Assessing Maximal Oxygen Uptake: Influence of Leg Length in the Harvard Step Test and Queen's College Step Test

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Abstract: - Maximal oxygen uptake (VO2max) indicates cardiovascular endurance in evaluating overall health and physical performance. The CPX method is accurate, but accessibility is lower due to issues related to cost and complexity. For this reason, the Harvard Step Test and Queen's College Step Test are drawing interest. Step-based tests are influenced by factors such as leg length, requiring an investigation into the correlation between leg length and VO_2max estimation using these methods. This study investigates the influence of leg length on predicted VO_2max (pVO2max) determined through both the Harvard Step Test and the Queen's College Step Test. The assessment of VO2max was carried out using CPX on a treadmill. Measurements were obtained through the Harvard Step Test and Queen's College Step Test on steps. The participants were informed about the experimental procedure, and the experiment was conducted 24 hours later. The experiment maintained controlled conditions, and each measurement was conducted as a single trial, repeated three times for accuracy. The study found a significant positive correlation ($r = 0.595$, $P < 0.05$) between CPX VO2max and lower leg length. Lower leg length was found to significantly influence exercise intensity as determined by both the Harvard Step Test pVO2max (explaining 35.4% of the variance, $P < 0.05$) and the Queen's College Step Test pVO2max (explaining 30% of the variance, $P < 0.05$). It is recommended to adjust the step height to the individual's body size when estimating exercise difficulty or pVO2max using step-based exercises.

Key-Words: - pVO2max, CPX, Harvard step test, Queen's step test, Leg Length, Tibia Length

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1 Introduction

Maximal Oxygen Uptake (VO2max) is a key measure of cardiovascular endurance, reflecting the body's utmost capacity to consume oxygen during intense exercise. It serves as an essential indicator of overall health and physical performance, highlighting the maximal capacity of the cardiovascular system, [1].

The exercise load is paramount in assessing VO2max. It denotes the level of stress the body undergoes during exercise and impacts the accuracy of VO2max. Despite ongoing increases in exercise load, the cessation of oxygen uptake increases marks the endpoint for the measurement process. Cardiopulmonary Exercise Testing (CPX) utilizes this methodology to ascertain maximum oxygen consumption, featuring gradual increases in load, [2].

The CPX VO2max method is the most accurate, but it has the limitation of requiring expensive equipment. Accordingly, there is an increasing demand for strategies that can easily measure an individual's cardiorespiratory endurance, [3], [4], [5].

There has been a need in the past for a method to measure cardiorespiratory endurance or measure predicted VO2max (pVO2max) related to cardiorespiratory endurance without high costs. The methods for assessing pVO2max were initially used to select military candidates. Cardiopulmonary endurance has evolved to become a measure of health, [6]. The Harvard Step Test and the Queen's College Step Test have also evolved into essential indicators of health, [7], [8], [9]. The Harvard step test is a method designed to measure heart rate. It is an evaluation method that checks recovery speed by measuring heart rate while sitting immediately after 5 minutes of up and down exercise, [8], [9]. Queens College step test calculates resting heart rate and 85% of maximum heart rate after exercise. It is conducted at 22 steps/min for 3 minutes and is a widely used evaluation method due to its low height, slow speed, and short exercise time compared to other step tests, [10], [11].

pVO2max measurement methods using steps can be affected by various parameters. Factors such as an individual's walking habits, similar stride length, and gait, as well as body-related factors like leg length, [11], [12] and leg length discrepancy, [13], can influence the accuracy of the results. Based on prior studies, pVO2max measurements can vary depending on the height of the step box, [14] and the comfort level while stepping on the box can also affect pVO2max measurements, [15].

The Step Test can result in variations between individuals of different heights due to its fixed height nature, [16]. One method to address this issue is the Modified Queen's College Step Test, which customizes the step height based on individual body size, [17]. Studies have suggested that individual body size affects the exercise load and VO2max when using steps. The extent of this relationship has not been established. To address this gap, there is a need to analyze the relationship between body size and pVO2max using steps. Therefore, this study aims to investigate the influence of leg length on pVO2max measured using the Harvard Step Test and the Queen's College Step Test.

2 Subjects and Methods

2.1 Subjects

The study selected young men in their 20s who reside in City A in South Korea. The required sample size was determined using G*Power 3.1.9.7 (Heine Heinrich University, Düsseldorf, German), assuming a significance level (α) of 0.05, a power of 0.80, and an effect size of 0.6 based on previous research. The sample size for correlation analysis was 17 participants. Considering potential dropout rates during the experimental measurements, 20 participants were recruited (Table 1).

Table 1. General characteristics of subjects

Variable	N=18
Age(year)	22.17±2.66a
Height(㎝)	173.89±5.41
Weight(㎏)	69.59±5.80
upper leg length(cm)	**38.28±3.32**
lower leg length(cm)	**40.22±3.20**

Mean ± SD

The criteria for selecting research participants are as follows: Males in their twenties. Individuals without significant impairment in vision or somatosensation that could affect the experiment. Individuals without lower limb pain could affect the experiment during its execution. Individuals are not taking medication related to muscle strength or mental disorders—individuals without heart or lung diseases.

