The Effect of Duration Protocols on VO2max and Presence of Plateau

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The purpose of this study was to compare VO2max, maximal power output, and presence of VO2 plateau across 4 protocol durations (5, 8, 12, and 16 min) during incremental cycling exercise to VO2max. Twenty moderately to highly trained subjects (24.9±6.6) participated in the study. The mean VO2max in the 5-min (3.55±0.80 l/min) and 8-min (3.66±0.88 l/min) duration protocols had higher and significantly higher mean value in the 8-min duration protocol compared to the 12-min (3.49±0.76 l/min) and 16-min (3.45±0.73 l/min) duration protocols. The AMPO across four protocols showed a significant difference. The AMPO for the 5-min protocol was 12%, 24%, and 35% higher than AMPO for the 8-min, 12-min and 16-min protocols. The presence of plateau was 12.5% for the 5 min protocol, 56.25% for the 8 min protocol, 37.5% for the 12 min protocol, and 56.25% for the 16 min protocol. This study indicates that the short duration protocol (<8 min) is a more valid measurement for VO2max than optimal duration protocol (8-12 min) in moderate to highly trained individuals on the cycle ergometer.

Key words : Incremental exercise, maximal power output, cycle ergometer, plateau

Introduction

The measurement of maximal oxygen intake (VO2max) determines an individual's capabilities for the uptake, transport and utilization of oxygen [17]. Since Hill and Lupton [12] developed the concept of VO2max, VO2max has been accepted as a most popular method for assessing an individual's cardiovascular performance and aerobic capacity [5,7,8,11,13].

The current recommendation for administering a VO2max test is to use exercise involving a relatively large muscle mass, a gradual increase in exercise intensity to volitional exhaustion, and to have an exercise protocol that does this in a time period of 8-12 min [6,10]. The original research of this protocol duration was performed by Buchfuhrer et al. [5]. However, this investigation only had five subjects, aged 36±9.7 yr, testing on both treadmill and cycle ergometer. Data demonstrated that VO2max values between 8-17 min on both the treadmill and cycle ergometer were higher than short duration (less than 8 min) and long duration (greater than 17 min). In addition, the short duration protocol had a significantly lower VO2max value than either the intermediate or long duration. A recent study by Lepretre et al. [16] indicated that VO2max values were not different between two durations (5 min 12 sec ± 2 min 25 sec and 12 min 6 sec ± 3 min 5 sec) on a cycle ergometer in highly trained males (aged=33±7yr). McCole et al. [17] also showed similar results on a treadmill in healthy men (N=6) and women (N=3), aged 27±4 yr. Astorino et al. [14] had 26 young subjects (16 men and 10 women), aged 21±3yr, perform incremental treadmill VO2max tests approximately 6, 10, and 14 min durations. VO2max was not different between the 6 min and 10 min duration, but it was significantly lower in the 14 min duration.

Past research [1,4,7,25] involving the VO2max test protocol durations often exceed 12 min in length. Longer protocols were often used to acquire added blood samples to test the lactate threshold or to detect the ventilatory threshold. Furthermore, longer protocol durations may also be more conductive to detecting the plateau in VO2 at VO2max, which is a main criterion for determining that VO2max has been attained. However, a plateau in VO2max is not always attained in subjects who perform incremental exercise to VO2max. In addition to, no suitable criteria for defining plateau have existed for over 82 years. Katch et al. [15] demonstrated that only 61% of tests showed a plateau when using criterion in ΔVO2 < 54 ml/min and Davis et al. [7] showed that only 74% of subjects were able to obtain a plateau (ΔVO2 < 150 ml/min) in the test. Therefore, other criteria have been used to indicate VO2max value in the absence of a plateau, including maximum heart rate values estimated for

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age, a respiratory exchange ratio of 1.15 or greater [14], and high post-exercise blood lactate levels, usually above 8 mmol/1 [3].

