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ORIGINAL ARTICLE

Are fixed-rate step tests medically safe for assessing physical fitness?

Dominique Hansen · Nele Jacobs · Steven Bex · Goedele D'Haene · Paul Dendale · Neree Claes

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Abstract Maximal oxygen uptake (VO_{2max}) can be predicted by fixed-rate step tests. However, it remains to be analyzed as to what exercise intensities are reached during such tests to address medical safety. In this study, we compared the physiological response to a standardized fixed-rate step test with maximal cardiopulmonary exercise testing (CPET). One hundred and thirteen healthy adults executed a maximal CPET on bike, followed by a standardized fixed-rate step test 1 week later. During these tests, heart rate (HR) and VO_2 were monitored continuously. From the maximal CPET, the ventilatory threshold (VT) was calculated. Next, the physiological response between maximal CPET and step testing was compared. The step test intensity was 85 ± 24% CPET VO_{2max} and 88 ± 11% CPET HR_{max} (VO_{2max} and HR_{max} were significantly different between CPET and step testing; $p < 0.01$). In 41% of the subjects, step test exercise intensities >95% CPET VO_{2max} were noted. A greater step testing exercise intensity (%CPET VO_{2max}) was independently related to higher body mass index, and lower body height, exercise capacity ($p < 0.05$). Standardized fixed-rate step tests elicit vigorous exercise intensities, especially in small, obese, and/or physically deconditioned subjects. Medical supervision might therefore be required during these tests.

Keywords Exercise testing · Step test · Medical safety · Physical fitness

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D. Hansen (✉) · P. Dendale
Jessa Hospital/Heart Centre Hasselt, Rehabilitation and Health Centre, Stadsomvaart 11, Hasselt, Belgium
e-mail: Dominique.hansen@jessazh.be

D. Hansen · P. Dendale
Rehabilitation and Healthcare Research Centre, Department Healthcare, PHL-University College, Hasselt, Belgium

D. Hansen · N. Jacobs · S. Bex · G. D'Haene · P. Dendale · N. Claes
Faculty of Medicine, Hasselt University, Diepenbeek, Belgium

Introduction

It is established that regular physical activity and/or exercise training lowers chronic disease incidence and premature mortality risk in humans (Renehan and Howell 2005). As a result, the importance of exercise in the prevention of cancer, diabetes, and cardiovascular disease is acknowledged (Renehan and Howell 2005).

In order to provide adequate individual exercise prescription when aiming to increase physical activity, the physical fitness should be assessed. In this regard, maximal oxygen uptake (VO_{2max}), which is considered the gold standard surrogate for maximal exercise capacity, should be measured. Unfortunately, due to time investment, costs of equipment, and/or required technical skills, some (non-medical) healthcare professionals, institutes, and/or laboratories are unable to execute ergospirometry tests. As a result, these are in need of physical fitness tests with limited time investment, need for equipment, and technical skills.

Decades ago, fixed-rate step tests were introduced (McArdle et al. 2010). In these tests, the patient steps up and down a bench at a fixed rate for a few minutes. Next, the test duration as well as heart rate at the end of testing and during recovery is used to predict $VO_{2max.}$ These tests have been shown to provide an adequate prediction of VO_{2max} in individuals free from chronic disease (Siconolfi et al. 1985), and are easy to use (Petrella et al. 2001, 2003). However, what percentage of the actual VO_{2max} is reached during such fixed-rate step tests remains to be studied.

Previous studies have assessed VO_2 during stepping exercise, but did not compare this to VO_{2max} reached during cardiopulmonary exercise testing (Buckley et al. 2004; Jones et al. 1987; Olson et al. 1991; Richardson and Hardman 1989; Stanforth et al. 1993; Thomas et al. 1993). It might be argued that probably low-to-moderate exercise intensities (<75% VO_{2max}) are elicited during fixed-rate step testing (Noonan and Dean 2000), thereby diminishing the need for medical supervision. As a result, it is speculated that non-medical healthcare professionals could execute these tests in the absence of a physician. On the other hand, vigorous-intensity physical exercise (>75% VO_{2max}) significantly increases the risk for myocardial ischemia, malignant cardiac arrhythmias, acute myocardial infarction and, in rare occasions, sudden death, in individuals unaccustomed to physical exercise (Albert et al. 2000; Bartsch 1999; Thompson et al. 2007). As a result, clinical guidelines declare that medical supervision is required during exercise tests with (near) maximal effort (Myers et al. 2009). The elicited exercise intensity during step testing procedures therefore requires investigation.

