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ESTIMATING AND TRACKING CHANGES IN VO_2MAX FROM A FIELD-BASED CRITICAL VELOCITY TEST IN COLLEGIATE SOCCER PLAYERS

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ABSTRACT

Maximal oxygen consumption (VO_{2max}) has been shown to be a significant predictor of performance in soccer players. Laboratory-based determination of VO_{2max} is time consuming and consequently not often used as an evaluation tool in collegiate soccer teams. The critical velocity (CV) test is a unique measure, requiring less time than individual graded exercise tests for VO_{2max}, and can offer analysis of anaerobic capacity, doubling its utility. **Purpose:** To examine a field-based CV test as a predictor of VO_{2max} in male collegiate soccer players, and to determine if a prediction equation using CV could accurately track changes in VO_{2max} following a 6 week off-season training intervention. **Methods:** Twelve male [mean ± SD, age (yr): 19.5 ± 1.2; height (cm): 175.9 ± 7.4; weight (kg): 71.7 ± 10.1] collegiate soccer players were recruited to participate in this study. Players completed a maximal graded running test to exhaustion to determine VO_2max. On a separate day, players completed three time-trials at various distances (1200m, 2400m, 3200m) on an outdoor track for the determination of CV and anaerobic running capacity (ARC). **Results:** A negative, but non-significant correlation was found between ARC and relative VO_{2max} ($r = -0.545$, $p = 0.067$). A positive correlation was observed between CV and relative VO_{2max} ($r = 0.744$, $p < 0.01$). Based on the significant correlation analysis, two linear regression equations were developed to predict, and one used to track relative VO_{2max} from CV. Additionally; VO_{2max} was accurately tracked using an equation from the Linear-V model. **Conclusions:** The proposed field-based method of predicting VO_2max is a time-efficient way to predict and track maximal oxygen consumption in collegiate male soccer players.

Keywords: aerobic, exercise performance, fitness, training, anaerobic

INTRODUCTION

Soccer is a sport utilizing a combination of energy systems, with short, high-speed anaerobic bursts interspaced between longer, aerobic based periods. A player's maximal oxygen consumption (VO_{2max}) (1) is strongly associated with performance, with elite players often exhibiting VO_2max values above 60 ml.min.kg^{-1}. (2,3) Furthermore, improvements in VO_{2max} have been shown to improve soccer performance, including number of sprints and involvement with the ball.(4) Laboratory-based determination of oxygen consumption is time consuming and consequently not often used as an evaluation tool in collegiate soccer teams. Additionally the pieces of equipment used in laboratories are expensive, require trained personnel, and often times are not readily accessible to teams. Thus, investigation of a time-efficient and valid field-based method for estimation of VO_2max is warranted.

Critical velocity (CV) is the running equivalent to the critical power test using cycle ergometry.(5) Bull and colleagues (6) posit that the CV test can be utilized to estimate two parameters: (1) "the maximal running velocity that can be maintained for an extended period of time without fatigue, and (2) the distance that can be run utilizing only energy sources within the muscle, called the anaerobic running capacity (ARC)." Additionally, equations may be used from CV to estimate maximal oxygen consumption. The CV theoretically represents the point at which prolonged exercise above it will illicit increases in lactate accumulation, a reduction in pH, and subsequent fatigue.(1,5,6) CV is estimated from the slope of a regression line between the distance covered and the respective completion time.(1) The CV test is a unique measure in that it requires less time than individual graded exercise tests for VO_{2max}, which in addition to its analysis of anaerobic capacity, doubles its utility.(6) These parameters can provide useful information for coaches to evaluate levels of fitness, predict performance, and assess the effectiveness of a training program. Several studies have examined different mathematical models to estimate CV.(5,6) Bull et al,(6) evaluated the physiological responses at five different estimates of CV and found as great as 20% variance from the mathematical models. This may be in part, to the various mathematical models utilized to estimate CV.(6)

While CV has demonstrated the capability to predict performance, the velocity determined from the equations may be an overestimate resulting in an inability to sustain the predicted work rate. (5). This over-prediction of CV may complicate the ability to prescribe exercise programs based on test results and cause athletes to fatigue prematurely. Premature fatiguing during training may muddle the potential beneficial training adaptions, or increase risk of injury. No study to date has proposed a single mathematical model as the single best estimate of CV. Thus, it's pertinent to apply several different models to determine the best fit.

