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The Correlation Analysis Between The Estimation Of VO_2max Using The Harvard Step Test, Queen's College Step Test, 90-90 Queen's College Step Test, And VO_2max in Cardiopulmonary Exercise Testing (CPX)

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Abstract
Introduction: The maximal oxygen uptake (VO_2max), indicative of cardiorespiratory endurance, is typically assessed using Cardiopulmonary Exercise Test (CPX) with a metabolic cart, a method limited by its high cost and technical requirements. Alternative step tests, like the Harvard Step Test, Queen's College Step Test, and the 90-90 Queen's College Step Test, offer simpler assessment methods. This study examines the correlation between these step tests and CPX for VO_2max estimation.
Objectives: This study aims to investigate the correlation between predicted VO_2max (pVO_2max) obtained from the 90-90 Queen's College step test, Harvard step test, and Queen's College step test with CPX VO_2max measurements.
Methods: Eighteen male college students in their 20s underwent VO_2max evaluation using CPX and the three step tests. The novel 90-90 Queen's College Step Test was included, which adjusts step height to individual body dimensions, potentially enhancing estimation accuracy. Pearson correlation analysis was used to compare the step test results with CPX measurements.
Results: There was a significant positive correlation between CPX VO_2max and Harvard VO_2max ($r = 0.762$), CPX VO_2max and Queen's VO_2max ($r = 0.724$), and CPX VO_2max and 90-90 Queen's VO_2max ($r = 0.770$) ($P<0.01$). There was a significant positive correlation between 90-90 Queen's VO_2max and Harvard VO_2max ($r = 0.703$), 90-90 Queen's VO_2max and Queen's VO_2max ($r = 0.652$), and Queen's VO_2max and Harvard VO_2max ($r = 0.770$) ($P<0.05$)
Conclusions: In conclusion, the 90-90 Queen's College Step Test offers reliable pVO_2max with consistent exercise loads, making it a preferable choice in situations where CPX equipment is unavailable. Nevertheless, this study has limitations, such as relying solely on Pearson correlation analysis and a small sample size. Future research should aim to overcome these limitations to further enhance the understanding of studies related to VO_2max.

Keywords: Harvard step test, Queen's step test, 90-90 Queen's step test, CPX, VO_2max

1. Introduction

The maximal oxygen uptake (VO_2max) is widely recognized as a key indicator of an individual's cardiorespiratory endurance and overall fitness level. It represents the maximum rate of oxygen uptake and utilization during high-intensity exercise [1]. The accurate assessment of VO_2max typically involves the analysis of respiratory gases during exercise, often using equipment such as a metabolic cart [2]. Cardiopulmonary exercise test (CPX) using a metabolic cart VO_2max measurement is often performed using a cycle ergometer or treadmill. Treadmills tend to yield higher VO_2max values due to increased muscle group activation and the effect of gravity, making them more suitable for healthy individuals. [3, 4]. Alternative methods include estimation techniques that derive predicted VO_2max (pVO_2max) values from various exercise tests and formulas [5, 6, 7].
However, CPX VO_2max testing poses limitations, including the need for expensive equipment, specialized testing facilities, and trained personnel, making it less accessible to the general population [8, 9, 10]. Since there is an increasing demand for simpler methods to assess cardiorespiratory fitness. Various step tests, such as the Harvard step test and Queen's College step test, have been used historically to estimate pVO_2max [11, 12, 13, 14]. The Harvard step test, developed by Brouha and Jonson at Harvard University, is a 5-minute step test that evaluates cardiorespiratory fitness

based on heart rate recovery [10, 11]. The Queen's College step test, designed by McArdle, estimates pVO_2max by calculating resting heart rate and 85% of maximal heart rate post-exercise [13, 14].
The standardized step box height in the Queen's College step test introduces a measurement deviation for individuals with varying heights. To solve this, previous studies modified the Queen's College step test by adjusting the step box height according to individuals' height, but the correlation between pVO_2max and VO_2max remained insufficient [15]. This inadequacy is hypothesized to arise from not accounting for varying upper to lower body ratios. To address this, the 90-90 Queen's College step test was conceived, setting the step height to align the subject hip and knee joints at a 90-degree angle, thus considering individual body size. This approach could potentially reduce the variability in exercise load due to body size differences, leading to a more accurate estimation of VO_2max. To validate this hypothesis, a correlation analysis with CPX measurements is essential. Therefore, this study aims to investigate the correlation between pVO_2max obtained from the 90-90 Queen's College step test, Harvard step test, and Queen's College step test with CPX VO_2max measurements.