In this study, we assessed the physiological response to a standardized fixed-rate step test in a large mixed population of healthy individuals, and compared this to the response to maximal cardiopulmonary exercise testing. We hypothesized that during step tests low-to-moderate exercise intensities (55–75% VO_{2max}) are elicited, indicating that these tests can be employed safely without medical supervision.

Table 1 Subject characteristics

	Mean ± SD	Range
General characteristics		
Gender (% male)	52	
Age (years)	45 ± 13	23–75
Body weight (kg)	71 ± 13	43–106
Body height (m)	1.72 ± 0.1	1.54–1.94
Body mass index (kg/m^2)	24 ± 3	16–34
Exercise capacity		
VO_{2max} (L/min)	2.6 ± 0.9	0.9–4.9
%predicted[a] VO_{2max}	114 ± 31	63–215
W_{max}	216 ± 78	90–400
HR_{max} (bpm)	172 ± 14	145–206
% predicted HR_{max}	98 ± 6	90–114
Ventilatory threshold (L/min)	1.6 ± 0.7	0.4–3.7
Ventilatory threshold/VO_{2max} ratio (%)	61 ± 11	38–84
Step test data		
Resting heart rate	89 ± 15	55–138
HR_{max} (bpm)	151 ± 20	108–197
% predicted HR_{max}	86 ± 12	58–116
HR recovery after 1 min (bpm)	108 ± 25	57–160
HR recovery after 2 min (bpm)	94 ± 21	46–152
HR recovery after 3 min (bpm)	89 ± 18	53–137
Test duration (sec)	283 ± 49	45–300
RPE Borg	13 ± 2	7–20
Physical activity[b]		
Total physical activity (kcal/week)	510 ± 351	0–1782
Moderate-intensity physical activity (kcal/week)	396 ± 289	0–1373
High-intensity physical activity (kcal/week)	119 ± 136	0–624

VO_{2max}, maximal oxygen uptake; W_{max}, maximal cycling power output; HR_{max}, maximal heart rate; RPE, ratings of perceived exertion

[a] Based on formulae from Fairbarn et al. (1994)

[b] Estimation based on IPAQ questionnaire

Materials and methods

Subjects

One hundred and thirteen (♂: 60, see Table 1) subjects, between age 23 and 75 years, were included in this study. These subjects were invited to participate in this study by local advertisement. All subjects were informed about the nature and risks of this study and provided written informed consent. The ethical committee for human research from Jessa Hospital approved the study protocol. Subjects were excluded from participation in the study in case of any acute and/or chronic disease, and/or orthopedic injury/dysfunction, and in case of heart rate-altering pharmacologic treatment. Subjects presenting myocardial ischaemia (ST segment depression >0.1 mV and/or angina pectoris) and/or severe ventricular arrhythmias during exercise testing were excluded.

Study design

Following inclusion, subjects filled out a physical activity questionnaire and performed a cardiopulmonary exercise test and step test on 2 separate days interspersed by a 1 week recovery. The cardiopulmonary exercise test was always executed first to assess myocardial function by ECG, followed by the step test. The same investigator performed all measurements at the same time of the day.

Measurements

Physical activity level

The International Physical Activity Questionnaire (Craig et al. 2003) was used to assess time engaged in moderate- and high-intensity physical activity in the last month before this study. Cut-off limits for exercise intensity (moderate vs. high intensity) were based on the ventilatory response during exercise. If the subject was able to talk during exercise without experiencing dyspnea, such exercise was considered as moderate intense. If the subject was no longer able to talk during exercise without experiencing dyspnea, such exercise was considered as high intense. Mean caloric expenditure was calculated by the sum of total physical activity duration, and correct this for body weight and applied exercise intensity.