CV has been shown in previous literature to be highly correlated to VO_{2max} in other sports such as swimming, cycling, rowing and running. (7-9) This has been followed up more recently by a study aiming to predict VO_{2max} from the CV test in female collegiate rowers.(7) To the authors knowledge however, utilization of the CV model to estimate VO_{2max} in collegiate soccer players has not yet been examined. Identifying a valid field-based predictor of VO_{2max} can improve the quality of testing and measurement of athletes, and offer a time-efficient means of testing team sports. The purpose of this study was to examine a field-based CV test as a predictor of VO_{2max} in male collegiate soccer players, and to determine if a prediction equation using CV could accurately track changes in VO_{2max} following a 6-week off season training intervention.

METHODS

Subjects

Twelve male [mean ± SD, age(yr): 19.9 ± 0.4; height(cm): 177.3 ± 2.2; weight(kg): 73.6 ± 3.0] collegiate soccer players were recruited to participate in this study. Participants were instructed to maintain their normal diet and hydration levels for the duration of the study. Additionally, water was provided at every testing session by the team's athletic trainer. All participants were made aware of the risks involved and provided written consent prior to participation in the study. The University's Institutional Review Board approved the study.

Study design

This study was a repeated-measures design conducted over an 8-week off-season period. Baseline testing occurred over the course of a week. Following a 6-week training period of standard soccer spring practice, players returned for post-testing. Standard spring practice included 3-4 soccer specific training sessions and 1-2 aerobic workouts per week. Both testing sessions (pre and post) included a maximal graded running test to exhaustion to determine VO_{2max}, followed 72 hours later by determination of CV and ARC on a 400m running track. Correlation analyses were conducted to determine the strength of the relationship between CV, ARC and VO_{2max} values. A prediction equation was formulated through a stepwise regression. Validation of the equation was conducted on the posttest scores of the players.

VO_{2max} testing

All participants performed a graded exercise test (GXT) to volitional exhaustion on a treadmill (Trackmaster, Kansas, USA) to determine VO_{2max}. All participants completed VO_{2max} testing on the same day, in a temperature and humidity controlled laboratory. Based on the protocol by Peake et al.,(10) the initial GXT velocity was set at 10 km h^{-1} at a 0% grade and increased 2 km h^{-1} every 2 minutes up to 16 km h^{-1}, followed by 1 km h^{-1} increments per minute up to 18 km h^{-1}. The gradient then increased by 2% each minute until VO_2max was achieved. Strong verbal encouragement was provided, and participants were urged to go until volitional fatigue at which point they straddled the treadmill using their hands on the handrail. The treadmill was then slowed, and a cool down period was completed. Open-circuit spirometry was used to estimate VO_{2max} with a metabolic cart (True One 2400® Metabolic Measurement System, Parvo-Medic Inc., Sandy, UT) by sampling and analyzing the breath-by-breath expired gases. The data were averaged over 15-second intervals, with the highest 15-second VO_2 value recorded as VO_{2max} if it coincided with at least two of the following criteria: (a) a plateau in heart rate or heart rate values within 10% of the age-predicted HRmax, (b) a plateau in VO_2 (defined by an increase of no more than 150 $mL \cdot min^{-1}$), or (c) a respiratory exchange rate value greater than 1.15. (11)

Determination of CV and ARC

Following a 72-hour rest period, participants completed a CV test for the determination of CV and ARC. All participants completed the test on the same day, and performed three "all-out" time trials at varying distances based off a protocol described by Galbraith et al.(12) Briefly, the

CV protocol involved three trials of increasing distance (1200m, 2400m, 3200m) on a standard 400-meter outdoor running track (on the same day). Following a standardized warm up, participants were asked to run each test as fast as possible. Fifteen minutes of passive rest and stretching was provided between trials. Heart rate was recorded prior to and at the end of each trial. CV was determined for each participant using three mathematical models:

1) Linear-Total Distance (TD) model: TD=ARC+CV·*t*; where *t* is equal to time,(5,13)

2) Linear-Velocity (V): *v*=ARC·(1/*t*)+CV(5); and

3) Nonlinear-2: *t*=ARC/(*v*-CV) (6,14)

A custom-written software program (LabView v.12) was used to calculate CV and ARC from each of the three models.

Statistical Analysis

Pearson's product-moment correlations were employed to examine the relationship between CV and ARC (determined from each of the three mathematical models) and VO_{2max}. If significant correlations were present, linear regression was used to generate prediction equations for determining VO_{2max} using the variables from the different models. Observed VO_{2max} values were compared to the predicted VO_{2max} values after six weeks of training via repeated measures analysis of variance (ANOVA) to determine the validity of the equations. The α level was set at $p \leq 0.05$, and all values are expressed as means ± SD.

