The validity of predicting VO_{2max} from RPE values elicited during PRET in endurance trained athletes

BY

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We hereby recommend that the Honours Project by Mr. WU CHEUK HO entitled “The validity of predicting maximal oxygen uptake (VO_{2max}) from RPE values elicited during the perceptually regulated graded exercise test (PRET) in endurance trained athletes” be accepted in partial fulfillment of the requirements for the Bachelor of Arts Honours Degree in Physical Education And Recreation Management.

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Chief Adviser	Second Reader

DECLARATION

I hereby declare that this honours project “The validity of predicting maximal oxygen uptake (VO_{2max}) from RPE values elicited during the perceptually regulated graded exercise test(PRET) in endurance trained athletes” represents my own work and had not been previously submitted to this or other institution for a degree, diploma or other qualification. Citations from the other authors were listed in the references.

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WU CHEUK HO

23rd April, 2010

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ABSTRACT

A new application of using RPE value from the perceptually regulated graded exercise test (PRET) to predict maximal oxygen uptake has been advocated since 2005. However, no previous study has been done in endurance trained athletes. The purpose of this study was to examine the validity of predicting VO_{2max} from RPE values elicited during the PRET in endurance trained athletes. Nine endurance trained athletes (N=9) from Hong Kong Baptist University participated in the study. Subjects were asked to perform a graded exercise test to establish VO_{2max} and two trails of PRETs. The mean of predicted VO_{2max} in Trail 1 and Trail 2 was 52.41±10.82 and 51.38±9.06 respectively. And mean actual VO_{2max} was 55.77±9.50. The Intra-class reliability between Trail 1 and 2 was significant (R= 0.972).Pearson correlation analysis found that there was a significant positive relationship between the predicted VO_{2max} and actual VO_{2max} ($r=0.855$, $p<0.01$). Results suggested that a sub-maximal PRET provides acceptable prediction of VO_{2max} in endurance trained athletes.

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INTRODUCTION

Cardio-respiratory (CR) fitness was referred to the ability to perform large muscle, dynamic, moderate-to-high intensity exercise for a prolonged period. Such exercise performance was depended on the respiratory, cardiovascular, and skeletal muscle systems (American College of Sports Medicine, 2006). Cardio-respiratory fitness improvement was associated with many health benefits and a reduction in all causes of death (ACSM, 2006). Therefore, cardio-respiratory fitness assessment was important for individuals to monitor their fitness and health status.

The criterion of measuring cardio-respiratory fitness was the maximal oxygen uptake (VO_{2max}). It is the product of the maximal cardiac output and arterial-venous difference (ACSM, 2006). VO_{2max} can be measured from the performance during a maximal graded exercise test (GXT).

The most standard means of measuring one's cardio respiratory fitness and maximal capacity for exercise was from direct measurement of maximal oxygen uptake (VO_{2max}). However, the expensive equipment, the necessary space, time constraints and trained personnel were needed to administer the test. Besides, the high intensity maximal graded exercise test (GXT) might not be suitable for those low fit or clinical population because the test required the subjects to exercise to the point of volitional exhaustion. As a result, without medical supervision, high-risk individuals should not perform the test (ACSM, 2006).

The above difficulties in measuring maximal oxygen uptake (VO_{2max}) had encouraged exercise researchers to develop some sub-maximal tests aiming at predicting maximal oxygen uptake. These tests were more convenient, easier for subjects to perform and less effort to administer.

In recent years, the application of ratings of perceived exertion (RPE) scales in exercise testing and prescription had been widely used. The 6–20 RPE Scale (Borg, 1998) was well established as the most commonly used indicator for monitoring an individual's exercise tolerance (ACSM, 2006). In an aerobic test, a subject was usually asked to rate his or her overall RPE towards the end of each workload. Thus, apart from the use of objective physiological markers of exercise response, RPE scale was also used to assist the prescription of exercise intensity (Davies, Rowland & Eston, 2008). Previous studies had been done to extrapolate the sub-maximal VO_2 responses to a theoretical maximal RPE of 20 to predict VO_{2max} (Eston, Lamb, Parfitt & King, 2005; Eston, Lambrick, Sheppard & Parfitt, 2008; Faulkner, Parfitt & Eston, 2007a).

Statement of Problem

As previous studies demonstrated that there were strong individual linear relationships between Borg 6-20 RPE scale and oxygen uptake, the tests seemed to be well established and validated in different population. But, no previous study has been done in endurance trained athletes. The purpose of this study was to examine the validity of predicting VO_{2max} from RPE values elicited during the perceptually-regulated graded exercise in endurance trained athletes of Hong Kong. According to the existing researches, we hypothesized that a strong relationship between RPE and VO_{2max} would result in acceptable estimation of VO_{2max}.

Significant of Study

Previous studies in foreign country had successfully demonstrated the validity and the reliability of using sub-maximal level RPE to predict the maximal oxygen uptake. However, the generalization of this study was still in question. Thus, the purpose of this study aimed at providing

a valid, safe and convenient method for Hong Kong Baptist University athletes to determine their VO_{2max} in convenience.

Moreover, this study hoped to apply in clinical population in Hong Kong, because this sub-maximal test might provide a safe and practical method of assessing the aerobic fitness for people who are low-fit, or likely to be limited by fatigue and pain.

Chapter 2

REVIEW OF LITERATURE

This review of literature was divided into five sections: (1) the importance of aerobic fitness, (2) direct measurement of aerobic fitness, (3) indirect measurement of aerobic fitness, (4) non-exercise methods of measuring aerobic fitness, (5) relationship between RPE and VO_{2max} and (6) summary.