Cardiopulmonary exercise capacity

All subjects performed a maximal incremental 1 min stage cardiopulmonary cyclo ergometer exercise test (CPET) (Buchfuhrer et al. 1983). Subjects were stimulated to achieve maximal exertion, and subjective symptoms (general/muscle fatigue, dyspnea) were primarily used to consider their effort (Poole et al. 2008). Secondary, objective criteria were then used to assess whether maximal exercise effort during exercise testing was achieved: respiratory exchange ratio >1.10 and/or heart rate >90% of maximal predicted value. During the cyclo ergometer test, an electronically braked Ergo 1,500 cycle (ErgoFit®, Pirmasens, Germany) was used. The cycling frequency was set at 70 rpm and the test was ended when the subject failed to maintain a cycling frequency of at least 60 rpm (Fletcher et al. 2001). At the morning of every test day, an automatic gas (software program of the ergospirometry device automatically tested the atmospheric air for oxygen, nitrogen, and carbon dioxide content, and a certified mix of gases) and manual volume calibration (with 2 L syringe) was performed. During the exercise tests, pulmonary gas exchange analysis was performed by a cardiopulmonary ergospirometry device (Schiller CS200®, Schiller AG, Switzerland). Oxygen uptake (VO_2) and carbon dioxide output (VCO_2) were collected breath-by-breath and averaged every 10 s. Predicted VO_{2max} was calculated from age, gender, height, and weight (Fairbarn et al. 1994), and compared to the actually achieved VO_{2max} (expressed in % predicted VO_{2max}). Ventilatory threshold (VT) was calculated by V-slope method (Beaver et al. 1986), and curves were carefully reviewed by the investigators, as executed in previous studies by our laboratory (Hansen et al. 2007). Using a 12-lead ECG device, heart rate (HR) was monitored and averaged every 10 s. Maximal cycling power output (W_{max}) was reported.

Step test

The step test was modified from earlier procedures (Petrella et al. 2003). The step test consisted of stepping up and down a platform at a rate controlled by a metronome (90 beats/min, corresponding to 22.5 steps/min). Each beat initiates the movement of one leg up or down the platform. The stepping period lasted for 5 min. The height of the platform was determined according to patients' body height. For individuals up to 170 cm a platform of 33 cm was used. For individuals with a body height above 170 cm a platform of 40 cm was used. The stepping rate and bench height was comparable to those used in previous studies. The heart rate was continuously monitored by a commercially available ambulatory system (Polar, Oy, Finland). The heart rate was recorded immediately after step testing, and in sitting position between 1 and 1:30 min after completing the step test, between 2 and 2:30 min, between 3 and 3:30 min. In addition to heart monitoring, pulmonary gas exchange analysis was performed during the step test by a cardiopulmonary ergospirometry device (Schiller CS200®, Schiller AG, Switzerland). On the morning of every test day, an automatic gas and volume calibration was performed (with similar methodology as mentioned in the section of 'cardiopulmonary exercise capacity'). Oxygen uptake (VO_2) was collected breath-by-breath and averaged every 10 s. VO_2 was measured and averaged during the final min during step testing. From this measurement, the step testing exercise intensity was calculated and expressed in percentages (%CPET VO_{2max}) = (VO_2 step test/VO_{2max} CPET) × 100. At the end of the step test, ratings of perceived exertion were immediately scored by a 20-point Borg scale.

Statistical analysis

Data are expressed as means ± SD. Statistical significance was set at $p < 0.05$ (2-sided). We compared the maximal physiological response (HR and VO_2) between CPET and step test by paired sample t tests. Step test exercise intensity was compared between genders by one-way ANOVA. Univariate correlations were calculated between step testing exercise intensity (%CPET VO_{2max}) and subject characteristics (age, body mass index, exercise capacity, body height, ratings of perceived exertion, and self-reported physical activity). Multivariate regression analysis was executed to examine the relationship between %CPET VO_{2max} (independent variable) and age, gender, body height, body mass index, VO_{2max}, VT, and high-intensity physical activity (dependent variables). These dependent variables were selected based on their significant univariate correlations with %CPET VO_{2max}. All calculations were performed using the Statistical Package for the Social Sciences, version 15.0.

Results

Subjects

Middle-aged (45 ± 13 years), physically active, normal-weight (body mass index of 24 ± 3 kg/m^2) subjects were included, with a large range for these parameters (see Table 1). None of the subjects developed myocardial ischaemia and/or severe ventricular arrhythmias during exercise testing on bike.

