The Rating of Perceived Exertion at the Ventilatory Anaerobic Threshold in Patients with Coronary Heart Disease - Prescribing Implications for Exercise-Based Cardiovascular Rehabilitation: A CARE CR study

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Abstract

Background: Exercise prescription guidelines for patients undertaking cardiovascular rehabilitation (CR) are based on heart rate training zones and ratings of perceived exertion (RPE). In the UK, guidelines indicate that patients should exercise at an exercise intensity between RPE 11 to 14.

Objectives: We aimed to determine the accuracy of this approach by comparing this RPE range with an objectively measured marker of exercise intensity, the ventilatory anaerobic threshold (VAT), and examine whether baseline directly-determined cardiorespiratory fitness (CRF) influences the association between VAT and RPE.

Methods: A maximal cardiopulmonary exercise test was conducted prior to an 8-week community-based CR programme. Peak oxygen uptake (VO_{2peak}) and the VAT were recorded and the RPE at the workload in which VAT was identified was recorded. Data were then split in to tertiles, based on VO_{2peak}, to determine if RPE at the VAT was different in patients with low, moderate or higher CRF.

Results: Seventy patients [age 63.1 (10.0) years; BMI 29.4 (4.0) $kg·m^{-2}$; 86% male] were recruited. At baseline, the mean RPE at the VAT (RPE@VAT) was 11.8 (95% CI: 11-12.6). The RPE@VAT was significantly different in low and higher CRF groups ($P<0.001$). The mean RPE@VAT was 10.1 (8.7-11.5), 11.8 (10.5-13.0), and 13.7 (12.5-14.9) for the low, moderate and higher CRF groups, respectively.

Conclusions: When using RPE to guide exercise intensity in CR populations, it is important to consider the influence of baseline CRF. Mean RPEs of ~10, 12 and 14 correspond to the VAT in low, moderate and higher fit patients, respectively.

Word Count: 250

Key words: cardiac rehabilitation; exercise prescription; cardiorespiratory fitness; ventilatory anaerobic threshold; RPE.

Introduction

Cardiovascular rehabilitation (CR) is a multi-disciplinary intervention that typically includes an individualised exercise training programme, alongside educational support and psychological counselling. The "dose of exercise" received by the patient can be influenced by manipulating a number of factors including exercise frequency, duration of each session, type/mode of training, and probably the most challenging aspect of prescribing, the exercise intensity [1]. In the United Kingdom (UK), current exercise training guidelines issued by relevant professional bodies recommend exercise intensities between 40 to 70% heart rate reserve (HRR), or a rating of perceived exertion (RPE) interval 6-20 scale between 11 to 14 ("light" to "somewhat hard" using verbal anchors) [2-4].

There are two assumptions for this range: a) that these intensities will be at, or above the ventilatory anaerobic threshold (VAT), and b) for a new or physically inactive participant and/or higher risk participants it is safer and more psychologically tolerable to start a new exercise regime at lower intensities (40-50%), knowing they will work at a minimum level to gain some training benefit [5]. The strongest correlation between physiological responses and RPE was reported to be percentage of maximum oxygen uptake and respiration rate in healthy adults [6]. On this basis, the RPE 6-20 scale is chosen when simple inexpensive intensity monitoring tools are required to represent either a relative target heart rate (%HRR), peak oxygen consumption (VO_{2peak}), or the VAT [7-9]. The association between RPE and exercise intensity remains stable regardless of health status [10-13], and is sensitive to changes elicited through exercise training [10]. Thus, RPE is a reasonably sensitive perceptual marker which can be used to guide exercise prescription in patients with coronary heart disease (CHD).

Exercise training studies have identified that training at or above the VAT (or so-called VT_1) can induce physiological adaptation leading to improvements in cardiorespiratory fitness (CRF) and other cardiovascular risk factors [14, 15]. Recently we showed that in 112 patients with CHD, baseline CRF was an important factor for identifying where VAT occurs within exercise prescription guidelines (between 40 to 70% HRR) [16]. In patients classified as having lower CRF, determined from a treadmill-based cardiopulmonary exercise test (CPET), patients achieved their VAT between 26-49% of their HRR. However, in patients classified as having higher CRF, patients achieved their VAT between 52-78% HRR. We were therefore concerned that current exercise training recommendations for prescribing exercise intensities, based on a RPE range of 11 to 14, needed to be verified for the association between the lower and upper ends of the CRF/risk continuum, within a standard CR population. Thus, we aimed to determine the accuracy of the RPE threshold approach (range 11 to 14) for prescribing exercise intensity by comparing it with an objectively measured marker, the VAT, and determined whether baseline directly-determined CRF mediated this relationship.