The Importance of Aerobic Fitness

Aerobic Fitness was our ability to take in and use oxygen to produce energy (ACSM, 2003). Regular aerobic exercise increased our physical fitness, and regular, low intensity aerobic exercise could also increase our ability to use oxygen, which was commonly referred to as the maximal oxygen consumption or aerobic capacity (ACSM, 2003). Thus, a person with a better aerobic fitness necessarily had better function in cardio-respiratory system (cardio-respiratory fitness).

Reductions in all cause and cardio-vascular diseases mortality rates was associated with Cardio-respiratory fitness (Blair et al., 1989). Lots of researches indicated that high levels of aerobic fitness and regular pattern of aerobic activity could be a useful method to prevent and tackle cardio-vascular diseases (Jennings et al., 1986; Wei et al., 1999).

A meta-analysis (Whelton, Chin, Xin & He, 2002) found that blood pressure in those normotensive and hypertensive persons could be reduced through regular aerobic exercise. Besides, Cornelissen and Fagard (2005) added that vascular resistance could also be reduced through aerobic endurance training, then result in a reduction in blood pressure, in which the renin-angiotensin system and the sympathetic nervous system occurred to be involved, and it would have favorable effects to cardiovascular risk factors. Therefore, regular aerobic exercise should be considered as a crucial component of our life for the treatment and prevention of hypertension.

Apart from high blood pressure in adults, research examined the beneficial effects of aerobic exercise in children (Hager, Tucker & Seljaas, 2004). The researchers found that higher total cholesterol, higher density lipoprotein cholesterol (LDL), triglyceride levels and lower high density lipoprotein cholesterol (HDL) levels were found in unfit children. It showed that aerobic fitness and physical activity are related to blood lipids in children as a function of body fat variation.

Last but not least, Colcombe et al., (2003) found that apart from cardiovascular health, the advantage of aerobic fitness was also related to brain health. The researchers suggested that aerobic fitness had a function to reduce loss in brain tissue in the elderly. A strong biological basis was advocated for the advantages of aerobic exercise on brain health in the elderly.

Direct Measurement of Aerobic Fitness

The 4 main parameters of aerobic function were aerobic power or maximal oxygen uptake (VO_{2max}), exercise economy, oxygen uptake kinetics, and the lactate/ ventilatory threshold (Jones & Carter, 2000). Maximal oxygen uptake (VO_{2max}) was generally accepted as the standard measurement of cardio respiratory fitness (ACSM, 2006). It was an important parameter because it reflected the upper limit of aerobic exercise tolerance. It was especially important in endurance exercise.

According to equations based on Fick principle, the body oxygen uptake could be determined from cardiovascular or respiratory measurements (Davis, 2006). Because the determinants of VO_2 were the heart and the mechanical properties of our lungs, so, a person with a high VO_{2max} would necessarily have a good function in cardio respiratory system.

Direct measurement of VO_{2max} could obtain the most accurate data. Graded exercise test (GXT) on a motor-driven treadmill and cycle ergometer were the most common methods. There were lots of maximal exercise test protocols had been developed to assess aerobic capacity, the testing protocols could be continuous, or discontinuous depending on the purpose of research. The time of graded exercise test should be designed between 8-12 minutes in that way the highest VO_{2max} value could be found (Davis, 2006). The most commonly accepted criterion of obtaining VO_{2max} from graded exercise test was a plateau in VO_2 as the work rate continues to increase. Other criteria were also able to define the achievement of VO_{2max} (ACSM, 2006), including heart rate at test termination >90% of age-predicted maximum HR, or the plateau of HR, respiratory exchange ratio (RER) greater than 1.15, RPE greater than 17 on the Borg scale (6-20), and blood lactate concentration exceeding 8 mmol/L in first 5 minutes of recovery.

Indirect Measurement of Aerobic Fitness

The need for expensive equipment, time and motivation or fitness level of subjects to measure maximal oxygen uptake (VO_{2max}) had aroused the interest of exercise scientists to develop a range of sub-maximal tests aiming to predict VO_{2max}.

Sub-maximal test was similar to maximal exercise test but it was terminated at some predetermined HR intensity. It assumed a steady state HR at each exercise intensity, and a linear relationship between HR, oxygen uptake and working intensity (Heyward, 2006). Similarly, Sub-maximal tests could be done on cycle ergometer or motor-driven treadmill using different well developed protocols like "Single stage treadmill walking or jogging test" or "YMCA cycle ergometer sub-maximal exercise test protocol". Whatever which protocol is used, each stage of these protocols should be in 3 minutes or longer to ensure a steady state HR response at each stage. The endpoint or termination of these tests should be in accordance with the research purposes.

Field test was also available to predict VO_{2max} when the above tests are not suitable for those low fit individuals or for large group of people. These tests were practical, inexpensive, easy to administer and suitable for personal training settings (Heyward, 2006). Two of the most commonly used and well developed tests were the 1.5 miles test for time and the Cooper 12 minutes test (ACSM, 2006).

Non-exercise Methods of Measuring Aerobic Fitness

Apart from laboratory or field tests to measure or predict VO_{2max}, there was means that do not require physical exercise demanding also able to estimate one's cardio respiratory fitness. Without any physical demanding in sub-maximal or maximal exercise, non exercise regression equations offered a more feasible estimation of cardio respiratory fitness. This approach was less expensive, time-saving, and appropriate in large groups, especially for clinical population.

Ages, gender, percent body fat, body mass index (BMI), and physical activity rating (PA-R) were the variables of Non-exercise method predictor (Heil, Freedson, Ahlquist, Price, & Rippe, 1995) and also the perceived functional ability (PFA) (George, Stone, & Burkett, 1997). The Perceived functional ability (PFA) was some questions asking the subjects to rate their ability to walk, jog, or run given distances. Study results show that the non exercise regression equations were relatively accurate and offered a convenient way to estimate VO_{2max} in large population (Heil et al., 1995; George et al., 1997).

