Original Article

Velocity at maximal oxygen uptake best predicts 3 km race time in collegiate distance runners

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ABSTRACT

Purpose: There is a lack of scientific investigation into the predictors of 3 km race performance in collegiate distance runners. The purpose of this investigation was to determine what physiological variables best predict 3 km race time in a group of collegiate distance runners. Methods: Twenty-one endurance trained runners (11 men, 10 women) volunteered for this investigation. Running economy (RE) and maximal oxygen uptake (VO_2max) testing were conducted within 9 ± 6 days of the race in a single session. All participants ran in a 3 km race at an NCAA sanctioned track meet. Pearson's product moment correlations were performed between 3 km race time and velocity at VO_2max (vVO_2max), relative VO_2max, RE at 9.7, 11.3, 12.9, and 14.5 km•hr^{-1} and percent of VO_2max. A stepwise multiple regression was performed with 3 km race time as the dependent variable and independent variables of vVO_2max, VO_2max, RE9.7, RE11.3, RE12.9, RE14.5. Results: The results revealed that vVO_2max was the best predictor of 3 km race performance in a heterogeneous group of collegiate distance runners (R^2=0.90). For the men, vVO_2max remained the best predictor of 3 km race performance (R^2=0.49). For the women, the best predictors of 3 km performance were vVO_2max and VO_2max (R^2=0.97). Conclusions: Distance coaches should consider emphasizing vVO_2max as a primary factor in training to improve 3 km race performance and conversely, the pace achieved in a 3-km race is a good predictor of vVO_2max. **Key words:** RUNNING PERFORMANCE, RUNNING ECONOMY, PERFORMANCE PREDICTION.

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INTRODUCTION

A number of factors have been used in predicting distance running performance including maximal oxygen uptake (VO_2max), running economy (RE), velocity at VO_2max (vVO_2max), or peak treadmill velocity, and lactate threshold (LT) (Conley & Krahenbuhl, 1980; Costill, Thomason, & Roberts, 1973; Foster, Costill, Daniels, & Fink, 1978; Grant, Craig, Wilson, & Aitchison, 1997; Morgan, Baldini, Martin, & Kohrt, 1989; Noakes, Myburgh, & Schall, 1990; Slattery, Wallace, Murphy, & Coutts, 2006; Stratton et al., 2009; Yoshida et al., 1990). Investigations have shown that in a heterogeneous group of runners, VO_2max has a high correlation with endurance performance (Costill et al., 1973; Foster et al., 1978). However, in groups of well-trained or elite distance runners that are homogenous in relation to VO_2max, this relationship tends to be low to moderate and other factors may become more important in determining distance running performance (Conley & Krahenbuhl, 1980; Morgan et al., 1989). Whereas these studies examined distance performance at 10 km and beyond, Yoshida et al. (1990) and Grant et al. (1997) similarly found significant relationships between 3 km running performance and VO_2max in a group of distance trained women and men, respectively. Moreover, Slattery et al. (2006) found a significant relationship between 3 km time trial performance and VO_2max in 16 experienced male triathletes. Studies at 5 km have also found significant relationships between VO_2max and running performance (Baumann, Rupp, Ingalls, & Doyle, 2012; Stratton et al., 2009).

RE has been defined as the relative oxygen uptake (expressed in $ml•kg^{-1}•min^{-1}$) at a given running speed (Conley & Krahenbuhl, 1980; Daniels, 1985). RE has been identified as a factor associated with running performance in a homogenous group of distance runners over the 10 km distance (Conley & Krahenbuhl, 1980; Morgan et al., 1989). For investigations examining RE and middle distance events, neither of the investigations of Yoshida et al. (1990) nor Slattery et al. (2006) showed a significant relationship between RE and 3 km performance. Both of these investigations were performed with heterogeneous groups of athletes. At 5 km, neither Stratton et al. (2009) nor Baumann et al. (2012) showed a significant relationship between RE and run performance.