Methods

Ethical approval was provided by the Yorkshire and Humber – Sheffield National (12/YH/0072) and Humber Bridge NHS (12/YH/0278) Research Ethics Committees. The methods for this study have previously been published [17]. Briefly, patients were recruited to the CARE CR study [17] following a referral to CR for angina, myocardial infarction (MI), coronary artery bypass graft (CABG), or percutaneous coronary intervention (PCI). Patients attended a baseline study assessment, where written informed consent was obtained. All available baseline data were included in this sub-study. CPET was conducted on a treadmill following the modified Bruce protocol [18], adopting previously outlined test termination and maximal effort criteria [19,20]. Directly determined HRR was calculated by subtracting resting heart rate (HR) from peak heart rate achieved during the CPET. Estimated HRR was calculated using the formula [3]:

((206 – (0.7 x age)) – resting heart rate (minus 30 if taking beta blockers)

Breath-by-breath metabolic gas exchange data were collected using Oxycon-Pro metabolic cart (Jaeger, Hoechburg, Germany), which was calibrated according to manufacturers' instructions and current recommendations [21]. Peak values were averaged over the final 30 seconds of the CPET. VO_{2peak} was reported in absolute values ($L \cdot min^{-1}$) and standardised to each patient's body mass ($ml \cdot kg^{-1} \cdot min^{-1}$). Individualised VAT was independently determined by two investigators (using a data smoothing technique incorporating the average of the middle five of every seven breaths), with ventilatory VCO_2/VO_2 plotted using the V-slope method, and verified using the ventilatory equivalents (VE/VCO_2 and VE/VO_2) [19, 22]. Where investigators reported different VAT values, a third reviewer was consulted and the VAT threshold value agreed by consensus. The VAT was expressed as a percentage of directly-determined and predicted VO_{2peak} [23].

We have previously reported where VAT occurred within the exercise training intensity guidelines [16]. Patients were sub-categorized based on equally distributed tertiles of baseline VO_{2peak}, and labelled as low, moderate, and high CRF categories. We reported VAT as a percentage of VO_{2peak}. Before the maximal CPET, patients were given a standardised explanation of the RPE scale. This included "anchoring" the bottom and top of the RPE sale. An RPE of 6 was explained as no exertion at all, such as sitting down and not taking part in any activity. An RPE of 20 was explained as feeling extreme shortness of breath, severe burning sensations in their muscles, as though they would have to terminate exercise imminently. Patients were asked to provide an RPE score at rest, in the last 10 seconds of each three minute stage throughout the CPET, and at peak exercise. The RPE value corresponding to the stage in which VAT occurred was noted at the RPE at VAT (RPE@VAT). When the VAT occurred in the first minute of a stage, the RPE from the final 10 seconds of the previous stage was noted as the RPE@VAT. RPE@VAT were reported for the entire patient cohort, and then according to CRF category.

Data analysis

We followed STROBE guidelines for the reporting of this study (Appendix A1) [24]. Statistical analysis was conducted using SPSS version 26 (IBM, NY, USA). Normality was vas visually assessed, and statistically assessed using the Shapiro-Wilk test. When data was not normally distributed, normalization of the distribution was attempted using $\log_{10}$ transformation. Logarithmically transformed data was analysed in its transformed state and reported as an arithmetic mean to allow for meaningful interpretation. Normally distributed and transformed data were analysed using a one-way analysis of variance (ANOVA) with a Bonferroni correction factor to identify between-group differences (between low, moderate and higher fit groups). We calculated Cohen's *d* effect sizes for RPE@VAT values in the low, moderate and higher fit groups [25]. Significance was set at an arbitrary level (P<0.05), and is presented as mean (95% confidence intervals) or (standard deviation). A power analysis was not conducted for this exploratory analysis of baseline data collected for the CARE CR study [26].