Relationship between RPE and VO_{2max}

Since 2005, there were lots of evidences to show the effectiveness of using the ratings of perceived exertion (RPE) to predict maximal oxygen uptake (Eston et al., 2005; 2008; Faulkner et al., 2007a).

In the past, the use of the rating of perceived exertion (RPE) was considered as an appropriate means to regular exercise intensity. However, Eston et al. (2005) advocated an alternative use of the RPE, the researchers aimed to find out whether using a range of sub-maximal RPE levels (RPE 9 to RPE 17) may provide a suitable to prescribe exercise intensity, as a result that such an application could lead to an appropriate estimation of the VO_{2max} in a perceptually regulated graded exercise test. The results found that no significant difference between actual VO_{2max} measured in the maximal graded exercise test, and VO_{2max} predicted from the sub maximal perceptually-regulated graded exercise tests.

As RPE elicited from the perceptually-regulated graded exercise tests could provide accurate prediction of VO_{2max} that was as good as heart rate (Faulkner & Eston 2007), the researchers were then interested in applying such effectiveness of RPE into sedentary population (Davies et al., 2008; Faulkner et al. 2007a). Besides, Coquart et al. (2009)

successfully used sub-maximal RPE to predict VO_{2peak} in 43 obese women. The observations continued to suggest that even from a lower perceptually regulated range (RPE ≤ 15), VO_{2max} could also be accurately predicted. It was definitely convenient for sedentary and clinical populations to assess their cardio-respiratory fitness.

Summary

Since evidences had continued to suggest a better cardio-respiratory fitness or aerobic fitness is associated with reductions in all cause and cardio-vascular diseases mortality rates throughout our life, so it is crucial for us to assess our aerobic fitness. Although direct measurement of VO_{2max} can provide the most accurate measure to us, they are not well-suitable for those sedentary or clinical populations. Sub-maximal measurement may be a good substitute.

However, Dishman (1994) pointed out the limitations of using percentage maximum heart rate to set the exercise intensity in sub-maximal level. On the other hand, RPE scales are relative reliable and valid tools for measuring the level of physical exertion during continuous, aerobic exercise. Pollock et al. (1998) found that RPE can be applied rather than heart rate, or combining with heart Rate, to regulate exercise intensity.

Together with the significant evidences to support the effectiveness of the ratings of perceived exertion (RPE) to predict maximal oxygen uptake (Eston et al., 2005; 2008; Faulkner, et al., 2007a), the importance and the application of RPE scale would continuously arouse the interest of exercise researchers.

Research Hypotheses

The hypotheses of the presentt study was as follow

1. There would be significant correlation between predicted VO2max from RPE values elicited during the perceptually regulated graded exercise test and the actually measured VO_{2max} in graded exercise test.
2. The perceptually regulated graded exercise test would be a reliable test for predicting VO_{2max} from RPE values.

Chapter 3

METHODS

The purpose of this study was to examine the validity of predicting VO_{2max} from RPE values elicited during the perceptually-regulated graded exercise. This chapter was divided into the following parts: (a) selection of subjects; (b) study design; (c) testing procedure; (d) data analysis (statistical hypotheses); (e) definition of terms; (f) delimitations; and (g) limitations.

Selection of Subjects

In this study, 9 endurance trained athletes from Cross-country run team, Rowing team, and Football Team of the Hong Kong Baptist University were invited to be the study participants. The 9 subjects, with six males and three females Total N= 9. All subjects had at least one year experience on endurance training with average 6 training hour per week. Before the test, all study participants were informed of all possible benefits and risks of this study and signed a written

informed consent form and the Physical Activity Readiness Questionnaire (PAR-Q). All physiological data from the participants during the testing procedures were kept confidentially.

Study Design

Each subject needed to complete 3 laboratory tests within 10 days. Subjects were required to perform a graded exercise test to establish VO_{2max} and two sub-maximal, perceptually regulated production trials in a random order to make sure the reliability of the test. 48 hours recovery time was set between each test.

The concept of protocol used in perceptually regulated production trials was similar to (Eston et al., 2008), but the instrument used in the present study was a motorized treadmill instead of a cycle ergometer. Moreover, the protocol also made reference to Modified Astrand protocol (Heyward, 2006).

Before the first perceptually regulated graded exercise test, Borg 6 – 20 RPE scales (Borg, 1998) and instructions of the test were introduced to the subjects on how to perform coming exercise trials. Questions about the RPE scale and the test were answered and emphasis was focused on subject's overall perception of exertion. Throughout the tests, Borg 6 – 20 RPE scale table was directly shown in front of each subject.

Testing Procedure

Perceptually-regulated graded exercise treadmill test

Two sub-maximal perceptually regulated production protocols were done on the motorized treadmill. The sub-maximal trail included five self-regulated exercise intensities (RPE 9, 11, 13, 15, and 17), in an incremental fashion. Each subject would be given a 5 minutes warm up until 70% of age-predicted maximal heart rate was met before starting the exercise at intensity that equal to RPE 9. The experimenter then asked the subject to adjust the gradient

on the treadmill until an RPE of 9 was met. The adjustment period should be within 2 minutes, after that no adjustments were allowed in the coming 2 minutes, heart rate and expired airs were recorded. At the end of this stage, subject would be given a 4-min active recovery in walking speed (2 mile/hour) before starting the second production level (RPE 11). This procedure was the same for RPE level 11, 13, 15, and 17, respectively.

During the transition phase (including the first phase) between each perceptually regulated exercise bout, a 2% gradient was applied as the initial increment in workload. After that, 0.5% increase in gradient was applied if the participant felt that more gradient was needed to meet the target RPE. If the participant felt that the target RPE was over, 0.5% decrement in gradient was applied until the target RPE was produced. A cool-down period was given to subjects at the end of each trail. Each test was separated by a recovery period of 48 hours.

