses were performed with SPSS (version 21; IBM Corporation, Armonk, NY, USA). The values are presented as mean (*SD*).

RESULTS

Characteristics of the Control and Training Groups Throughout the Study

At the beginning of the study, the control and the training groups showed similar anthropometric characteristics and cardiometabolic response to maximal exercise (Table 1). Accordingly, no differences were observed in the HRR parameters at W0 between the control and the training groups (Table 2). Exercise training increased maximal power output and $\dot{V}O_2max$ in the training group, whereas no change was observed in the control group (Table 1).

Training-Induced Effects on Heart Rate Recovery

Several improvements in HRR parameters were apparent over 8 weeks of exercise training (Figure 2). These

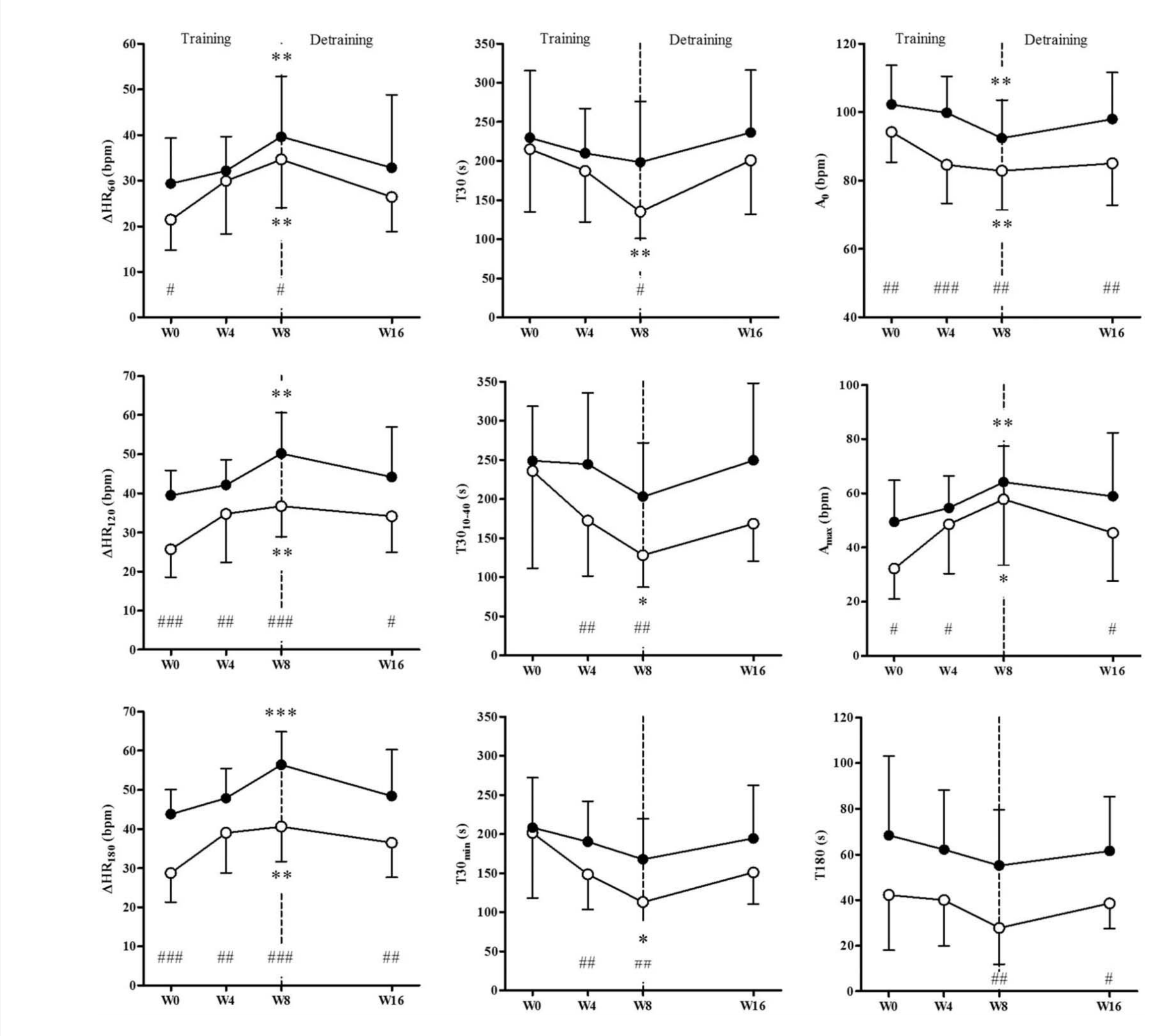

Figure 2. Evolution of the HRR variables with training (W0–W8) and detraining (W8–W16) after 6 minutes of exercise at 65 (○) and 80% (●) of the HR_{max}. ΔHR_{60}, ΔHR_{120}, and ΔHR_{180} are the measurements of absolute HRR ($b \cdot min^{-1}$) at 60, 120, and 180 seconds. T30, $T30_{10-40}$, and $T30_{min}$ are the measurements of fast HRR recovery (refer to the Methods section for mathematical calculations). A_0, A_{max}, and T180 are the parameters of the monoexponential decay function. Error bars represent *SD*. $^*p \leq 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$ (W0). $\#p \leq 0.05$, $\#\#p < 0.01$, $\#\#\#p < 0.001$ (65 and 80% HR_{max} at the same week). HRR = heart rate recovery; HR = heart rate.