RESULTS

Negative, but non-significant correlations were found between ARC and relative VO_{2max} for all three models (r = -0.130-0.509, p = 0.09 - 0.69). A significant, positive correlation was observed between Linear-TD CV and relative VO_2max (r = 0.744, p = 0.006), as well as Linear-V CV and relative VO_{2max} (r = 0.672, p = 0.017) (Figure 1). The Nonlinear 2 model produced a positive, but non-significant correlation between CV and relative VO_{2max} (r = 0.532, p = 0.075). Based on the significant correlation analyses, two linear regression equations were developed to predict relative VO_{2max} from Linear-TD CV and Linear-V CV:

Equation 1: VO_{2max} $(ml \cdot kg \cdot min^{-1})$= 7.663[Linear-TD CV]+29.885; SEE=3.23 (ml/kg/min)

Equation 2: VO_{2max} $(ml \cdot kg \cdot min^{-1})$= 8.417[Linear-V CV]+26.143; SEE=3.58 (ml/kg/min)

Although both equations resulted in a strong relationship with low prediction errors, Equation 1 was used to track changes in VO_{2max} using CV due to the lower SEE and higher correlation coefficient (Table 1). Repeated measures ANOVA indicated no significant difference between observed and predicted VO_{2max} $(ml \cdot kg \cdot min^{-1})$ following six weeks of training (p=0.171) (Table 2).

Figure 1a The relationship between CV estimated from the Linear-TD model and observed VO_{2max}.

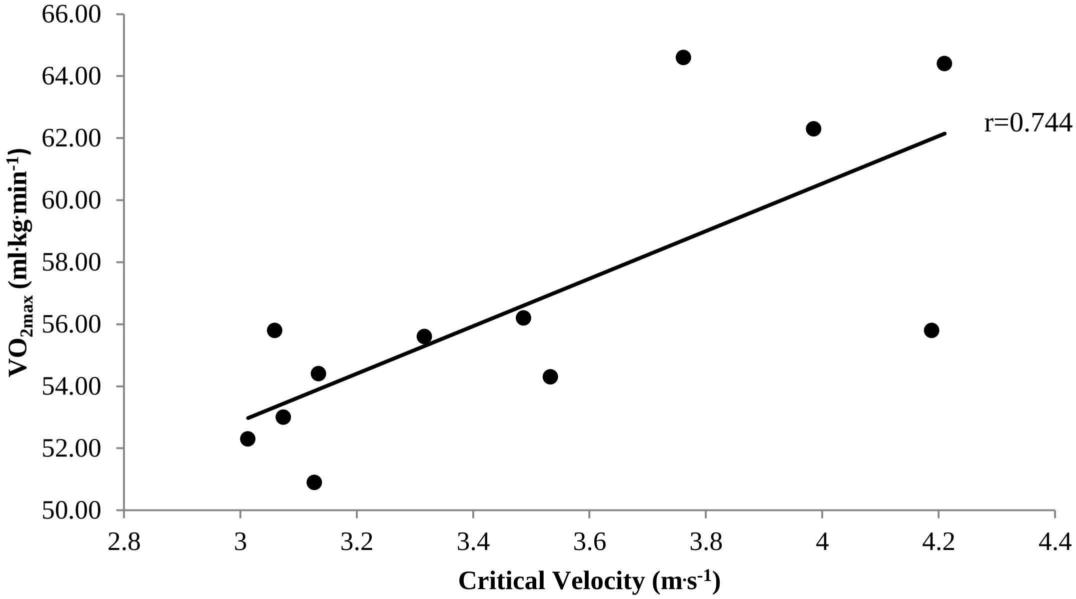

Figure 1b The relationship between CV estimated from the Linear-V model and observed VO_{2max}.