Graded exercise test

The graded exercise test using Modified Astrand protocol (Heyward, 2006) was performed on a motorized treadmill. The exercise speed was kept constant at 5-8 miles per hour. The exercise speed (initial speed) was set according to the subject's 70% of age-predicted maximal heart rate during the warm up stage. In the first stage, subject was required to exercise on the initial speed with 0% gradient for 3 minutes. After that, increment in gradient by 2.5% was applied for every 2 minutes. Analysis of respiratory gas was carried out every 10 seconds throughout the test. Heart rate of the subject was monitored through the Polar system (Polar, Finland). During the last 10 seconds of each stage, Heart rate, RPE and RER were recorded, and adjustment of gradient was made at the same time. For the VO_{2max} to be attained, two of the following criteria had to be met: (i) failure of heart rate to increase with increases in exercise intensity, (ii) respiratory exchange ratio (RER) greater than 1.15, (iii) RPE greater than 17 on the Borg scale and (iv) venous lactate concentration

exceeding 8 mmol/L in first 5 minutes of recovery (ACSM, 2006).

Data Analysis

The purpose of present study was to examine the concurrent validity of predicting (VO_{2max}) from RPE values elicited during the perceptually-regulated graded exercise as well as the reliability. The following are the statistical (null) hypotheses of the study:

1. There would be no significant relation between measured VO_{2max} and the predicted VO_{2max}.
2. There would be significant mean difference between the two perceptually-regulated graded exercise tests.

Analysis of data was done on subject who completed all tests. Physical characteristics such as age, weight, height, BMI and average training hours of the subjects were recorded. Statistical data were analyzed by Statistical Package for Social Science Version 14.0 (SPSS 14.0). Descriptive data, such as mean, standard deviation and range were worked out

and all data were described in mean ±SD.

Pearson Product Moment Coefficient of Correlation (r) was used to examine the relationship between the results of the two perceptually-regulated graded exercise tests and the graded exercise test. Besides, Intra-class reliability coefficient (R) was calculated to test the reliability of perceptually-regulated graded exercise test. Linear regression analysis was performed on each participant's five RPE: VO_2 values from each production trial in order to predict his/her VO_{2max} at RPE 20 using the equation (VO_{2max} = a + b (RPE 20)). All above, an alpha level of 0.05 was used for indicating statistical significance.

Definition of Terms

The following terms were operationally defined especially for this study:

Ratings of Perceived Exertion (RPE)

Perceived exertion is the feeling of how heavy and strenuous a physical task is (Borg, 1998). "RPE refers to overall perceived exertion, which depends on many factors including sensory cues and somatic symptoms, emotional factors, rating behavior, and so on, integrated into a kind of gestalt or configuration" (Borg, 1998, p.9)

Aerobic fitness

"Aerobic Fitness is the body's ability to take in and use oxygen to produce energy" (ACSM, 2003, p.5).

Aerobic Capacity

"Aerobic capacity is a function of how efficiently you can transport oxygen through the body and use it for the production of energy" (ACSM, 2003, p.5).

Maximal oxygen uptake VO_{2max}

"Maximal oxygen uptake (VO_{2max}) is the product of the maximal cardiac output (L blood • min^{-1}) and arterial-venous oxygen difference (mL O_2 per L blood)" (ACSM, 2006, p.66). Wasserman, Hanson, Sue, Whipp, and Casaburi (1999) defined as "the point at which oxygen consumption reaches a peak and plateaus, or only increase slightly, in response to an increased work rate" (as cited by Billat & Lopes, 2006, p.19).

Perceptually-regulated graded exercise test (PRET)

A graded exercise test performs on a motorized treadmill to predict VO_{2max} of the subjects. Subjects were required to exercise on five self-regulated RPE level 9, 11, 13, 15, and 17 prescribed in an incremental fashion (Eston et al,. 2005).

Concurrent Validity

"It is made when there are two tests which aimed to measure the same variable. One of the tests that applied is the criterion, and the other is the test to be validated. The

accuracy of the test is determined by the degree of statistical relationship between two tests" (Berg & Latin, 2008, p.190).

Reliability

"It is the consistency or repeatability of the test scores or data" (Berg & Latin, 2008, p.192)

Delimitations

The study was delimited to the followings:

1. The subjects were delimited to endurance trained athletes of Hong Kong Baptist University who are all physically active, apparently healthy and asymptomatic of illness.
2. All the subjects aged from 20-24 years, are well trained cross-country runners, rowers and football players of the university team.
3. The subjects were delimited to 9 endurance trained athletes with 6 average training hours per week.

4. The tests were conducted over a period of approximately 10 days.

Limitations

The study was limited by the following factors:

1. The past experience and history of the subjects was not counted as a factor in this study.
2. The participants' attitude toward the test such as motivation and cooperation might affect the results of the study.
3. The data of Ratings of perceived exertion (RPE) was depended mainly on the subjects' subjective feeling.
4. The performance of the subjects might be affected by their eating habit such as a high or low carbohydrate diet.

Chapter 4

ANALYSIS OF DATA

Results

Total nine endurance trained athletes with six males and three females from Hong Kong Baptist University Sport teams were invited to be the subjects in the present study. The purpose of this study was to examine firstly, the validity of predicting VO_{2max} from RPE values elicited during the perceptually-regulated graded exercise test in endurance trained athletes of Hong Kong and the reliability of the test. Each subject underwent 3 laboratory-based sessions to complete two perceptually-regulated graded exercise tests and one graded exercise test over a period of approximately 10 days.

The physical characteristics and average training hours per week of the subjects were shown in Table 1.