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improvements reversed after 8 weeks of detraining (Figure 2). The HRR parameters in the control group were not affected by the 8-week period (see Table, Supplemental Digital Content 1, http://links.lww.com/JSCR/A94). Absolute HRR (ΔHR_{60}, ΔHR_{120}, and ΔHR_{180}) improved significantly in the training group at W8 and at both intensities (65 and 80% HR_{max}, Figure 2). The fast HRR kinetic parameters (T30, $T30_{10-40}$, and $T30_{min}$) improved during the training period, but differences were identified only at the lower exercise intensity (Figure 2). A tendency toward a significant effect of exercise training on fast HRR was observed after 80% HR_{max} exercise at W8, but the difference did not reach statistical significance ($p = 0.088$ for T30, $p = 0.086$ for $T30_{10-30}$, and $p = 0.073$ for $T30_{min}$). Two parameters, A_0 and A_{max}, of the monoexponential function fit the HR data during the 3-minute recovery periods and changed in response to aerobic training (Figure 2). Nevertheless, the time constant of the 3-minute recovery, T180, did not show significant changes ($p = 0.313$ at 65%; $p = 0.457$ at 80%).

Effect of Exercise Intensity on Heart Rate Recovery

The HRR test allows information on HRR to be obtained from 2 different exercise intensities (i.e., 65 and 80% HR_{max}). Before the training period, ΔHR_{120} and ΔHR_{180} were significantly higher at 80% than at 65% HR_{max} ($p < 0.01$, Figure 2). ΔHR_{60} was also significantly different between the 2 exercise intensities, but the magnitude of the effect was much smaller ($p < 0.01$, Figure 2) than in ΔHR_{120} and ΔHR_{180}. A_0 and A_{max}, calculated from the monoexponential function, also differed at the 2 exercise intensities, but the differences in A_0 were larger (Figure 2).

In response to training, the absolute HRR parameters, as well as A_0 and A_{max} from the monoexponential function, maintained a similar degree of difference between the 2 exercise intensities. It is noteworthy that the fast HRR analysis showed a clear dissociation from exercise at 65 and 80% HR_{max} in response to training ($p < 0.05–0.01$, Figure 2).

DISCUSSION

This study shows that changes in cardiac fitness in response to training and detraining can be measured by a novel easy-to-perform submaximal 18-minute HRR test. Several exercise protocols have been used to assess HRR in trained and sedentary subjects (2,3,13). In particular, the novel Lamberts and Lambert Submaximal Cycle Test test has shown good reliability and correlation between cycling performance and HRR parameters after submaximal power (14). However, in that study, HRR was measured only as the absolute HR recovered after a single exercise intensity.

This novel HRR test provides a wide array of information because HRR is determined at 2 exercise intensities. We found that some of the HRR parameters changed at both exercise intensities during the training and detraining periods, whereas other parameters changed only for the low-intensity exercise. This is especially the case for all the calculations performed on the fast component of HRR (<1 minute), where adaptations were evident only after the 65% HR_{max} HRR test. This finding is consistent across 3 different calculation methods (T30, $T30_{10-30}$, and $T30_{min}$), which rules out any artifact caused by a specific mathematical analysis. We previously reported that after 80% HR_{max}, HRR provides more reliable measurements than 65% HR_{max} (1). This is consistent with the findings reported by another group, which analyzed HRR from different exercise intensities to find that a workload of approximately 90% HR_{max} gives more reliable measurements than lower workloads (12). Nevertheless, exercise workloads of different intensities elicit varying degrees of cardiac nerves activity; sympathetic tone increases above 65% HR_{max}, which is concomitant with parasympathetic tone withdrawal (19). This can also be observed in the recovery phase. Higher intensity exercise requires both vagal reactivation and sympathetic tone withdrawal (16,18). It is important to note that the use of maximal exercise may limit the assessment of parasympathetic reactivation because the parasympathetic tone is blunted or even absent after maximal exercise (6). Thus, we maintain that early adaptations in parasympathetic reactivation can be better unmasked when the sympathetic tone is low, which highlights the importance of selecting low-intensity exercise to assess parasympathetic reactivation.

The proposed HRR test provides information for fast and prolonged HRR. The fast recovery phase from exercise (<1 minute) is regulated mainly by parasympathetic reactivation, and sympathetic tone withdrawal contributes more thereafter. Our analysis shows a highly significant change in several HRR parameters (absolute HRR and monoexponential decay) measured ≥1 minute. This highlights that the responsiveness of both sympathetic and parasympathetic activity adapts to aerobic exercise training and contributes to overall HRR. The A_0 and A_{max}, parameters of the monoexponential function improved, whereas T180 did not show significant changes. This is consistent with our previous study, where we found poor reliability for T180, which means that the training effect can be easily masked by wide variability in the measurement itself.

This novel HRR test can be easily performed with a minimal learning process. It is based on moderate intensity exercise, which makes it safer, avoids special requirements, confers good reliability (1), and produces results, which are easy to analyze. Given these characteristics, it will be interesting to assess its performance in other populations, where pathology, aging, or physical impairment may limit or impede the use of standard tests for cardiac and physical assessment.

Our study shows that the HRR test even monitors early adaptations in physical fitness, and that a combined analysis of HRR at 2 different exercise intensities (65 and 80% HR_{max}) provides further information on cardiac fitness. Considering the reduced costs, the high safety level, and the great utility of this testing protocol, we believe that the HRR test is a valuable tool to monitor changes in cardiac fitness in the general population.

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Practical Applications

In this article, we show that HRR parameters (ΔHR_{60}, ΔHR_{120}, ΔHR_{180}, T30, $T30_{10-40}$, $T30_{min}$, A_0, and A_{max}) determined by a simple submaximal test can be used to monitor adaptation and deadaptation to physical training. This test is easy to perform and does not require expensive material. Moreover, the data are reliable, easy to analyze, and provide information about HRR at 2 different exercise intensities. We consider this novel HRR test to be potentially very useful in the fields of sports science and physical fitness.

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