Results

Seventy patients [age 63.1 (10.0) years; BMI 29.4 (4.0) $kg \cdot m^{-2}$; 86% male; 98.6% White British] were recruited. Sixteen (23%) patients had sustained an ST-elevation myocardial infarction (STEMI), 22 (31%) had sustained a non-STEMI, and 19 (27%) had undergone elective PCI. Seven patients (10%) were medically managed for stable angina, and six (9%) had undergone CABG.

Table 1 shows baseline clinical and CPET characteristics for patients, separated by tertiles, according to CRF levels. In the low fit group, $\dot{V}O_{2peak}$ was 17.3 (2.7) $ml \cdot kg^{-1} \cdot min^{-1}$ (equivalent to ~5 metabolic equivalents [METs]), in the moderate fit group $\dot{V}O_{2peak}$ was 22.9 (2.7) $ml \cdot kg^{-1} \cdot min^{-1}$ (equivalent to ~6.5

METs), and in the high fit tertile VO_{2peak} was 30.0 (4.0) ml·kg^{-1}·min^{-1} (equivalent to ~8.5 METs). The low fit group were older, had higher N-terminal pro B-type natriuretic peptide (NT-pro BNP) levels, completed less exercise time on the treadmill, and had a lower VAT than the moderate and high fit groups (Table 1).

Respiratory exchange ratio (RER) at peak and HR values - indices of effort during maximal CPET - were lower in the low CRF group than in the moderate and high CRF groups, despite RPE being similar. The VAT occurred between 40-70% of predicted HRR in 36% of patients that were categorised as having a low CRF. 57% of patients achieved their VAT at <40% of their HRR. For higher-fit patients, VAT occurred between 40-70% of predicted HRR in 50% of patients, at <40% HRR in 20%, and >70% HRR for the remaining 30% of patients.

The RPE at the VAT (RPE@VAT) was 11.8 (11-12.6), for all patients. The mean RPE@VAT for patients in the low, moderate and higher fit groups was 10.1 (8.7-11.5), 11.8 (10.5-13.0) and 13.7 (12.5-14.9), respectively (Table 2).However, RPE@VAT was significantly different between low and higher fit groups (P<0.01; d = 1.183; large effect), and moderate to higher fit groups (P<0.01; d = 0.682; moderate effect; Figure 1 and 2). We noted that 37% of all patients achieved their RPE@VAT at an RPE <11, lower than the minimum RPE exercise training guidelines for cardiac patients. In low fit patients, 70% of patients had an RPE@VAT <11. We also found that 26% of all patients achieved their RPE@VAT at an RPE >14 which is higher than the maximal RPE exercise training guidelines for cardiac patients. In higher fit patients, this equated to 35% of patients.

Discussion

When CPET is unavailable, the British Association for Cardiovascular Prevention and Rehabilitation (BACPR) recommends that exercise prescription for patients undertaking CR is often guided by the HRR, RPE, and METs relationships found in a submaximal assessment of functional capacity. In this case, the exercise is guided by the estimated MET values that correspond to the zones of 40-70% HRR and/or RPE 11 to 14 (“light to somewhat hard”) [2,3]. We aimed to determine the accuracy of this approach by comparing this range with the VAT as an objective marker of exercise intensity and suggested as the minimum training stimulus needed to increase CRF [16]. We also determined whether the RPE at the VAT was different among people with a low, moderate and high CRF. Our findings indicate that there are clear differences where the RPE@VAT occurred based on baseline CRF levels. In the low fit group, the mean RPE@VAT was 10.1 (8.7-11.5), in the moderate fit group, the mean RPE@VAT was 11.8 (10.5-13.0), and in the higher fit group, the mean RPE@VAT was 13.7 (12.5-14.9). This equated to 37% of all patients achieving their RPE@VAT at an RPE <11 which is lower than the minimum RPE exercise training guidelines for cardiac patients. We also found that 26% of all patients achieved their RPE@VAT at an RPE >14 which is higher than the maximal RPE exercise training guidelines for cardiac patients. In higher fit patients, this equated to 35% of the population. These findings have important implications for exercise training guidelines in patients with CHD.