The vVO2max has been included along with other factors in regression-generated prediction equations of endurance performance. For example, Noakes et al. (1990) showed that peak treadmill velocity was the best laboratory predictor of running performance at 10, 21.1, 42.2, and 90 km distances in ultra-marathon runners, and it was also the best predictor of running performance for 10 and 21.1 km distances in marathon runners. Later work by Grant et al. (1997) reported that the velocity at VO_2max accounted for 74% of the variance in 3 km run performance in male distance runners. Slattery et al. (2006) found that vVO_2max and velocity at LT were significant predictors of 3 km run performance in well trained triathletes. In an investigation of 5 km performance, Stratton et al. (2009) showed that peak treadmill velocity was found to be the single best predictor of performance when compared with lactate threshold, VO_2max, and VO_2 at LT.

The available literature examining the factors that determine running performance, complicated by studies involving diverse athlete groups and running distances is not yet conclusive. Better understanding the factors that determine running performance, especially in shorter distance events common in collegiate running, can help coaches maximize their limited training time to best prepare their athletes. The purpose of this investigation was to determine which physiological variables best predict 3 km race time in a group of collegiate distance runners and examine the relationships between 3 km race time and these physiological variables.

METHODS

Participants

Twenty-one endurance trained Division I collegiate runners (11 men, 10 women) volunteered for this investigation. Participant demographic data is presented in Table 1. Participants reported to the human performance laboratory (HPL) on one occasion for RE and VO_2max testing. All participants entered and ran in a National Collegiate Athletic Association (NCAA) sanctioned 4-team track meet, running the 3 km race. RE and VO_2max testing was conducted within 9 ± 6 days of the race, beginning two weeks prior to the race and concluding 3 weeks following the race. The track meet was separated into men's and women's events with the races held on a 400m synthetic track with calm wind conditions and a temperature of 14˚C. The university institutional review board approved the investigation and all participants provided written informed consent prior to data collection.

Table 1. Participant data.

Variable	Overall (*n* = 21)	Men (*n* = 11)	Women (*n* = 10)	Cohen's d
Weight (kg)	60.0 ± 7.5	65.4 ± 4.0	54.1 ± 5.6*	2.332
Height (cm)	171.7 ± 8.5	177.6 ± 4.8	165.1 ± 6.7*	2.148
Age (yrs)	19.8 ± 1.4	19.6 ± 1.6	19.9 ± 1.2	0.189
VO_2max (ml•kg^{-1}•min^{-1})	63.4 ± 7.3	68.2 ± 5.4	58.1 ± 5.1*	1.908
vVO_2max (km•hr^{-1})	19.3 ± 2.1	21.1 ± 0.6	17.4 ± 0.8*	5.405
3K Time (sec)	571.9 ± 52.5	528.6 ± 13.1	619.5 ± 33.5*	3.578
RE9.7 (ml•kg^{-1}•min^{-1})	34.5 ± 2.6	34.7 ± 1.9	34.3 ± 3.3	0.163
RE9.7%	55.0 ± 6.9	51.2 ± 4.4	59.3 ± 6.8*	1.422
RE11.3 (ml•kg^{-1}•min^{-1})	38.6 ± 2.9	38.5 ± 2.4	38.7 ±3.5	0.052
RE11.3%	61.5 ± 7.7	56.7 ± 4.6	66.8 ± 6.9*	1.733
RE12.9 (ml•kg^{-1}•min^{-1})	44.6 ± 3.5	44.6 ± 2.8	44.7 ± 4.3	0.038
RE12.9%	71.2 ± 9.2	65.6 ± 4.8	77.4 ± 8.9*	1.641
RE14.5 (ml•kg^{-1}•min^{-1})	49.7 ± 4.3	49.9 ± 3.4	49.3 ± 5.6	0.152
RE14.5%	78.4 ± 9.6	73.5 ± 4.9	85.2 ± 10.6*	1.425

**Significant difference between groups at $p \leq 0.05$; vVO_2max: velocity at VO_2max; RE9.7: VO_2 at 9.7 km•hr^{-1}; RE9.7%: % of VO_2max at 9.7 km•hr^{-1}; RE11.3: VO_2 at 11.3 km•hr^{-1}; RE11.3%: % of VO_2max at 11.3 km•hr^{-1}; RE12.9: VO_2 at 12.9 km•hr^{-1}; RE12.9%: % of VO_2max at 12.9 km•hr^{-1}; RE14.5: VO_2 at 14.5 km•hr^{-1}; RE14.5%: % of VO_2max at 14.5 km•hr^{-1}; MD = Mean Difference.*