By the ethical standards outlined in the Helsinki Declaration, all participants were provided with a comprehensive explanation of the general details regarding the purpose and procedures of this study before the experiment. They voluntarily agreed to participate in the experiment.

This study was performed with 18 (M) college students attending S University in Chung-cheongnam-do. The age was 22.17 ± 2.66 years; height was 173.89 ± 5.41 cm, and body weight was 69.59 ± 5.80 kg.

2.2 Study Protocol

Before conducting the experiments, the participants were instructed about the procedures, and measurements of height, age, weight, and leg lengths (both upper leg length and lower leg length measured from the patella) were obtained. Upper and lower leg lengths were measured using the landmark according to Standards for Anthropometry Assessment, [18].

Each participant performed VO2max measurements using CPX equipment while running on a treadmill during the experiment. pVO2max was measured using the Harvard Step Test and the Queen's College Step Test, both performed using steps.

Before the experiments, participants received thorough explanations from researchers and were allowed to practice. To ensure adequate rest between different types of tests, a 24-hour break was provided after each examination.

The laboratory environment was maintained at a temperature of 23 degrees Celsius and 50% humidity, [19]. The research was conducted in a calm environment to minimize the influence of the sympathetic nervous system. Each measurement was performed three times, and the average value was used. All measurement results are presented as mean ± standard deviation.

2.3 Harvard Step test's and Queen`s College Step Test's pVO2max

Before commencing the Harvard Step Test and the Queen's College Step Test, the participants practiced stepping to the rhythm of each step test's metronome for 20 seconds. Then, they rested for 5 minutes while seated in a chair. After the rest period, the test was conducted, and at the 15-second mark immediately following the test, the heart rate was measured using oximetry (finger pulse oximeter, IlJin Medical, Korea). The measured heart rate was then used in the (1) to calculate pVO2max, [8].

VO2max(males) = 111.3 – (0.42 * HR) (1)

For the Harvard Step Test, participants performed the stepping movement on the step box for a maximum of 5 minutes at a rate of 120 steps/min, corresponding to 60 steps per minute, synchronized with a metronome. The test continued until either the 5-minute duration was completed or the participant voluntarily discontinued due to fatigue. The step box's height was 50.8 cm, [6].

In the Queen's College Step Test, the step box was set at a height of 41.27 cm, and participants repeated the stepping movement for 3 minutes at a metronome rate of 22 steps/min, [11].

2.4 CPX VO2max

The CPX VO2max were measured using the Bruce protocol on a motorized treadmill (Quinton TM 55 Treadmill, Cardiac Science, US).

Participants were equipped with a standard 12-lead electrocardiogram and put on a mask covering their nose and mouth. A metabolic cart (TrueOne 2400, Parvo Medics, US) was utilized to measure Oxygen consumption, and heart rate was continuously monitored through an electronic monitor (Tango M2 stress test monitor, Sun Tech Medical, US). The protocol was deemed complete when participants met the following three conditions, indicating maximum exercise capacity: 1) Respiratory Exchange Ratio (RER) > 1.1, 2) Maximal Heart Rate (HRmax) not less than 15 beats below the predicted maximum Heart Rate (HRmax = 220 – age), 3) Levelling off of VO2 despite an increase in workload, [2]

2.5 Statistical Analysis

For the data analysis in this study, SPSS for Windows (version 22.0) was employed. Descriptive statistics were used to obtain the typical characteristics of the participants.

The Pearson correlation coefficient was utilized to investigate the correlation between height, upper leg length, lower leg length, and VO2max measured using CPX. To understand the impact of these variables on static balance ability, simple linear regression analysis was employed.

Before performing the simple linear regression analysis, the selection of variables for analysis was determined through the Pearson correlation coefficient. The statistical significance level was set at $\alpha = .05$.

3 Result

3.1 Correlation between Exercise Intensity Using CPX VO2max and Upper Leg Length, Lower Leg Length, and Height

A significant positive correlation was found between CPX VO2max and lower leg length ($r = 0.595$, $P < 0.05$). However, no significant correlations were observed with the other variables ($P > 0.05$) (Table 2).

Table 2. Correlation between Exercise Intensity Using CPX VO2max and Upper Leg Length, Lower Leg Length, and Height

	Height	**upper leg length**	**lower leg length**
	173.47± 5.41	38.28± 3.32	40.22± 3.20
CPX VO2max	0.376	0.060	0.595**
(p)	0.124	0.814	0.009

Mean±SD, *p<.05, **p<.01

3.2 Simple Linear Regression Analysis Results for Lower Leg Length and Exercise Intensity using the Havard Step Test pVO2max

A simple linear regression analysis was conducted after confirming a significant correlation between exercise intensity using Havard Step Test pVO2max and lower leg length. The results of a simple linear regression analysis where the independent variable, X, represents the lower leg length(measured in centimeters) and the dependent variable, Y, represents the pVO2max value obtained from the Havard Step Test(measured in ml/kg/min). The analysis demonstrated an explanatory power of 35.4%, indicating that lower leg length significantly influenced exercise intensity using the Havard Step Test pVO2max ($P < 0.05$).