In the UK, patients are initially stratified for risk of a cardiac event during exercise and are placed in a category of low, moderate or high risk using the BACPR risk stratification criteria [27], or the equivalent American Association of Cardiovascular and Pulmonary Rehabilitation (AACVPR) risk criteria [28]. Whilst both these criteria are similar, differences between them do exist. For example, with the AACVPR criteria, patients are classified as low risk if they have a functional capacity ≥7 METs, and moderate risk if they have a functional capacity < 5 METs. In our study, our low fit group, had a mean (range) MET score of ~5 METs putting patients automatically at a moderate level of risk according to AACVPR criteria [28]. Based on this risk category, and data presented in our study, exercise professionals could prescribe a lower dose of exercise (for example, RPE 10-11), legitimately due to health and safety concerns, and have confidence that exercise was being prescribed at the VAT [16]. We acknowledge that some patients may be stratified into a moderate or high risk category due to other cardiac factors from the risk stratification criteria, however, our findings strengthen the requirement for baseline exercise capacity to be used as a guiding criteria for risk stratification in the UK, and internationally.

Based on our findings, low fit patients who are about to commence CR, could commence initial training intensity at an RPE threshold as low as 9 to 11 (very light to light), with exercise doses being up-titrated based on individual progress. Current UK guidelines would indicate that patients initiate exercise at a RPE threshold of 11 [3]. Conversely, in higher fit patients, current UK guidelines [3] of an RPE training threshold between 11 to 14 may be insufficient. Based on our findings, we recommend increasing the upper range of exercise prescription guidelines to an RPE 15 (hard) and in some cases beyond. This would provide greater scope for training progression in those patients that could tolerate it. It would also align UK exercise prescription guidelines closer to those seen internationally [22].

A valid and reproducible baseline oxygen uptake/ functional capacity value is key to stratifying patients based on baseline exercise testing. Thus, we strongly recommend that a baseline exercise test is conducted for each patient prior to commencing a CR programme. Patients should then be provided with an individualised exercise prescription based on factors including baseline functional capacity, relevant symptoms and perceived exertion responses. Current exercise prescription guidelines in the UK may be inappropriate for many patients with cardiovascular disease (CVD) -especially those classified as low fit or higher fit. We speculate that this may contribute to the 23% attrition rate recently reported in UK CR [29], as some patients exceed their training stimulus (i.e. low fit patients), which may be uncomfortable, whilst some do not reach it, thus providing minimal benefit (i.e. high fit patients), both of which may cause patients to discontinue CR.

Limitations and conclusions

The lower peak RER observed in the low fit group, compared with the moderate and high fit groups, may indicate that they did not exercise until the point of physical exhaustion. The lower peak HR observed in the low fit group may support this assertion, however it may also indicate chronotropic incompetence. Thus, the lower peak RER and peak HR, observed in the low fit group, could be due to a greater disease burden, preventing them from continuing to exercise to a greater physiological marker of physical exhaustion. This theory is supported by the high NT-proBNP and low haemoglobin values reported in the sub-group. The peak RPE values were similar in all sub-groups, suggesting that similar rates of exertion were achieved. It is also possible that patients in the low fit group overestimated the effort required to conduct any given workload, or that they were more sensitive to the perception of symptoms associated with exercise above the VAT, including increased respiration and muscle fatigue. Nonetheless, our findings indicate that individual baseline CRF level should be used to determine which intensity of exercise patients with CHD initiate their CR programmes, and could be used to support the risk stratification process.

Training at or above the VAT, often referred to as the first ventilatory threshold, indicates the point above which further increments in work rate are increasingly supplemented through anaerobic metabolism [19, 30]. Despite being associated with mild metabolic perturbations [30], regular exercise bouts conducted at work rates equivalent to VAT are well tolerated [31] and induce physiological adaptation, leading to improved CRF and improvements in other cardiovascular risk factors [14,15]. We found distinct differences in RPE responses at the VAT in patients with CHD during a maximal walking CPET. This equated to 37% of all patients who achieved their RPE@VAT at an RPE <11 which is lower than the minimum RPE exercise training guidelines for cardiac patients. We also found that 26% of all patients achieved their RPE@VAT at an RPE >14 which is higher than the maximal RPE exercise training guidelines for cardiac patients.