Physiological response to CPET and step test

Based on CPET VO_{2max} (114 ± 31% of predicted value), the subjects had a normal maximal exercise capacity (see Table 1). In extent, VT occurred at 61 ± 11% of the CPET VO_{2max}, which is considered normal. Subjects reached 98 ± 6% of their maximal predicted HR, indicating that subjects cycled until exhaustion during CPET.

As result of the fixed-rate step test, HR rose from 89 ± 15 bpm at rest up to 151 ± 20 bpm (see Table 1). Of the subjects, 12% did not achieve the total step test time (5 min) because of physical exhaustion. Subjects scored an average RPE Borg of 13 ± 2 immediately after the step test.

Comparison between CPET and step test

The step test VO_2 (2.0 ± 0.6 L/min, 28.7 ± 5.5 mL/kg/min) was significantly lower when compared to CPET VO_{2max} (2.6 ± 0.9 L/min, 36.4 ± 11.7 mL/kg/min) ($p < 0.01$) (see Fig. 1). The step test VO_2 was on average 85 ± 24% of CPET VO_{2max} and 88 ± 11% of CPET HR_{max}. In 41 and 67% of the subjects, step test exercise intensities >95 and >75% CPET VO_{2max}, respectively, were noted.

Univariate correlations

A significant univariate correlation was found between step test VO_2 and CPET VO_{2max} ($r = 0.54$, $p < 0.01$). A greater step testing exercise intensity (%CPET VO_{2max}) was significantly related to higher age and body mass index, and lower body height, total and high-intensity physical activity, VT, and VO_{2max} ($p < 0.05$) (see Table 2). A significant correlation was found between step test exercise intensity

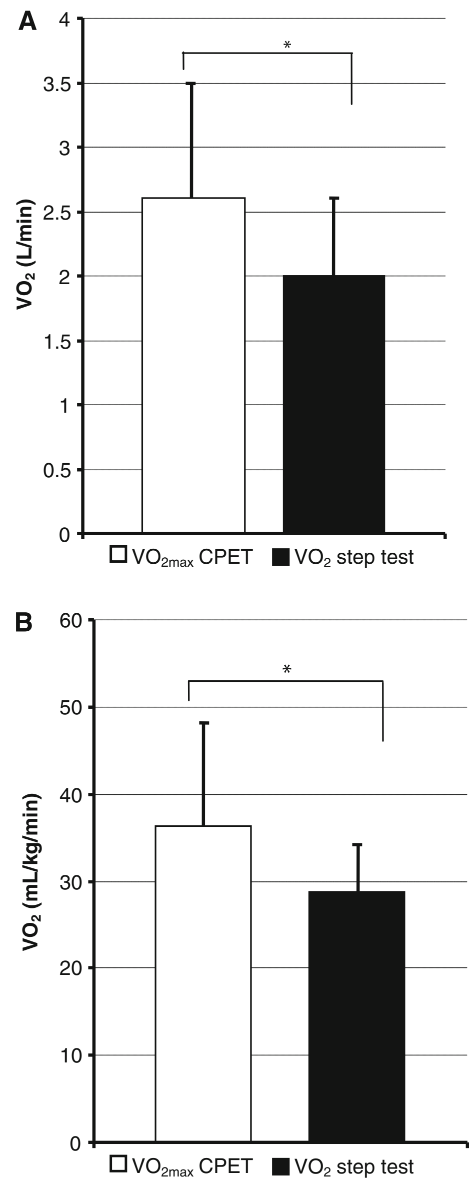

Fig. 1 Physiological response to maximal cardiopulmonary exercise test and step test. **a** VO_2 expressed in absolute values. **b** VO_2 corrected for body weight. *Significantly different between tests ($p < 0.05$). VO_2, oxygen uptake; *CPET* cardiopulmonary exercise test

and RPE Borg ($p < 0.01$). In addition, step testing exercise intensity was significantly different between males and females (79 ± 24 vs. 91 ± 21% CPET VO_{2max}, respectively; $p < 0.01$).