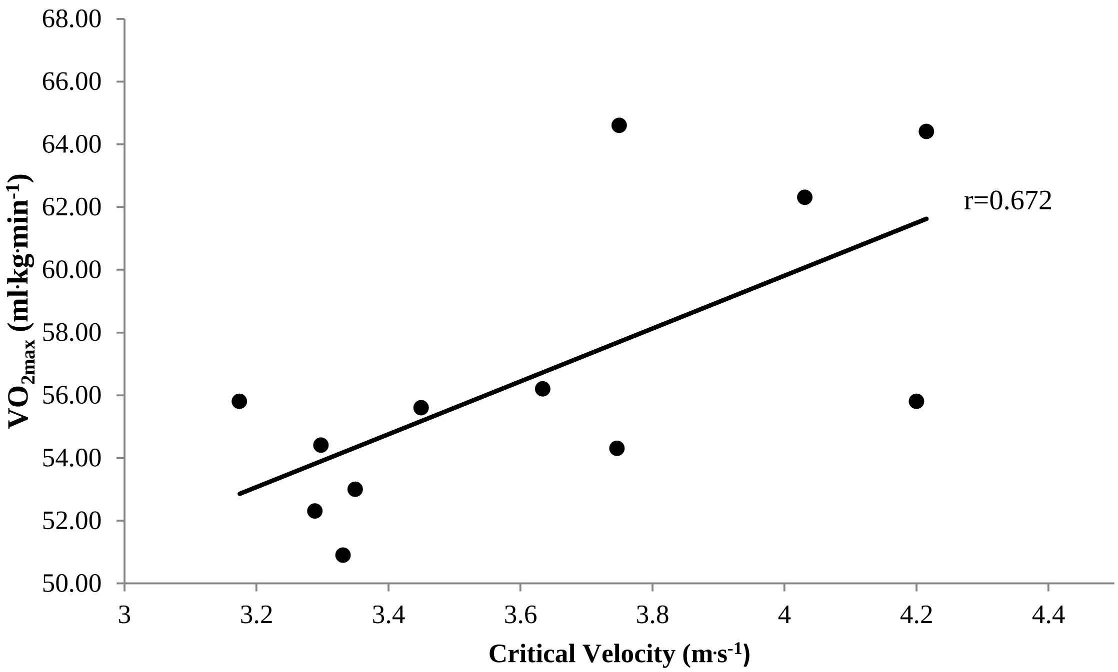

Table 1. VO_{2max} prediction equations using CV from the Linear-TD and Linear-V models

	Observed VO_{2max} $(ml \cdot kg \cdot min^{-1})$	Predicted VO_{2max} $(ml \cdot kg \cdot min^{-1})$	r	SEE $(ml \cdot kg \cdot min^{-1})$	%SEE	CE	*p*	TE $(ml \cdot kg \cdot min^{-1})$	%TE
Linear-TD model	56.63 ± 4.61	56.35 ± 3.41	0.744	3.23	5.7	-0.28	0.757	2.96	5.2
Linear-V model	56.63 ± 4.61	56.34 ± 3.06	0.672	3.58	6.3	-0.29	0.774	3.28	5.8

CE= constant error;
SEE= standard error of estimate;
TE=total error;
%SEE calculated as SEE/mean of observed VO_{2max} X 100;
%TE calculated as TE/mean of observed VO_{2max} X 100.

Table 2. Observed and predicted relative VO_{2max} and delta scores following 6 weeks of offseason training.

	Pre	**Post**	**Δ Pre-Post**
Observed $VO_{2max}$$(ml \cdot kg \cdot min^{-1})$	56.63±4.61	56.20±3.15	-0.28±0.48
Predicted VO_{2max} $(ml \cdot kg \cdot min^{-1})$ from Linear TD	56.35±3.41	57.75±2.80	2.14±5.0

DISCUSSION

The results of the present investigation support the use of the CV test as a field-based method for predicting relative VO_{2max} in male collegiate soccer players.

VO_{2max} has been repeatedly shown to be an indicator of performance in soccer players.(3,4,15) At least 90% of the energy demands of soccer come from aerobic processes(16) with players running approximately 10km during a 90-minute match(17) at an intensity close to 80-90% of maximal heart rate.(4,17) Previous research has demonstrated a significant relationship between VO_{2max} and distance covered during a match,(17) and a correlation between VO_{2max} and placement in elite European leagues.(18) Although aerobic metabolism controls the majority of energy delivery during a soccer match, short sprints, jumps, tackles, and duel play are highly influenced by anaerobic capacity, and are often crucial for the match outcome.(19) In recent years, researchers have attempted to find time-efficient, field based methods of estimating VO_{2max} in athletes.(20) Most soccer-specific endurance tests use an intermittent pattern stimulating match play. Units of measurement

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vary, and include the time to cover a specified distance, distance covered in a limited amount of time, and time to fatigue. The Beep test, the Yo-Yo Intermittent Recovery test, and the Hoff test are all commonly used endurance tests in soccer because of their ability to monitor each player's endurance throughout a soccer season. Although these tests have been shown to be significantly correlated to VO_{2max},(21-23) overall accuracy and their applicability to "non-elite" teams is questionable. Moreover, less is known of the ability of these tests to accurately track changes in VO_{2max} across a season.