Declarations

Ethics approval and consent to participate

Ethical approval was provided by the Yorkshire and Humber – Sheffield National (12/YH/0072) and Humber Bridge NHS (12/YH/0278) Research Ethics Committees. All participants provided full written consent prior to study inclusion.

Consent for publication

Not applicable

Availability of data and material

A request for the data can be made directly to the corresponding author.

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Competing interests

The authors declare that there are no competing interests.

Author contributions

SN, SC and LI contributed to the design of the work. SN conducted data collection. SN, BE and LI conducted data analysis and drafted the manuscript. SN, BE, SC, JB and LI undertook data interpretation. SN, SC, LI and JB critically reviewed the manuscript. All gave final approval and agree to be accountable for all aspects of work ensuring integrity and accuracy.

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References:

1. ACSM. ACSM's Guidelines for Exercise Testing and Prescription. 9th ed. Baltimore: Lippincott, Williams, & Wilkins.; 2014.

2. Borg GA. Borg's Rating of Perceived Exertion and Pain Scales. Champaign, IL: Human Kinetics; 1998.

3. ACPICR. Standards for physical activity and exercise in the cardiovascular population. 3rd ed. Heather P, Helen B, Samantha B, John B, Laura Burgess, Keri G, et al., editors: Association of Chartered Physiotherapists in Cardiac Rehabilitation, 2015.

4. Mitchell B, Lock MJ, Davison K, et al. What is the effect of aerobic exercise intensity on cardiorespiratory fitness in those undergoing cardiac rehabilitation? A systematic review with meta-analysis. British J Sports Med 2019; 53:1341-1351.

5. Blumenthal JA, Rejeski WJ, Walsh-Riddle M, et al. Comparison of high- and low-intensity exercise training early after acute myocardial infarction, Am J Cardiol 1988; 1: 26-30.

6. Chen MJ, Fan X, Moe ST. Criterion-related validity of the Borg ratings of perceived exertion scale in healthy individuals: A meta-analysis. J Sports Sci 2002; 20: 873-99.

7. Green JM, Crews TR, Bosak AM, et al. Overall and differentiated ratings of perceived exertion at the respiratory compensation threshold: effects of gender and mode. Eur J Appl Physiol 2003;89: 445-450.

8. Green JM, McLester JR, Crews TR, et al. RPE association with lactate and heart rate during high-intensity interval cycling. Med Sci Sports Exerc 2006;38: 167172.

9. Hetzler RK, Seip RL, Boutcher SH, et al. Effect of exercise modality on ratings of perceived exertion at various lactate concentrations. Med Sci Sports Exerc 1991; 23: 8892.

10. Hill DW, Cureton KJ, Grisham SC, et al. Effect of training on the rating of perceived exertion at the ventilatory threshold. Eur J Appl Physiol 1987;56: 206-211.

11. Seip RL, Snead D, Pierce EF, et al. Perceptual responses and blood lactate concentration: Effect of training state. Med Sci Sports Exerc 1991; 23: 80-87.

12. Demello JJ, Cureton KJ, Boineau RE, et al. Ratings of perceived exertion at the lactate threshold in trained and untrained men and women. Med Sci Sports Exerc 1987;19: 354362.

13. Kunitomi M, Takahashi K, Wada J, et al. Re-evaluation of exercise prescription for Japanese type 2 diabetic patients by ventilatory threshold. Diabetes Res Clin Pr 2000; 50: 109-115.

14. Zheng H, Luo M, Shen Y, et al. Effects of 6 months exercise training on ventricular remodelling and autonomic tone in patients with acute myocardial infarction and percutaneous coronary intervention. J Rehabil Med 2008;40: 776-9.

15. Seki E, Watanabe Y, Shimada K, et al. Effects of a phase III cardiac rehabilitation programme on physical status and lipid profiles in elderly patients with coronary artery disease: Juntendo Cardiac Rehabilitation Programme (J-CARP). Circ J: Official J Japan Circ Soc 2008;72: 1230-4.