Clearly, the scientific evidence for appropriate test duration to determine optimal VO_2max values is currently unclear and needs further investigation. The purpose of this study is to compare VO_2max, maximal power output, and presence of VO_2 plateau across 4 protocol durations during incremental cycling exercise to VO_2max. The protocol durations will be approximately 5, 8, 12, and 16 minutes.

Materials and Methods

Subjects

Twenty subjects of moderate to high endurance training status (12 males and 8 female) participated in this study. Subjects were recruited from university and community cycling and triathlon teams. Potential subjects first completed a health history questionnaire to assess their risk factors. The Standard Operational Procedures document for the Exercise Physiology Laboratories was explained. Subject exclusion criteria included 1) the inability to refrain from training the day prior to or of each test of VO_2max, 2) no caffeine or alcohol ingestion the day prior to or of each test, 3) no exposure to altitudes <1,000 ft or >12,000 ft for the month prior to the study, 4) a VO_2max value <45 ml/kg/min for male and <40 ml/kg/min for female (as assessed from initial VO_2max test), 5) any cardiovascular, pulmonary, and metabolic disorder. 6) aged under 18 yr or over 40 for male and 50 for female.

Procedures

After subjects passed the initial health history screening, the details of the study, including risks and benefits, were explained to the subjects. Subjects then signed a university-approved informed consent. Once the informed consent was signed, subjects were answered training history questionnaire and then completed measurements for height, weight, and 3-site skinfold thicknesses by using Jackson/ Pollock equation. Subjects then performed a familiarization ramp protocol to volitional fatigue with expired gas analysis on a cycle ergometer (Excalibur Sport, Corval Lode B.V., Lode Medical Technology, Groningen, The Netherlands). The duration of familiarization trial was approximately 10-12 min. When the subject met the inclusion criteria, subjects then were scheduled to visit the laboratory on two other

occasions to complete the four tests of VO_2max. Two tests in a day were separated by approximately 45 minutes recovery period. The subjects warmed up 10 min at 75 Watt/min before the tests and test order was randomly assigned by subjects. During each test, expired air was sampled and analyzed by electronic analyzers (AEI Technologies, Model S-3A and Model CD-3H, Pittsburg, PA), and expired ventilation quantified by a turbine (L.L. Engineering Model S-430, Van Nuys, CA). Data were integrated to a computer and computations of expired gas analysis were performed each breath. Heart rate was recorded from a 3-lead electrocardiography system (Quinton 4000, Quinton, Seattle, WA) where an analogue signal of heart rate from the ECG was integrated in the data analysis software (Labview, National Instruments, Austin, TX) used to compute metabolic data.

Protocols

The duration of each test to VO_2max was based on a computer controlled ramp function to the cycle ergometer. Based on maximal power output from the familiarization trial (MPOF), ramp functions of 15- 90 Watts/min were used to determine protocol duration.

  5-min protocol: MPOF (watt) / 5 (min) × 120%
  8-min protocol: MPOF (watt) / 8 (min) × 110%
  12-min protocol: MPOF (watt) /12 (min) ×100%
  16-min protocol: MPOF (watt) /16 (min) × 90%

During the test subjects were instructed to pedal at a self-selected rate above 60 rev/min and maintain this rate throughout the trial. The criterion for termination of the exercise tests was failure to maintain 40 rev/min, or volitional fatigue.

Statistics

All data were presented as mean ± standard deviation and were analyzed using the SPSS. A one-way analysis of variance with repeated measured was used to examine differences in VO_2max across the various VO_2max tests. When a significant F ratio was obtained, Tukey's post hoc test was used to locate significant differences between means. The acceptable level of significance was set a priori at $p \leq 0.05$.

Results

The descriptive characteristics of the subjects are presented in Table 1. The characteristics indicate that subjects vary with respect to fitness level, age, height, weight, and

Table 1. Subjects characteristics

	Mean±SD	Range
Age (yr)	24.9±6.6	20-46
Height (cm)	171.9±10.6	155.7-186.1
Weight (kg)	66.8±11.1	47.3-82.3
Fat %	16.4±5.8	8.06-26.26
VO₂max (l/min)	3.66±0.88	2.38-4.93

VO_{2max}: maximal oxygen uptake in 8 min protocol.