The regression equation is (2) suggesting that as lower leg length increases, exercise intensity using Havard Step Test pVO2max decreases (Table 3).

$$Y = 0.935X + 84.88, \quad (2)$$

Table 3. Simple linear regression analysis results of Tibia length on exercise intensity using the Harvard Step Test's pVO2max

	R^2	B	Significance (p)
Constant	0.354	84.88	0.000**
Lower leg length		0.935	0.009**
Regression equation	Y= 0.935 X + 84.88		

Mean±SD, *p<0.05, p<0.01**

3.3 Simple Linear Regression Analysis Results for Lower Leg Length and Exercise Intensity Using Queen's College Step pVO2max

A simple linear regression analysis was performed following the identification of a significant correlation between exercise intensity using Queen's College Step pVO2max and lower leg length. The results of a simple linear regression analysis where the independent variable, X, represents the lower leg length(measured in centimeters) and the dependent variable, Y, represents the pVO2max value obtained from the Queen's College Step Test(measured in ml/kg/min). The analysis demonstrated an explanatory power of 30%, indicating that lower leg length significantly influenced exercise intensity using the Queen's College Step pVO2max ($P < 0.05$).

The regression equation is (3) suggesting that as lower leg length increases, exercise intensity using Queen's College Step pVO2max decreases (Table 4).

$$Y = 0.836X + 79.05 \quad (3)$$

Table 4. Simple linear regression analysis results of Tibia length on exercise intensity using Queen's College step test's pVO2max.

	R^2	B	Significance (p)
Constant	0.300	79.05	0.000**
lower leg length		0.836	0.019*
Regression equation	Y= 0.836 X + 79.05		

Mean±SD, *p<0.05, **p<0.01

4 Discussion

In this study, we conducted an investigation of the correlation between VO2max measured through CPX, height, and leg length. Additionally, we analyzed the impact of leg length on equations based on widely used clinical tests, the Harvard Step Test and Queen's College Step Test.

The first result demonstrated a significant positive correlation between the VO2max and the lower leg length. Various studies have investigated the impact of leg length on oxygen consumption and exercise performance, emphasizing that longer lower leg lengths correlate with higher VO2max among long-distance runners, which is noteworthy, [20]. An increase in VO2max indicates enhanced endurance, [21], [22]. Additionally, research has shown that longer bone lengths in the lower limbs are positively associated with running performance and contribute to performance improvements in activities like jumping due to enhanced neuromuscular activation and biomechanical adaptations, [23], [24]. Moreover, research indicates a strong positive correlation between lower limb length and maximum walking speed, emphasizing its significance in performance and walking, [25]. Studies not considering VO2max have shown that longer leg lengths are associated with improved exercise performance. From the perspective of exercise efficiency, these findings could support the positive correlation between lower leg length and VO2max, as observed in our findings. However, the absence of a significant correlation between VO2max and upper leg length or height suggests that, aside from leg length, various factors such as individual exercise patterns, gait, walking speed, and stride length can influence energy consumption and exercise efficiency, [13].

In the regression analysis for pVO2max using the Harvard step test and the Queen's College step test, it was observed that as lower leg length increased, pVO2max values also increased. Notably, in the Harvard Step Test, the B value was 0.935, indicating a more significant influence on lower leg length. This result is attributed to the higher step height used in the Harvard Step Test than the Queen's College step test, [6], [11]. In the Harvard Step Test, where the step height is higher, individuals with shorter lower leg lengths may face increased difficulty in performance compared to those with longer lower leg lengths. This introduces a potential issue of performance difficulty due to the difference in step height.

Previous studies, such as the one conducted by Shahnawaz with ten male participants, set the step box height to 30-60% of the participants' lower leg length and observed a trend where lower step box heights were associated with higher VO2max, and conversely, higher step box heights were associated with lower VO2max values, [16]. In a study by [15] using the Queen's College Step Test, the height of the step box was adjusted based on the knee angle. Higher VO2max values were observed when the knee angle was 60° compared to angles exceeding 90°. It indicates that a knee angle of 60° was associated with more manageable difficulty levels [15]. These previous research findings align with our study results, providing support for our findings.

Individual body sizes highly influence methods using a fixed step height to estimate exercise difficulty or VO2max. For individuals with significant differences in body size, it is recommended to use methods that involve adjusting the step height to accommodate these variations. In conclusion, customizing the step height based on individual body size is recommended when estimating exercise difficulty or VO2max through stepping exercises. Because step height varies among individuals, it is essential to develop new methodologies to estimate cardiorespiratory capacity unaffected by the step box. This allows for a more personalized and accurate assessment of cardiopulmonary function.

This study has several limitations. It only explored methods utilizing steps to assess the impact of individual body size on exercise load differences, and the sample size of the participants is limited. Future research should address these limitations to conduct more comprehensive studies related to VO2max.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

Please, indicate the role and the contribution of each author:

- Jin-Seop Kim has conceptualized the research framework and providing the overarching research direction and guidance.
- Seong-Gil Kim organized and executed the experiments.
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