Laboratory testing

RE and VO_2max testing was performed during one visit to the HPL. Participants were allowed a 5-min self-paced warm-up on the treadmill (Woodway 4Front; Waukasha, WI). Following the 5-min warm-up, runners were fitted with a mask (Hans Rudolph 7450 V2; Shawnee, Kansas) and heart rate monitor (COSMED SZ990; Rome, Italy) prior to returning to the treadmill for the RE testing. During the RE portion of the laboratory testing, participants completed 5 minute stages at 9.7, 11.3, 12.9, and 14.5 km•hr^{-1} as a continuous, 20 min run. Expired gases were collected and analyzed continuously via metabolic cart (COSMED Quark CPET; Rome, Italy). The analyzer and turbine were calibrated in accordance with manufacturer's recommendations before each test. The mean oxygen uptake (VO_2) over the final minute of each running speed during the RE testing was used for analysis. At the conclusion of the RE testing, participants were given a 10 min rest prior to VO_2max testing. VO_2max testing began at the final speed of the RE portion with speed increased by 0.5 km•hr^{-1} (6 – 7 sec•mile^{-1}) every minute until the runner could no longer continue. Expired gases were collected and monitored throughout the VO_2max portion of the test. The VO_2 data during this portion of the test was averaged over 30 sec periods with the highest 30 sec VO_2 data considered VO_2max. The criteria for determining if VO_2max was achieved was less than a 2.1 ml•kg^{-1}•min^{-1} increase in VO_2 with an increase in running speed (Taylor, Buskirk, & Henschel, 1955). The velocity corresponding to the 30 sec period where VO_2max occurred was defined as the vVO_2max.

Track meet data collection

Runners performed their normal pre-race warm-up consisting of ~3.2 km run, followed by individually determined dynamic and static stretching routines. All runners performed pre-race sprints after stretching and wore racing flats or spiked track shoes. Times were measured via stopwatch by race officials. One co-investigator used a stopwatch to confirm race official times. The 3 km race was conducted in accordance with NCAA track and field rules, with runners being called to their marks and then a starter's gun used to begin the race. The race was 7.5 laps around the 400 m track, utilizing waterfall starts, where each runner ran the same distance to the first curve. Runners were encouraged to give maximal effort and unlike a time trial, there were other competitors, spectators, and coaches to provide additional motivation. Official event times were used in data analysis for this investigation.

Statistical analysis

All data are provided as mean ± standard deviation. Pearson's product moment correlations were performed between 3 km race time and vVO_2max, VO_2max, RE at 9.7, 11.3, 12.9, and 14.5 km•hr^{-1}, measured in ml•kg^{-1}•min^{-1} and percent of VO_2max. Independent samples t-tests were used to examine group differences in performance measures. A stepwise multiple regression was performed with 3 km race time as the dependent variable and the independent variables of vVO_2max, VO_2max, RE9.7, RE11.3, RE12.9, RE14.5. A *p*-value of 0.05 was used for significance in all calculations which were conducted using statistical package SPSS, version 22 (IBM Corp.; Armonk, NY).

RESULTS

From Table 1, the mean VO_2max value of 63.4 ± 7.3 ml•kg^{-1}•min^{-1} is indicative of a group of well-trained aerobic athletes. The Pearson's product moment correlations are presented in Table 2. A scatterplot of vVO_2max versus 3 km race time is presented in Figure 1. The results of the stepwise regression indicate that vVO_2max was the single best predictor of 3 km race time for the group. As a group, none of the other variables added significance to the prediction equation. The R^2 value was 0.90 and the prediction equation was:

$$\text{3 km race time (in seconds)} = 1053.75 - 40.09\,(vVO_2max)$$

When separated by sex, the prediction equation factors remain the same for the men, with vVO_2max being the single best predictor of 3 km race time. No other factors added significantly to the prediction of 3 km race time. However, the R^2 value was 0.49. The prediction equation for the men was:

$$3\text{ km race time (in seconds)} = 843.27 - 23.99\,(vVO_2max)$$

For the women, VO_2max was also a significant factor in the prediction equation for 3 km race time. The R^2 value with both vVO_2max and VO_2max was 0.97 and the prediction equation was:

$$3\text{ km race time (in seconds)} = 1126.41 - 20.72\,(vVO_2max) - 4.89\,(VO_2max)$$