% body fat. Overall, the average age of the subjects were 24.87±6.6 yr with males and females being 23.75±3.2 and 26±3.9 yr, respectively. The group mean for VO_2 max was 3.66±0.88 l/min with 4.44±0.39 l/min for male and 2.87±0.36 l/min for female, respectively. Both men and women were classified as above 80% based on current fitness norms. The average testing time in each protocol is shown in the table 2. The mean testing times were within 1min of the goal time for this investigation.

There are significant differences in VO_2max across the four incremental tests, $F(3, 45) = 4.71$, $p < 0.01$. Tukey's post hot test reveals that the mean VO_2max for the 8-min protocol is significantly higher compared to 12-min protocol ($p = 0.038$) and 16-min protocol ($p < 0.01$). The mean VO_2max for 8-min (3.66±0.88 l/min) protocol is the highest value and 5-min (3.55±0.80 l/min) protocol has the next highest value. However, the results indicate that 5-min protocol is not statistically different compare to 12-min (3.49±0.76 l/min) and 16-min (3.45±0.73 l/min) protocols although 5-min protocol has higher value than those protocols. Figure 1 shows the mean of VO_2max across the four tests.

The average maximal power outputs (AMPO) across four protocols are significant difference, $F(3, 45) = 164.7$, $p < 0.01$. The AMPO for 5-min protocol is 12%, 24%, and 35% higher than AMPO for 8-min, 12-min and 16-min protocols, respectively. Fig. 2 indicates the difference of average maximal power output among the four protocols. The presence of plateau is 12.5% for 5-min protocol, 56.25% for 8-min protocol, 37.5% for 12-min protocol, and 56.25% for 16-min protocol.

Table 2. Average testing time in four protocols

Variable	Mean±SD	Range
5 min	5.05±0.17 min	4.77- 5.5 min
8 min	7.77±0.23 min	7.37- 8.25 min
12 min	11.53±0.42 min	11.03- 12.07 min
16 min	16.25±0.42 min	15.38- 16.83 min

min=minutes
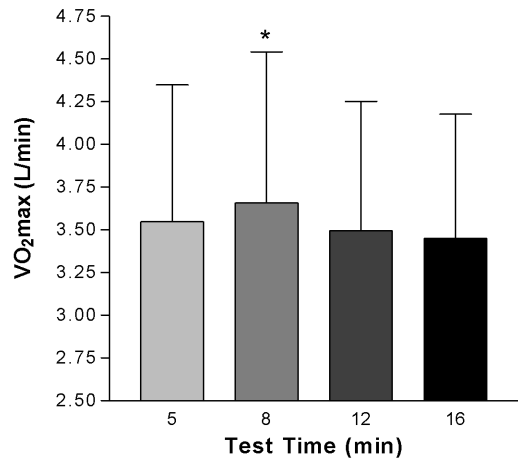
*=significantly higher compare to 12-min and 16-min protocols.

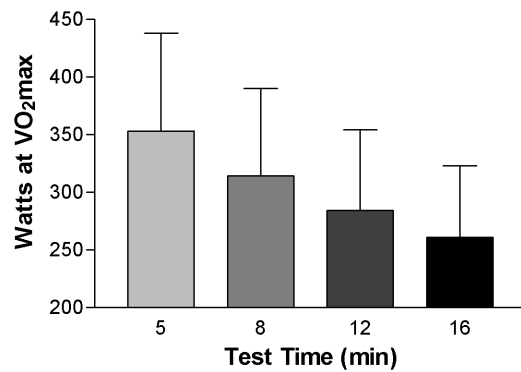Fig. 1. The mean±SD of VO₂max across the four tests.

Fig. 2. The mean±SD maximal power output at VO₂max. The means for all protocols were all significantly different from each other.