Table 1

Physical characteristics of the subjects (N=9)

	Range	Mean	±SD
Age (yr)	20- 24	22.33	1.32
Weight (kg)	44.6 - 69.3	58.05	7.42
Height (cm)	157 - 175	168.61	6.65
BMI (kg/m²)	17.72 – 22.62	20.33	1.41
Training hours/week	4 - 12	6	3

After the physical characteristics of the subjects, the results of (i) Reliability and (ii) Concurrent validity would be shown as follow.

First of all, the descriptive statistics of the predicted VO_{2max} in the two perceptually-regulated graded exercise treadmill tests were shown in Table 2.

Table 2

Descriptive statistics of the subjects' VO_2 value ($ml.kg^{-1}.min^{-1}$) in each RPE stage during the two perceptually-regulated graded exercise tests (N = 9)

Trail 1	Range	Mean	±SD
RPE 9	22.9 – 41.7	32.10	7.26
RPE 11	26.6 – 49.6	35.90	8.65
RPE 13	30.1 – 54.2	38.35	9.11
RPE 15	33.8 – 57.9	42.66	8.40
RPE 17	37.1 – 62.3	47.46	10.03

Trail 2	Range	Mean	±SD
RPE 9	23.1 – 42.9	31.97	6.69
RPE 11	26.5 – 43.9	35.10	6.26
RPE 13	29.2 – 47.4	38.27	7.51
RPE 15	31.9 – 53.9	42.43	7.76
RPE 17	36.2 – 57.3	46.27	8.07

Analysis of Linear regression was done on each subject's five RPE: VO_2 values from the two production trials in order to predict the subjects' VO_{2max} at RPE 20 using the equation $VO_{2max} = a + b$ (RPE 20). An example of predicting VO_{2max} using linear regression analysis from RPE 9, 11, 13, 15 and 17 was shown in Figure 1. And the results of predicted VO_{2max} in the two trails and the measured VO_{2max} were shown in Table 3.

Figure 1

Example of predicting VO2max in PRET using linear regression analysis (Solid line), from RPE 9, 11, 13, 15 and 17

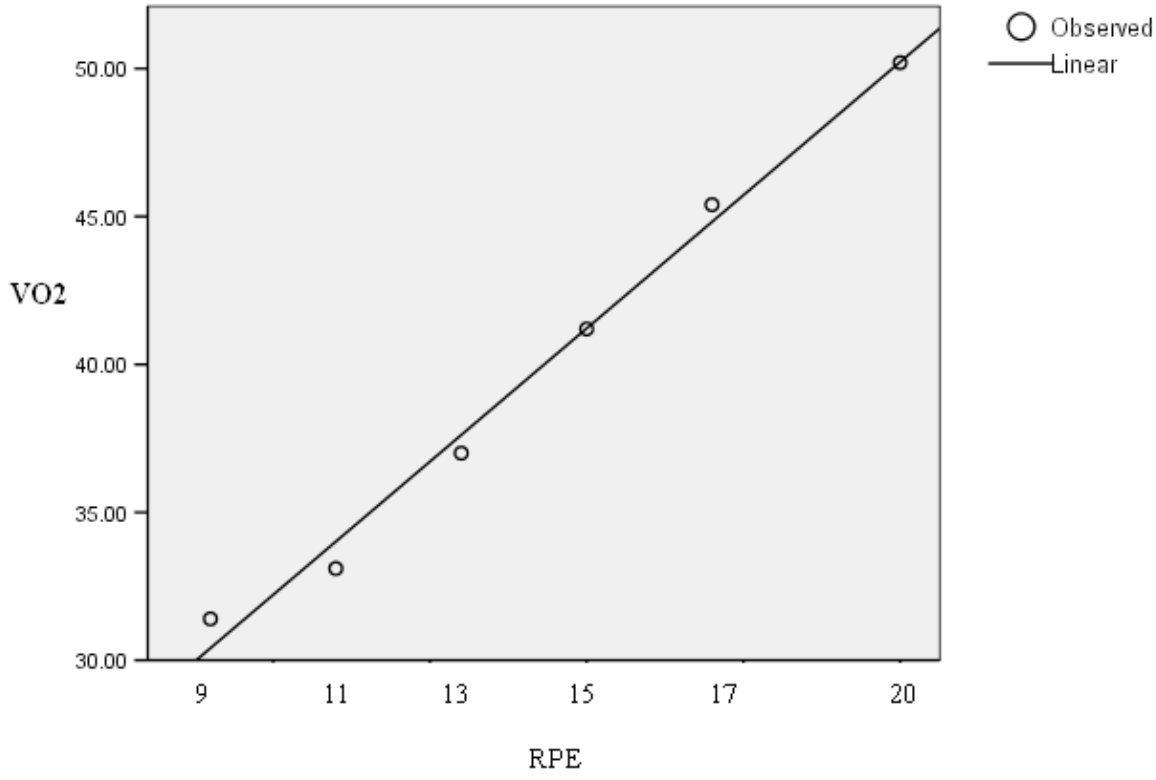


Table 3

Descriptive statistics of the subjects' predicted and measured VO2max in the tests (N = 9)

	Range	Mean	±SD
Trail 1	42.46 - 71.41	52.41	10.82
Trail 2	39.70 - 65.31	51.38	9.06
VO2max	41.50 - 69.50	55.77	9.50

Trail 1: Trail 1 of perceptually-regulated graded exercise treadmill test

Trail 2: Trail 2 of perceptually-regulated graded exercise treadmill test

VO2max: Measured VO2max in graded exercise treadmill test

The above results of current study showed that there was no significant mean difference between the predicted VO_{2max} of first trail 52.41 ±SD 10.82 and the second trail 51.38 ±SD 9.06. And the ranges of the Trail 1 and Trail 2 were 42.46 to 71.41 and 39.7 to 65.31 respectively. For the graded exercise treadmill test for establishing VO_{2max}, the mean VO_{2max} was 55.77 ±SD 9.5.