In recent years, researchers have attempted to find time-efficient, field based methods of estimating VO_{2max} in athletes.(20) The CV test has been proposed for coaches as a practical alternative to the traditional VO_{2max} test to determine aerobic endurance level and performance due to the field-based nature of the protocol and minimal equipment needed.(24) Previous studies have found a strong correlation between CV estimates and VO_{2max} in a number,(7-9) suggesting its use as a practical alternative to measuring VO_{2max} in the absence of a metabolic cart. Additionally, Kendall et al.(7) found that a regression equation using CV and ARC could accurately predict VO_{2max} in a group of collegiate-level rowers. The authors noted that CV was the single best predictor of VO_2max, and proposed that changes in CV and ARC could be used to estimate changes in VO_{2max}.

Data from the present study supports previous findings, showing CV to be a significant predictor of VO_{2max} in male collegiate soccer players. There was no significant difference between observed and predicted VO_{2max} values using both linear models, indicating that a generalized equation can be used to estimate VO_{2max} from CV in this population. Furthermore, the current study is the first of its kind to use a prediction equation using CV to track changes in VO_{2max} following an offseason training program. Using an equation derived from the Linear-TD model, we were able to assess changes in VO_{2max} after a 6-week training period. No significant differences were found between observed and predicted VO_{2max} values derived from the CV equation (56.20 ± 3.15 $ml \cdot kg \cdot min^{-1}$ vs. 57.75 ± 2.80 $ml \cdot kg \cdot min^{-1}$). It is important to note however, that the predicted post-test VO_{2max} increased non-significantly despite a non-significant decrease in observed VO_{2max}. It may be possible, however, that a slight learning effect for the CV protocol was experienced, resulting in a non-significant overestimation of VO_{2max}.

Contrary to previous studies utilizing CV and ARC in equations to predict VO_{2max},(7) our analyses found no significant correlation between ARC and VO_2max, and consequently solely utilized CV from the linear-TD model in our regression equation to predict and track VO_{2max}. A closer examination of the relationship between ARC and VO_{2max} in collegiate soccer players may be warranted in future studies. Nevertheless, knowledge of an athlete's ARC, in a sport that involves short periods of high intensity sprints across a 90-minute timespan, will still provide useful information. ARC provides an estimate of the distance a person can run on anaerobic stores alone,(5,6) and can provide coaches with a tool to assess athletes and specify training needs.

Laboratory-based estimation of VO_{2max} requires access to a lab, a metabolic cart, and professionals trained to administer testing and analyze results. Furthermore, testing can be extremely time-consuming, lowering its feasibility for use with team sports. Field-based determination of CV however, can test multiple athletes at one time, with our protocol in particular taking just over an hour to complete. This offers coaches an attractive tool to estimate VO_{2max}, which can then be used to assess levels of fitness, evaluate training programs, and prescribe appropriate intensities.

Furthermore, the CV test offers a more comprehensive evaluation of an athlete (including both aerobic and anaerobic indices), which may be more specific to the intermittent nature of soccer. Additional studies are needed to validate the regression equation and to determine the accuracy of the equation for tracking changes after a training intervention. Finally, investigation into the utility of this test in soccer players of different skill levels, or athletes of different sports is warranted to determine its generalizability.

PRACTICAL APPLICATIONS

The proposed field-based method of predicting VO_{2max} is a time-efficient way to predict maximal oxygen consumption in collegiate male soccer players, which may be helpful for coaches and athletes when determining strengths and weaknesses of each athlete. The utility of the CV test in deriving three estimates of measures (CV, ARC, and VO_{2max}) offers considerable advantage over traditional field estimates of aerobic capacity. One benefit of the proposed prediction method is the ability to test both team, and individual improvements. The application to a team based result, rather than an individual, may decrease the variability between CV and VO_{2max} seen in individuals with higher VO_{2max}. The CV test can also double as a training tool to prescribe training intensities above or below a certain threshold, along with providing individual prescription to athletes.

CONCLUSIONS

The positive relationship between CV and VO_{2max} suggests that the CV test may be a practical alternative to measuring and tracking maximal oxygen uptake in the absence of a metabolic cart. Coaches should consider the CV test, along with the regression equations offered, to obtain multi-component analyses of their players.

Conflict of Interest

No conflict of interest was declared for this study.

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