Materials and Methods

2.1 Subjects

This research selected young male adults in their 20s residing in City A, South Korea, as its subjects. The study was conducted with 18 male college students from S University in Chungcheongnam-do. The subjects' average age was 22.17 ± 2.66 years, their average height was 173.89 ± 5.41 cm, and their average body weight was 69.59 ± 5.80 kg (Table 1). Based on previous studies, the required sample size was calculated using G*Power 3.1.9.7 (Heinrich Heine University, Düsseldorf, Germany), assuming a significance level (α) of .05, a power of .80, and an effect size of .6 for the correlation analysis. The results indicated a minimum requirement of 17 subjects. Considering potential dropout rates during the experiment, a total of 20 subjects were initially recruited. The study commenced with these 20 subjects, but two dropped out during the measurement phase, leading to the completion of the study with 18 male subjects.
The selection criteria for the research subjects were as follows: 1) Male individuals in their 20s; 2) Individuals without significant visual or proprioceptive impairments that could affect the experiment; 3) Individuals free from lower limb pain that could influence the performance during the experiment; 4) Individuals not currently taking medications related to muscle strength or mental disorders; 5) Individuals without cardiac or pulmonary diseases.
In compliance with the ethical standards of the Declaration of Helsinki, all subjects were thoroughly informed about the objectives and procedures of the study before its commencement. Voluntary consent was obtained from the subjects for their involvement in the experiment. All the partcipants understood the purpose of this study and provided written informed consent prior to participation in the study in accordance with the ethical standards of the Declaration of Helsinki.

Table 1. General subject characteristics(N=18)

Variable	Mean± SD
Age(year)	22.17±2.66a
Height(cm)	173.89±5.41
Weight(kg)	69.59±5.80

Data are expressed as means ± standard deviations. SD standard deviation.

2.2 Study Protocol

Subjects were assessed for their VO_2max using several protocols. Initially, VO_2max was measured using a CPX while the subjects followed Bruce protocol on a treadmill. Additionally, the Harvard Step Test and the Queen's College Step Test, were employed to estimate pVO_2max.
A modified version of the Queen's College Step Test, termed the 90-90 Queen's College Step Test, was also utilized. This adaptation involved adjusting the step height so that the subject's knee and hip joints formed a 90-degree angle, optimizing the test for individual body proportions.
Prior to conducting the experiments, researchers provided thorough instructions and practice opportunities to the subjects. To ensure adequate rest between each type of test, a 24-hour rest period was mandated post each test session.
The experimental environment was controlled, with room temperature set at 23°C and humidity at 50%. The experiments were conducted in a quiet lab setting to minimize the influence of the sympathetic nervous system. Each measurement was taken three times, and the average value was used. The results were presented as mean ± standard deviation.
For the step tests, heart rate was measured using oximetry (finger pulse oximeter, ilJin Medical, Korea) at 15 seconds immediately after exercise. These heart rate measurements were then used to calculate pVO_2max according to established formula [12]. The Harvard Step Test involved a 5-minute exercise period, stepping on and off a 50.8 cm high step box at a rate of 60 steps per minute, synchronized with a metronome set to 120 beats per minute, continuing until exhaustion

[11]. The Queen’s College Step Test differed in that it used a 41.27 cm high step box, with a 3-minute exercise period at a rate of 22 steps per minute [14]. The 90-90 Queen’s College Step Test adapted the height of the step box based on each individual's body dimensions, measuring from the floor to the sole of the foot in a position where the hip and knee joints are bent at 90 degrees.
The CPX VO_2max values were measured using a motorized treadmill (Quinton TM 55 Treadmill, Cardiac Science, US) set to the Bruce Protocol. After the motorized treadmill was calibrated in order to make sure the accuracy of grade and speed, subjects were equipped with a standard 12-lead electrocardiogram and wore a mask covering the nose and mouth. Oxygen intake was measured using a metabolic cart (TrueOne 2400, Parvo Medics, US), and heart rate was continuously monitored with an electronic monitor (Tango M2 stress test monitor, Sun tech medical, US). The protocol was deemed complete when subjects met three criteria: (i) a Respiratory Exchange Ratio (RER) > 1.1, (ii) a maximal heart rate (HRmax) not less than 15 beats below the predicted HRmax (220 - age), and (iii) a leveling off of VO2 despite an increase in workload [2, 16].
Figure 1

$$Equation\ 1\ (males):\ VO_2max = 111.3 - (0.42 * HR)$$

Fig. 1. Formula

2.3 Statistical Analysis

Data analysis in this study was conducted using SPSS for Windows (version 28.0). To explore the relationships between pVO_2max and VO_2max measurements, the Pearson correlation coefficient was employed. This statistical method was chosen based on the data's adherence to normality assumptions. The Pearson correlation coefficient was utilized to investigate the correlation between the pVO_2max values from the Harvard Step Test, the Queen’s College Step Test, the 90-90 Queen’s College Step Test, and the VO_2max measurements obtained from CPX. The threshold for statistical significance was set at $\alpha = .05$.