The Reliability of the PRET

In order to examine the reliability of predicting VO_{2max} from RPE values elicited during the perceptually-regulated graded exercise test, Paired Samples T-Test (t) and Intra-class reliability coefficient (R) was computed to examine the mean difference and the test-retest reliability between the two production trails. The results were shown in table 4 and table 5.

Table 4

Paired Samples T-Test of Trail 1 and Trail 2

	Paired Differences				
	Mean	SD	*t*	df	Sig (2-tailed)
Pair1 Trail 1 – Trail 2	1.0355	3.303	.940	8	.375

From above results, for the computed t= 0.94, df= 8, p=0.375 > 0.05, was significantly lower than the critical t value (2.306, df= 8). As Paired Samples T-Test indicted that there was no significant mean difference between the two sub-maximal, perceptually-regulated graded exercise treadmill tests. In other words, the null hypothesis that "There would be significant mean difference between the two perceptually regulated graded exercise tests" was rejected.

Table 5

Intra-class reliability coefficient (R) for Trail 1 & 2

	R (test-retest)
Trail 1 & Trail 2	0.972

The above results showed that the test-retest reliability between Trail 1 and 2 was high (R= 0.972), it reflected that the reliability of the test is high. According to the above results, again, it could be concluded that the null hypothesis "There would be significant mean difference between the two perceptually-regulated graded exercise tests" was rejected.

The Concurrent Validity of the PRET

The Pearson correlation between the predicted VO2max in the two sub-maximal perceptually-regulated graded exercise treadmill tests and the actual VO2max measured in the graded exercise treadmill test was computed. The Pearson correlation coefficient and the coefficient of determination were shown in Table 6.

Table 6

Pearson Correlation between the predicted VO_{2max} in the two sub-maximal PRET trails and the actual VO_{2max} in GXT

	VO_{2max}		
	r	r^2	*P*
Trail 1	.778	.605	*0.05
Trail 2	.855	.758	**0.01

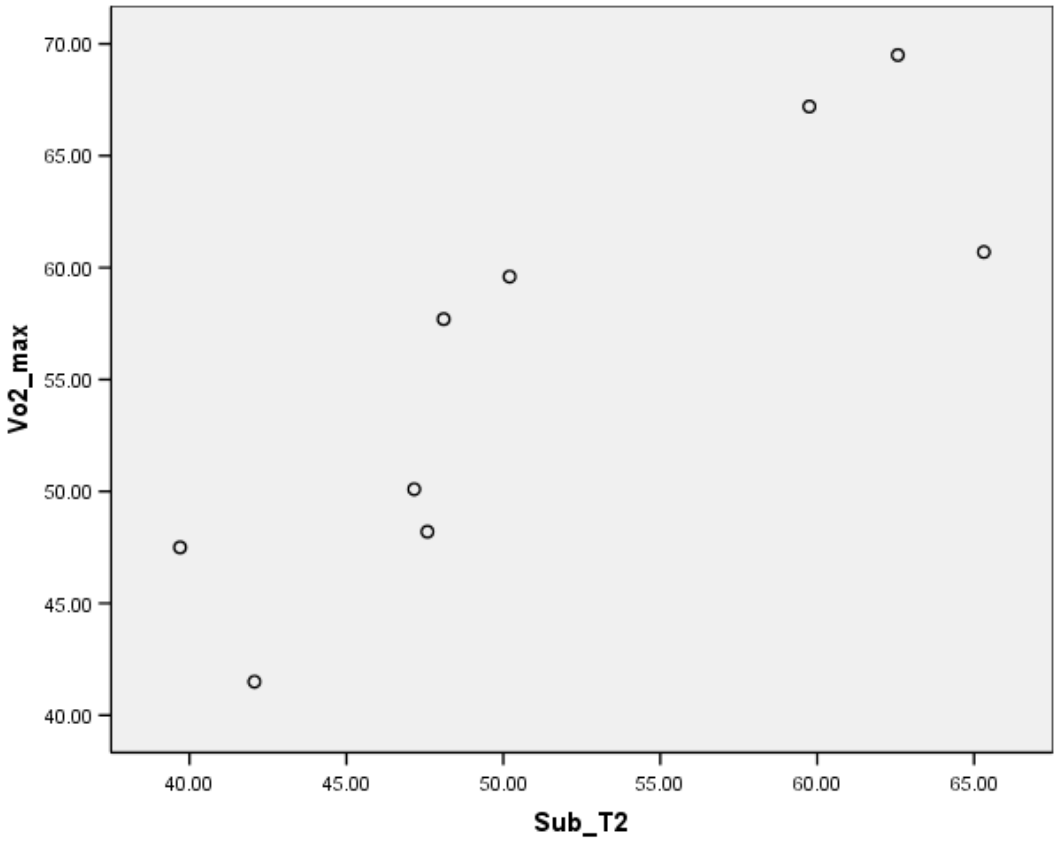
** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

From the above figure, the correlation of subjects' performance in the two PRET trails and the Actual VO_{2max} measurement test in GXT was significant. For Trail one, $r = 0.778$, $p<0.05$. For trail two, $r = 0.855$, $p<0.01$. The coefficient of determination (r^2) for Trail 1 was 0.605 and 0.758 for Trail 2.

There was a positive relationship between the predicted VO_{2max} from the two perceptually-regulated graded exercise tests and the actual VO_{2max} in graded exercise test. Graphic presentation of the relationship was shown in a scatter plotted graph in Figure 2.