Discussion

The primary purpose of this study was to compare VO_2max, maximal power output, ventilation threshold and presence of VO_2 plateau across 4 duration protocols (5, 8, 12 and 16 min) during incremental cycling exercise to VO_2max. The significant finding in this study was that higher mean VO_2max in the 5-min (3.55±0.80) and 8-min (3.66±0.88) duration protocols and significantly higher mean value in the 8-min duration protocol compare to 12-min (3.49±0.76) and 16-min (3.45±0.73) duration protocols. These finding suggest that short duration protocol (less than 8 min) may be better protocol for the moderate to highly trained individuals on the cycle ergometer.

Our finding are in contrast to Buchfuhrer et al. [5] demonstrating that the duration of 8-17 min tests had higher VO_2max values than the <8 min tests on the treadmill and cycle ergometer. The tests lasting shorter than 8 min resulted

in a mean reduction in VO$_2$max of about 10%. However, Buchfuhrer et al. [5] were only obtained in a subset of five subjects (mean age 36±9.7, mean VO$_2$max 52±8.4 ml/kg/min). This study from 16 subjects varying in age, gender, and fitness presented that the mean VO$_2$max for the 8-min protocol was significantly higher compared to 12-min protocol and 16 min protocol. In addition, 12-min and 16-min duration protocols had lower VO$_2$max than 5-min and 8- min duration protocols although 5-min protocol wasn't statistically different to 12-min and 16-min protocols.

Our data are agreement with the previous studies [2,11, 16,17] supporting no difference between short duration (5 min) and longer duration (>12 min). Fairshter and colleagues [11] evaluated a short duration maximum exercise VO$_2$max test by comparing a 15-s incremental exercise protocol using a 1-min incremental method with fifteen subjects, aged 35±8 yr, on a cycle ergometer. During the incremental exercise tests, power output was incremented at a rate of 16.3 W (100 kpm/min) every 15 s or every minute. The 15-s protocol never exceeded 5 min and the average time of the 1 min protocol was 15 min. There was no significant difference in VO$_2$max between the two protocols (3.42±0.72 l/min vs. 3.55±0.80 l/min). In addition, McCole et al. [17] and Lepretre et al. [16] compared the effect of a short duration protocol (approximately 6 min) to a 12-min protocol duration. McCole and colleagues tested 9 healthy subjects to compare VO$_2$max between 6-min and 12-min protocols on a treadmill (3.96±0.95 l/min versus 3.96±1.20 l/min) and Lepretre et al. tested the difference between two durations on a cycle ergometer with nine highly trained male subjects (4545±500 ml/min for 6-min versus 4363±453 ml/min for 12-min). McCole et al. and Lepretre et al. demonstrated that VO$_2$max was not statistically different between the two protocols. Thus, the investigations by McCole et al. and Lepretre et al. are congruent with the findings of the present study. Those studies suggested that the highly trained individuals don't necessary long duration protocol.

Our finding is also similar to Astorino et al. [2] demonstrating that VO$_2$max was significantly higher in response to incremental protocols of approximately 7-10 min duration. Astorino et al. tested different durations (approximately 6-min, 10-min, and 14-min) during incremental treadmill VO$_2$max tests with twenty-seven healthy subjects (16 men and 11 women, ages = 21±3 yr). There was no difference in mean VO$_2$max between short (7.38±0.60 min, 3.56±0.83 l/min) and medium (10.50±0.87 min, 3.58±

0.83 l/min) duration protocols, yet VO$_2$max was significantly lower (p<0.05) in the long (13.90±1.34 min, 3.45±0.79 l/min) duration protocol. Astorino et al. explained that the lower VO$_2$max in long duration protocol might be due to lower cardiac output (Q), higher core temperature, and failure to reach the same maximal workload.

Our results the higher value in 5-min and 8-min duration protocols might be explained by the Fick equation. VO$_2$max is affected by Q and arterio-venous difference (a-vO$_2$Δ). In fact, Q and stroke volume (SV) are significantly higher in short (6-min) versus long (12-min) incremental protocols [16,17]. In spite of different Q and SV, a-vO$_2$Δ is not different between short and long protocols. McCole et al. [17] stated that Q is maximized during protocols of 5-9 min duration and Saltin [20] presented that Q was greater in 6-9 min duration protocol as compared with a test of 3-4 min. Therefore, our 8 min duration protocol may have the highest VO$_2$max as compare to other protocols as a function of Q.