Multivariate regression analysis

A greater step testing exercise intensity (%CPET VO_{2max}) was significantly and independently related to higher body mass index, and lower body height, VT, VO_{2max} ($p < 0.05$). Age, gender, and high-intensity physical

Table 2 Univariate correlations between step test exercise intensity (%CPET VO_{2max}) and subject characteristics

	Step test exercise intensity (%CPET VO_{2max})	
	r	p value
Age	0.22	0.02
Body height	−0.26	<0.01
Body weight	0.09	0.36
Body mass index	0.31	<0.01
VO_{2max}	−0.67	<0.01
W_{max}	−0.64	<0.01
Ventilatory threshold	−0.64	<0.01
Total physical activity	−0.25	0.01
Moderate-intensity physical activity	−0.11	0.28
High-intensity physical activity	−0.37	<0.01
RPE Borg during step test	0.59	<0.01

VO_{2max}, maximal oxygen uptake; W_{max}, maximal cycling power output; RPE, ratings of perceived exertion

activity were no longer significantly related to %CPET VO_{2max}.

Discussion

In this study, we examined the physiological response to a standardized fixed-rate step test in a mixed population of healthy individuals, and compared this to the response from maximal cardiopulmonary exercise testing (CPET). By doing so, we examined whether these tests can be employed safely in healthy adults (low risk for adverse cardiovascular events). From this study, two important findings emerged. First, standardized fixed-rate step tests elicit vigorous exercise intensities. Second, greater step test intensities were noted in small, obese, and/or physically deconditioned subjects.

Vigorous exercise intensities were elicited during standardized fixed-rate step tests: the step test exercise intensity was on average ~85% of CPET maximal oxygen uptake (VO_{2max}). Moreover, in 41 and 67% of the subjects, step test exercise intensities >95 and >75% CPET VO_{2max}, respectively, were noted. These results are in clear contrast with the widely upheld belief that fixed-rate step tests elicit exercise intensities up to maximally ~75% of VO_{2max}.(Noonan and Dean 2000) Hence, it is therefore assumed that medical supervision is not required during these exercise tests. Based on these assumptions, fixed-rate step tests are currently mainly executed by non-medical personnel, or in physician offices without medical supervision. On the other hand, vigorous-intensity physical exercise (>75% VO_{2max}) significantly increases the risk for acute myocardial infarction and, in rare occasions, sudden death, in individuals unaccustomed to physical exercise (Albert et al. 2000; Bartsch 1999). This might be related to acute platelet activation and aggregation, increased formation of thrombin and fibrin, augmentation of blood catecholamine concentrations, increased endothelial shear stress triggering fissure or rupture of plaques (Bartsch 1999; Cadroy et al. 2002; Hilberg et al. 2008; Ikarugi et al. 2003). In case of coronary artery disease patients, the risk for acute myocardial infarction and/or malignant ventricular arrhythmias could be related to an insufficient coronary blood supply during increased myocardial work (Thompson et al. 2007). According to our results, 67% of the subjects achieved exercise intensities above this threshold during step testing. Clinical guidelines declare that medical supervision is required during exercise tests with such intensities (Myers et al. 2009).

Even though there might be an increased relative risk for adverse cardiovascular events during step testing, the absolute risk might be low. The combined morbidity and mortality rate during maximal cardiopulmonary exercise testing is about 0.2% (Myers et al. 2009). Statistics about the morbidity and mortality rate during step testing are, to our knowledge, absent.

Because vigorous exercise intensities were elicited during step testing, test methodology modifications might be required to lower physical exertion. For this purpose, it might be suggested to lower step height (even though we already adjusted step height according to body height in our study), slow stepping rate, and/or allow the subject to self-select the stepping rate (Olson et al. 1991; Petrella et al. 2001; Stanforth et al. 1993; Thomas et al. 1993). In this regard, further study indeed noted lower cardiovascular/physiological responses during stepping activity when lowering stepping rate/height (Buckley et al. 2004; Olson et al. 1991; Petrella et al. 2001; Stanforth et al. 1993).