3. Results

The assessment methods showed a significant positive correlation with CPX VO_2max. There was a significant positive correlation between CPX VO_2max and Harvard VO_2max (r = 0.762), CPX VO_2max and Queen's VO_2max (r = 0.724), and CPX VO_2max and 90-90 Queen's VO_2max (r = 0.770) ($P<0.01$).
Significant positive correlations were also observed between the remaining assessment methods. There was a significant positive correlation between 90-90 Queen's VO_2max and Harvard VO_2max (r = 0.703), 90-90 Queen's VO_2max and Queen's VO_2max (r = 0.652), and Queen's VO_2max and Harvard VO_2max (r = 0.770) ($P<0.05$) [Table 2].

Table 2. Correlation analysis between measures of assessment tools

	Harvard VO_2max	Queen's VO_2max	90-90 Queen's V02max	CPX VO_2max
	58.49±5.28	45.97±5.69	45.44±4.89	47.28±5.03
CPX VO_2max	0.762**	0.724**	0.770**	1
(p)	0.000	0.001	0.000	-
90-90 Queen's VO_2max	0.703**	0.652**	1	0.770**
(p)	0.001	0.003	-	0.000
Queen's VO_2max	0.770**	1	0.652**	0.724**
(p)	0.000	-	0.003	0.001

*p<0.05; (Mean±SD); **p<0.01

4. Discussion

This study investigated the correlation between VO_2max measurements obtained through CPX and pVO_2max values from the Harvard Step Test, Queen’s College Step Test, and the 90-90 Queen’s College Step Test. Significant positive correlations were found between the CPX VO_2max measurements and the pVO_2max values from the three step tests. The Harvard Step Test, developed by Brouha, is widely acknowledged for its efficacy in evaluating cardiorespiratory fitness

through a straightforward yet effective methodology. This test is particularly valuable for measuring an individual's fitness level by assessing the body's response to a submaximal lo
ad. [11]. However, previous studies have indicated a low correlation between pVO_2max values from submaximal step tests like the Harvard Step Test and VO_2max measurements from treadmills or cycle ergometers [5, 17, 18]. These findings suggest limitations in the precision of submaximal step tests in measuring cardiorespiratory endurance. Nevertheless, our study showed a positive correlation between pVO_2max values from the Harvard Step Test and CPX VO_2max values, presenting a contrasting view to previous research and suggesting the potential accuracy of the Harvard Step Test under certain conditions. The results of this study could deepen the understanding of cardiorespiratory endurance measurement methodologies and contribute to the development of more precise assessment tools.
The Queen's College Step Test, unlike the Harvard Step Test, is not a submaximal step test and focuses on cardiorespiratory endurance measurement by lowering the height of the step box and reducing the number of steps [14]. Studies on the correlation between the pVO_2max values from this test and CPX VO_2max values have been divided, with some showing a correlation and others not. In a review by Bennett et al., two out of four studies analyzed showed a significant positive correlation between the Queen's College Step Test pVO_2max and CPX VO_2max, while the other two did not [20]. Since these four studies showed varied results across different populations, the correlation between the Queen's College Step Test pVO_2max and VO_2max remains uncertain. However, according to the study conducted by Perroni et al. on 15 firefighters, which reported a low correlation [21]. Bennett et al. noted that it is unclear whether the regression equations used to calculate the correlation are suitable for the firefighter population (aged 31±6) and that there might be random errors in the procedures [20]. Despite these potential concerns, Perroni et al., did not address these factors, making it a noteworthy omission [21]. Excluding this study, our results, along with the strong correlation (r=0.95) found in a study on young males by Chatterjee et al., support the existence of a positive correlation between CPX VO_2max and the Queen’s College Step Test pVO_2max [19].
Our study also found a higher positive correlation between CPX VO_2max measurements and the 90-90 Queen’s College Step Test pVO_2max values compared to the other two tests. This outcome may be attributed to the method of setting the step height in the 90-90 Queen’s College Step Test, which was customized to each subject's body size by ensuring a 90-degree angle at the hip and knee joints. This individualized adjustment allowed for a consistent exercise load regardless of body size variations. Chung et al. supported this theory in their study by employing a 3-minute progressive knee-ups and step test [22]. They observed a significant correlation between pVO_2max and VO_2max values. The customization of step height based on body size in step tests like the 90-90 Queen’s College Step Test could influence the correlation with CPX VO_2max values.

5. Conclusion

In conclusion, the 90-90 Queen’s College Step Test provides reliable pVO_2max with consistent exercise loads, making it a preferable choice when CPX equipment is unavailable. However, this study has limitations, including the sole use of Pearson correlation analysis and a small sample size. Future research should address these limitations to advance the understanding of VO_2max-related studies.

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