Figure 2
Scatter Plotted graph showing the relationship between the subjects' performance in PRET Trail 2 and the actual VO_{2max} in graded exercise test (GXT)



As Pearson correlation analysis found that there was a significant positive relationship between the predicted VO_{2max} in the two sub-maximal perceptually-regulated graded exercise treadmill tests and the Actual VO_{2max} measured in the graded exercise treadmill test. As a result, the null hypothesis "There would no significant relation between measured VO_{2max} and the predicted VO_{2max}." was rejected.

Discussion

The purpose of this study was to examine firstly, the validity of predicting VO_{2max} from RPE values elicited during the perceptually-regulated graded exercise (PRET) on a motorized treadmill in endurance trained athletes of Hong Kong as well as the reliability of the test. The following parts would be divided for discussion :(i) Reliability of the PRET. (ii) Concurrent validity of the PRET. (iii) Factors affecting the concurrent validity of the PRET, and (iv) Review of the PRET.

Reliability of the PRET

The result showed the reliability of predicting VO_{2max} from RPE values elicited during the perceptually-regulated graded exercise tests. From the Paired Samples T-Test, the results showed that there was no significant mean different ($t= 0.94$; $p=0.375 > 0.05$) in the two trails. Moreover, Intra-class correlation coefficient (R) for Trail 1 & Trail 2 was ($R= 0.972$), it indicated that the reliability of the test is high.

First of all, population used in this study was attributed to the high reliability. It was because it is an easier task for endurance trained athletes to regulate and perceive a level of exertion compared to sedentary subjects (Faulkner et al., 2007a).According to the researchers, in moderate to vigorous exercise level, endurance trained athletes were more skillful in regulating and adjusting their pace because they had more regular exercise experience. Thus, a high reliability of the test could be shown.

A further observation in the present study was that "Protocol familiarization" was an important factor for higher correlation to actual VO_{2max} in prediction Trail 2 (r= 0.855) than Trail 1 (r= 0.778). This observation was similar to previous studies (Eston et al 2005; 2006; 2008; Faulkner et al., 2007a). This was an important factor concerning the use of RPE scale, because it implied that feedback from the first trail might facilitate a "Learning effect" to the subjects.

Concurrent validity of the PRET

According to the results of the current study, there was a strong positive relationship between RPE and VO2 derived from each subject in the present study with correlations (r) 0.778 and 0.85*5* for Trail 1 and Trail 2 respectively. And Trail two provided a more accurate estimation of maximal aerobic power than Trail one. As a result, it was possible to use of one's RPE: VO_2 value to extrapolate to the theoretical maximal RPE 20 to predict VO_{2max} because the predicted VO_{2max} of each subject were similar to the actual VO_{2max} values measured in the graded exercise test. In other words, the perceptually-regulated graded exercise test was a valid test to predict VO_{2max} in a sub-maximal nature.

Factors affecting the concurrent validity of the PRET

When comparing the mean value between the two prediction trails and the actual VO_{2max}, the results showed that there was an underestimation of VO_{2max} in both prediction trails, and it got similar results with the previous researches (Eston,

et al., 2005; 2008; Faulkner, et al., 2007a;). The underestimation of VO_{2max} was due to the following factors.

To begin with, the underestimation of VO2max from the two perceptually-regulated graded exercise tests was due to peripheral perceptions of exertion (Faulkner & Eston 2008). Peripheral perceptions of exertion would underestimate the measured VO_{2max} value significantly. Such exertion included cardio-respiratory and muscle fatigue in the latter stages.

The reason for underestimation of predicted VO_{2max} in the present study was the protocol used. In this study, Modified Astrand protocol (Heyward, 2006) was chosen as the reference for perceptually regulated graded exercise tests. This protocol, unlike previous researches (Eston et al., 2005; 2008; Faulkner et al., 2007a) which used cycle ergometer as the instrument, might generate more peripheral perceptions of exertion to the subjects. It was known that exercising on a motorized treadmill was different to a cycle ergometer.

Because more muscles had to be recruited when exercising on treadmill, whereas only lower limb muscles were required on a cycle ergometer, thus, as more muscles were required in a treadmill test, a higher effect of peripheral perceptions of exertion would be resulted.

The second reason for underestimation was the extent of the underproduction occurring in the earlier stages of the perceptually-regulated graded exercise tests. It was because the subjects would "hold back" because they knew that it would be more strenuous in the latter stage of exercise. As a result, they would adopt pacing strategies during the tests. As VO_2 is directly dependent on the work rate, so it is reasonable to expect that a lower value of predicted VO_{2max} would be resulted when this value was extrapolated to RPE 20. This finding supports (Noakes, 2004). The researcher suggested that one can sustain an expected duration of exercise without activating the whole body physical exhaustion and energy depletion because our subconscious brain will calculate the

expected exercise duration. This concept was known as 'Feedforward", it would be affected by the known time allowed to estimate the power output. In a previous study (Eston, Faulkner, Mason & Parfitt, 2006), the researchers found that the mean power output produced in a 4 minutes RPE-regulate exercise bout was significantly lower than a 2 minutes bout at the same RPE level.

The third reason for the underestimation was the motivation of the subjects. Unlike previous studies, the population used in this study was all endurance trained athletes. In performing the graded exercise test for the actual VO_{2max} measurement, the above concept of "holding back" would not appear because they would perform their best to achieve the peak point of VO_{2max}. Moreover, unlike sedentary population, endurance trained athletes was considered to more tough in performing graded exercise test and, from our observation, they could sustain a longer exercise duration. As a result, their motivation in this graded exercise test was higher than

that in the two sub-maximal, RPE-regulate exercise test trails.

Review of the PRET

The aim of the present study was to examine the application of the concept of perceptually regulated graded exercise tests in endurance trained athletes. Therefore, the protocol used in the present study should have limited application for clinical population. The test results reflected the validity of using RPE scale and perceptually regulated exercise test to predict the maximum oxygen uptake. It had the only implication that the test is worthy of further study. However, if the test was used for clinical application, the duration of the protocol used might be too long, especially for those who were unfit.