The presence of plateau in this study is 12.5% for 5 min protocol, 56.25% for 8 min protocol, 37.5% for 12 min protocol, and 56.25% for 16 min protocol. In our study, we assessed the presence of plateau by using the slope of the VO$_2$-time relationship in the final 30 seconds. VO$_2$-time slope values <0.05 l/min were interpreted as a VO$_2$ plateau. Although Hill and Lupton [12] introduced the concept of a VO$_2$ plateau in the early 1920's, no suitable criteria to determine a plateau have existed for over 82 years. Mitchell et al. [19] showed that 78% of subjects obtained the plateau when using criterion in ΔVO$_2$ <54 ml/min. Eldridge et al. [9] observed a plateau in 77% of normal subjects and patients with coronary artery disease when using a Δ VO$_2$ ≤3 ml/kg/min during the final 90 s. In addition, Duncan et al. [8] demonstrated that 50% and 60% of subjects completing continuous and discontinuous VO$_2$max test on a treadmill, respectively, had a plateau phenomenon of the Taylor [23] criterion (ΔVO$_2$ ≤150 ml/min). These different results may be explained by the test protocol, the fitness and age of the subjects, the criteria used for establishing a plateau, and the VO$_2$ sampling interval [24].

Consequently, the most interesting result in this study was that the 8-min (3.66±0.88 l/min) duration protocol has the highest VO$_2$max compare to 5-min (3.55±0.80 l/min), 12-min (3.49±0.76 l/min), and 16-min (3.45±0.73 l/min) duration protocols and significantly higher value than 12-min and 16-min duration protocol. We recommend that the short duration protocol (<8 min) is a valid measurement for

VO₂max than optimal duration protocol (8-12 min) in moderate to highly trained individuals on the cycle ergometer.

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초록 : 운동검사시간이 최대산소섭취량과 정체현상에 미치는 영향

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이 연구의 목적은 자전거 에르고미터 점증 부하 운동 검사를 통하여 4가지 다른 운동 검사시간 프로토콜 (protocol)이 최대 산소 섭취량(VO_2max)과 산소 섭취량 정체($VO_2plateau$)에 어떠한 영향을 미치는지를 비교 분석하는 것이다. 연구를 위하여 설정된 운동 시간 프로토콜은 5, 8, 12 그리고 16분이다. 평균 이상의 자전거 운동 능력을 지닌 20명의 자발적 피 실험자들이 연구에 참여하였다. 8분 프로토콜의 평균 최대 산소 섭취량(3.66±0.88 l/min)은 통계적으로($p < 0.05$) 12분(3.49±0.76 l/min)과 16분 프로토콜의(3.45±0.73 l/min) 최대 산소 섭취량보다 높게 제시되었다. 5분 프로토콜의 평균 최대 산소 섭취량은 두 번째로 높은 수치를 나타냈으나, 통계적으로 12분과 16분 프로토콜의 최대 산소 섭취량과는 다르지 않았다($p > 0.05$). 평균 최대 운동 강도(average maximal power output)는 운동 검사시간들이 영향을 미치는 것으로 나타났다. 5분 프로토콜의 평균 최대 운동 강도가 8분 프로토콜 보다 12%, 12분 프로토콜 보다 24%, 그리고 16분 프로토콜 보다 35% 높게 나타났다. 산소 섭취량 정체($VO_2plateau$)는 5분 프로토콜에서 12.5%, 8분 프로토콜에서 56.25%, 12분 프로토콜에서 37.5%, 그리고 16분 프로토콜에서 56.25%의 빈도를 보였다. 이 연구는 평균 이상의 운동 능력을 지닌 피 실험자에게는 6분에서 10분 사이의 검사시간이 적합하다고 제안하고 있다.