16. Pymer S, Nichols S, Prosser J, et al. Does exercise prescription based on estimated heart rate training zones exceed the ventilatory anaerobic threshold in patients with coronary heart disease undergoing usual-care cardiovascular rehabilitation? A United Kingdom perspective. Eur J Prev Cardiol 2019 22:2047487319852711.

17. Nichols S, Nation F, Goodman T, et al. CARE CR-Cardiovascular and cardiorespiratory Adaptations to Routine Exercise-based Cardiac Rehabilitation: a study protocol for a community-based controlled study with criterion methods, BMJ Open 2018;8:e019216.

18. Bruce RA, Kusumi F, Hosmer D. Maximal oxygen intake and nomographic assessment of functional aerobic impairment in cardiovascular disease. Am Heart J 1973;85:546-62.

19. Nichols S, Taylor C, Ingle L. A clinician's guide to cardiopulmonary exercise testing 2: test interpretation. Br J Hosp Med 2015;76:281-9.

20. American Thoracic Society. ATS/ACCP statement on cardiopulmonary exercise testing. Am J Respi Crit Care Med 2003;167:211.

21. Balady GJ, Arena R, Sietsema K, et al. Clinician's Guide to Cardiopulmonary Exercise Testing in Adults: A Scientific Statement From the American Heart Association. Circulation 2010;122:191-225.

22. Mezzani A, Agostoni P, Cohen-Solal A, et al. Standards for the use of cardiopulmonary exercise testing for the functional evaluation of cardiac patients: a report from the Exercise Physiology Section of the European Association for Cardiovascular Prevention and Rehabilitation. Eur J Cardio Prev Rehabil 2009;16:249-67.

23. Hansen J, Sue D, Wasserman K. Predicted values for clinical exercise testing. Am Rev Resp Dis 1984;129:S49-55.

24 Cohen, J. Statistical Power Analysis for the Behavioral Sciences. New York, NY: Routledge Academic, 1988.

25. von Elm E, Altman DG, Egger M, Pocock SJ, Gotzsche PC, Vandenbroucke JP. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement: guidelines for reporting observational studies, Lancet. 2007;370(9596):1453-1457.

26. Nichols S, Taylor C, Goodman T, et al., Routine exercise-based cardiac rehabilitation does not increase aerobic fitness: A CARE CR study. International Journal of Cardiology, 2020. 305: 25-34.

27. BACPR Standards and core components for cardiovascular disease prevention and Rehabilitation. Available from: http://www.bacpr.com (accessed: Jan 2020).

28. AACVPR Stratification Algorithm for Risk of an Event https://www.aacvpr.org/Portals/0/Registry/AACVPR%20Risk%20Stratification%20Algorithm_June2012.pdf (accessed Jan 2020).

29. Doherty P, Petre C, Onion N, et al. National Audit of Cardiac Rehabilitation (NACR): Annual Statistical Report 2017. 2018.

30. Mezzani A, Hamm LF, Jones AM, et al. Aerobic exercise intensity assessment and prescription in cardiac rehabilitation: A joint position statement of the European Association for Cardiovascular

Prevention and Rehabilitation, the American Association of Cardiovascular and Pulmonary Rehabilitation and the Canadian Association of Cardiac Rehabilitation. Eur J Prev Cardiol 2013; 20: 442–467.

31. Ekkekakis P, Hall EE and Petruzzello SJ. Practical markers of the transition from aerobic to anaerobic metabolism during exercise: Rationale and a case for affect based exercise prescription. Prev Med 2004; 38: 149–159.

Figure Legends

Figure 1. The mean rating of perceived exertion threshold (95% confidence intervals) where ventilatory anaerobic threshold occurs in patients with low, moderate and higher baseline cardiorespiratory fitness. Note the clear separation between low and higher fitness groups.

Figure 2. Panel A shows a scatterplot of individual ratings of perceived exertion at the ventilatory anaerobic threshold standardised to body mass. Panel B shows ratings of perceived exertion at the ventilatory anaerobic threshold as a percentage of peak oxygen uptake. Blue, red and yellow circles indicate patients in the lower, moderate, and higher fitness categories, respectively.