Even though previous investigations have examined the validity, reproducibility, and applicability of step tests for the estimation of VO_{2max} (Siconolfi et al. 1985; Petrella et al. 2001, 2003), and other studies have assessed VO_2 during step testing/stepping exercise (Buckley et al. 2004; Jones et al. 1987; Olson et al. 1991; Richardson and Hardman 1989; Stanforth et al. 1993; Thomas et al. 1993), the elicited relative exercise intensity (%CPET VO_{2max}) during these tests remained to be shown. As a result, we were not able to contrast our findings with those from previous studies.

Greater step test exercise intensities (%CPET VO_{2max}) were achieved in small, obese, and/or physically deconditioned subjects. Consequently, in subjects with these characteristics, the medical safety of fixed-rate step testing might be questioned further. Thomas et al. (1993) noted correlations between age, leg length, aerobic fitness, and

VO_2 during stepping in 121 individuals. Stanforth et al. (1993) revealed in 28 females that a decreased leg length and/or increased fat-free mass increased VO_2 during stepping activity. Jones et al. (1987) found a significant correlation between step test VO_2 and body weight, height in 53 participants. On the other hand, Buckley et al. (2004) failed to observe correlations between subject characteristics and stepping activity VO_2, except for body height, in 13 subjects.

It should be mentioned that during step testing one leg is tested more vigorously (the leg that steps up) as opposed to the other leg (the leg that follows the step-up). Such difference in exercise intensity between legs is not present during exercise testing on bike. It follows that when severe differences in muscle strength and/or endurance are present between the legs (for example as result of unilateral knee prosthesis, neurologic disease), the outcome between step testing and testing on bike could be different. In the present study, subjects with lower extremity disease/anomalies were excluded.

From this study, an important clinical implication might emerge. When executing fixed-rate step tests to estimate VO_{2max}, medical supervision (or immediate physician presence) seems required to optimize patient safety. This seems especially the case in small, obese, and/or physically deconditioned subjects. Moreover, it might be suggested to execute continuous ECG monitoring during step testing, in order to detect malignant cardiac arrhythmias and/or myocardial ischemic responses. Because of the lack of a gradual workload increase, such complications might be prevalent. Since medical supervision, and assessment of medical safety (such as ECG monitoring), seems warranted during step testing, it might be argued that these tests can no longer be regarded as easy and inexpensive.

This study might be limited by the lack of measurements of physiological parameters directly addressing adverse cardiovascular event risk (platelet activation and aggregation, blood pressure, and/or blood catecholamine concentrations) during step testing. Therefore, further study might be required to assess these parameters during fixed-rate step testing. Moreover, we used a questionnaire to assess physical activity, as well as the intensity of physical activity. It might be more accurate to use objective physical activity assessment instruments (heart rate monitoring, accelerometry).

In conclusion, standardized fixed-rate step tests elicited vigorous exercise intensities in healthy individuals, especially in small, obese, and/or physically deconditioned subjects. Therefore, medical supervision during step testing seems required.

Ethical standards. The experiments comply with the current laws of the country in which they were performed.

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Conflict of interest The authors declare that they have no conflict of interest.

References

Albert CM, Mittleman MA, Chae CU, Lee IM, Hennekens CH, Manson JE (2000) Triggering of sudden death from cardiac causes by vigorous exertion. N Engl J Med 343:1355–1361

Bartsch P (1999) Platelet activation with exercise and risk of cardiac events. Lancet 354:1747–1748

Beaver WL, Wasserman K, Whipp BJ (1986) A new method for detecting anaerobic threshold by gas exchange. J Appl Physiol 60:2020–2027

Buchfuhrer MJ, Hansen JE, Robinson TE, Sue DY, Wasserman K, Whipp BJ (1983) Optimizing the exercise protocol for cardiopulmonary assessment. J Appl Physiol 55:1558–1564

Buckley JP, Sim J, Eston RG, Hession R, Fox R (2004) Reliability and validity of measures taken during the Chester step test to predict aerobic power and to prescribe aerobic exercise. Br J Sports Med 38:197–205

Cadroy Y, Pillard F, Sakariassen KS, Thalamas C, Boneu B, Riviere D (2002) Strenuous but not moderate exercise increases the thrombotic tendency in healthy sedentary male volunteers. J Appl Physiol 93:829–833