Chapter 5

SUMMARY AND CONCLUSIONS

Summary of Results

The present study was designed to examine the concurrent validity of predicting VO_{2max} from RPE values elicited during the perceptually-regulated graded exercise test, and also the reliability of the test. Total nine endurance trained athletes with six males and three females from Hong Kong Baptist University Sport teams were invited to be the subjects in this study. Each subject had 3 laboratory-based sessions to complete two perceptually regulated graded exercise tests and one graded exercise test within a period of approximately 10 days. Results were recorded during the tests, and the test result data were analyzed by Statistical Package for Social Science Version 14.0 (SPSS 14.0). Pearson Product Moment Coefficient of Correlation (r), Paired Samples T-Test (t), and Intra-class correlation coefficient (R) were applied. The level of significant was set at 0.05 ($p<0.05$).

The results of this study were summarized as follows:

1. There was a significant correlation between actual VO_{2max} and the predicted VO_{2max} from RPE values elicited during the perceptually-regulated graded exercise test. ($r = 0.778$, $p < 0.05$) for Trail one; ($r = 0.855$, $p < 0.01$) for Trail two. It indicated that the test was a highly valid test to predict VO_{2max} from RPE values.
2. There was no significant mean difference between the two perceptually-regulated graded exercise tests (Trail1 & Trail 2). For ($t = 0.94$; $p = 0.375$, >0.05), the results indicated that there would be no significant mean difference between the two trails.
3. The perceptually-regulated graded exercise test was a reliable test. Intra-class correlation coefficient (R) for Trail 1 & 2 was ($R = 0.972$). The result pointed out that the test is highly reliable.

Conclusion

The present study provides support to the use of RPE scale and perceptually-regulated, sub-maximal graded exercise test to predict VO_{2max} in endurance trained athletes. The result suggests that a sub-maximal, PRET can provide reliable and valid estimation of maximal oxygen uptake. Also, the findings of present study can provide further support to the application of RPE in sub maximal exercise setting or when other objective physiological markers are not available.

Recommendations for Further Study

Based on the present study, recommendations are suggested for further study.

1. The enlargement of sample size should be considered in order to obtain more generalizations.
2. Gender, age groups, and fitness level of the subjects should be considered. Because the age difference, fitness level, exercise experience of the subjects would

affect the perceptually-regulated procedures in predicting VO_{2max}.

3. Further research should determine the optimal duration of the perceptually regulated graded exercise test and consider the effects the 4-min recovery periods between each of perceptually regulated exercise bouts.
4. Further study should also explore if heart rate in combination with RPE, can provide a useful additional measure to estimate the VO_{2max}.

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APPENDIX A

Informed Consent

Explanation of the tests

The graded exercise test and the perceptually-regulated graded exercise test are performed on a motor-driven treadmill. The workload is increased every few minutes until exhaustion or until other symptoms dictate that we terminate the test. You may stop the tests at any time because of fatigue or discomfort.

Risks and discomforts

During the graded exercise tests, certain changes may occur. These changes include abnormal blood pressure responses, fainting, irregularities in heart beat, and heart attack. Every effort is made to minimize these occurrences. Emergency equipment and trained personnel are available to deal with these situations if they occur.

Expected benefits from testing

The tests allow us to assess your physical working capacity and to appraise your physical fitness status. The results are used to prescribe a safe, sound exercise program for you. Records are kept strictly confidential unless you consent to release this information.

Inquiries

Questions about the procedures used in the physical fitness tests are encouraged. If you have any questions or need additional information, please ask us to explain further.

Freedom of Consent

Your permission to perform these physical fitness tests is strictly voluntary. You are free to stop the tests at any point, if you so desire.

I have read this form carefully and I fully understand the test procedures that I will perform and the risks and discomforts. Knowing these risks and having had the opportunity to ask questions that have been answered to my satisfaction, I consent to participate in these tests.

Date: _____ Signature of patient: _____

Date: _____ Signature of witness: _____

From Vivian H. Heyward, (2006). Advanced Fitness Assessment and Exercise Prescription, 5th Ed.

APPENDIX B

Perceptually-regulated graded exercise (Treadmill)

Data Recording Sheet

Subject's name: _____ Gender: M / F Age: _____

Height: _____ cm Weight: _____ kg

Pre-test HR: _____ bpm Age-predicted HR max: _____ bpm

Initial speed (70% of HR max) = _____ km/h (_____ bpm)

Major Sport: _____

Times of Training: _____ days/week

Duration: _____ hours

Stage no.	RPE	Gradient	Heart rate	RER	VO_2
0 | 2 | 4 1	**9**				
8 | 10 | 12 2	**11**				
16 | 18 | 20 3	**13**				
24 | 26 | 28 4	**15**				
32 | 34 | 36 5	**17**				

APPENDIX C

Graded exercise test (Treadmill)

Data Recording Sheet

Subject's name: _____ Gender: M / F Age: ____

Height: _____ cm Weight: _____ Test start: _____ Test end: _____

Speed = 70% of max. HR (/min) = _____ km/h Pre-test HR: _____

Maximal treadmill test (Modified Astrand Protocol)

Stage no.	Time (minute)	Gradient	Heart rate	RPE	RER	VO2
1	0 - 1	0				
	1 - 2					
	2 - 3					
2	3 - 4	2.5				
	4 - 5					
3	5 – 6	5				
	6 - 7					
4	7 – 8	7.5				
	8 – 9					
5	9 - 10	10				
	10 - 11					
6	11 – 12	12.5				
	12 – 13					

Vo2 max = _____