Craig CL, Marshall AL, Sjöström M, Bauman AE, Booth ML, Ainsworth BE, Pratt M, Ekelund U, Yngve A, Sallis JF, Oja P (2003) International physical activity questionnaire: 12-country reliability and validity. Med Sci Sports Exerc 35:1381–1395

Fairbarn MS, Blackie SP, McElvaney NG, Wiggs BR, Paré PD, Pardy RL (1994) Prediction of heart rate and oxygen uptake during incremental and maximal exercise in healthy adults. Chest 105:1365–1369

Fletcher GF, Balady GJ, Amsterdam EA, Chaitman B, Eckel R, Fleg J, Froelicher VF, Leon AS, Piña IL, Rodney R, Simons-Morton DA, Williams MA, Bazzarre T (2001) Exercise standards for testing and training: a statement for healthcare professionals from the American Heart Association. Circulation 104:1694–1740

Hansen D, Dendale P, Berger J, Meeusen R (2007) Low agreement of ventilatory threshold between training modes in cardiac patients. Eur J Appl Physiol 101:547–554

Hilberg T, Menzel K, Glaser D, Zimmermann S, Gabriel HH (2008) Exercise intensity: platelet function and platelet-leukocyte conjugate formation in untrained subjects. Thromb Res 122:77–84

Ikarugi H, Shibata M, Shibata S, Ishii H, Taka T, Yamamoto J (2003) High intensity exercise enhances platelet reactivity to shear stress and coagulation during and after exercise. Pathophysiol Haemost Thromb 33:127–133

Jones PW, Wakefield JM, Kontaki E (1987) A simple and portable paced step test for reproducible measurements of ventilation and oxygen consumption during exercise. Thorax 42:136–143

McArdle WD, Katch FI, Katch VL (2010) Individual differences and measurement of energy capacities. Exercise physiology, 7th edn. Lippincott Williams & Wilkins, Philadelphia, pp 225–247

Myers J, Arena R, Franklin B, Pina I, Kraus WE, McInnis K, Balady GJ (2009) Recommendations for clinical exercise laboratories. A scientific statement from the American Heart Association. Circulation 119:3144–3161

Noonan V, Dean E (2000) Submaximal exercise testing: clinical application and interpretation. Phys Ther 80:782–807

Olson MS, Williford HN, Blessing DL, Greathouse R (1991) The cardiovascular and metabolic effects of bench stepping exercise in females. Med Sci Sports Exerc 23:1311–1317

Petrella RJ, Koval JJ, Cunningham DA, Paterson DH (2001) A self-paced step test to predict aerobic fitness in older adults in the primary care clinic. J Am Geriatr Soc 49:632–638

Petrella RJ, Koval JJ, Cunningham DA, Paterson DH (2003) Can primary care doctors prescribe exercise to improve fitness? The step test exercise prescription (STEP) project. Am J Prev Med 24:316–322

Poole DC, Wilkerson DP, Jones AM (2008) Validity of criteria for establishing maximal O_2 uptake during ramp exercise tests. Eur J Appl Physiol 102:403–410

Renehan AG, Howell A (2005) Preventing cancer, cardiovascular disease, and diabetes. Lancet 365:1449–1451

Richardson S, Hardman AE (1989) Endurance fitness and blood lactate concentration during stepping exercise in untrained subjects. Br J Sports Med 23:190–193

Siconolfi SF, Garber CE, Lasater TM, Carleton RA (1985) A simple, valid step test for estimating maximal oxygen uptake in epidemiologic studies. Am J Epidemiol 121:382–390

Stanforth D, Stanforth PR, Velasquez KS (1993) Aerobic requirement of bench stepping. Int J Sports Med 14:129–133

Thomas SC, Weller IM, Cox MH (1993) Sources of variation in oxygen consumption during a stepping task. Med Sci Sports Exerc 25:139–144

Thompson PD, Franklin BA, Balady GJ, Blair SN, Corrado D, Estes NA 3rd, Fulton JE, Gordon NF, Haskell WL, Link MS, Maron BJ, Mittleman MA, Pelliccia A, Wenger NK, Willich SN, Costa F (2007) Exercise and acute cardiovascular events placing the risks into perspective: a scientific statement from the American Heart Association Council on Nutrition, Physical Activity, and Metabolism and the Council on Clinical Cardiology. Circulation 115:2358–2368