Table 2. Group, men, and women pearson product moment correlations with 3 km race time.

Variable		**vVO_2 max**	**VO_2 max**	**RE9.7**	**RE9.7%**	**RE11.3**	**RE11.3%**	**RE12.9**	**RE12.9%**	**RE14.5**	**RE14.5%**
3 km Race Time											
Group	*r*	-0.949	-0.865	-0.152	0.749	-0.078	0.796	-0.095	0.780	-0.176	0.763
	p	<0.001	<0.001	0.510	<0.001	0.738	<0.001	0.350	<0.001	0.235	<0.001
Men	*r*	-0.697	-0.523	-0.134	0.445	-0.031	0.534	0.016	0.627	0.013	0.680
	p	0.017	0.099	0.695	0.170	0.929	0.090	0.964	0.039	0.969	0.021
Women	*r*	-0.861	-0.971	-0.174	0.636	-0.284	0.608	-0.199	0.625	-0.291	0.561
	p	0.003	<0.001	0.631	0.048	0.426	0.062	0.319	0.049	0.243	0.074

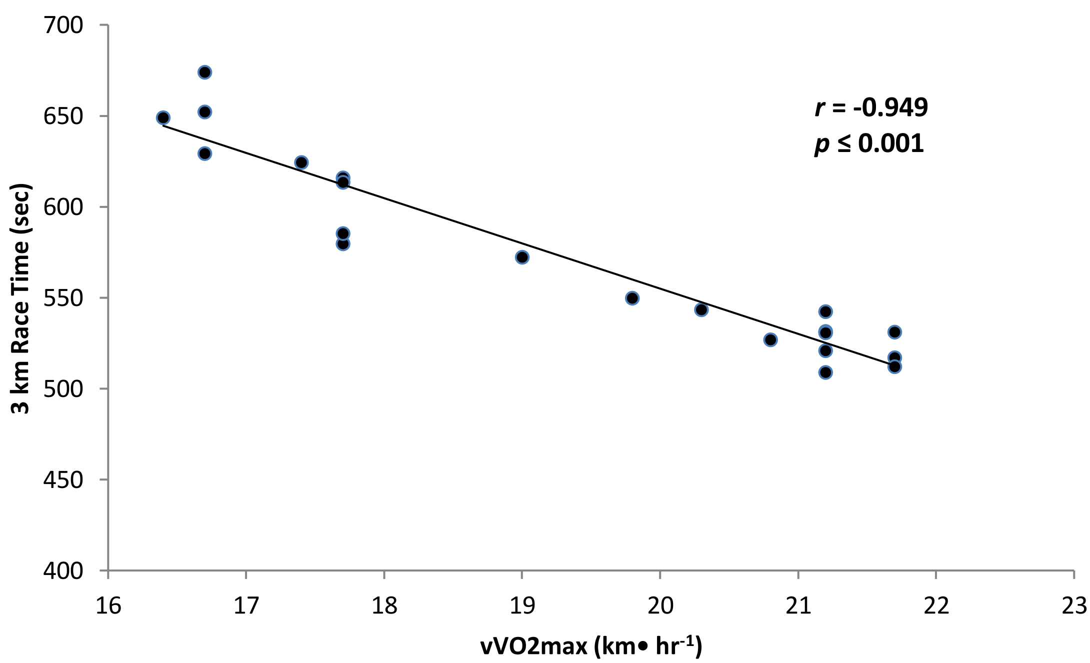

Figure 1. Scatterplot of vVO2max vs. 3 km race time.

DISCUSSION

The results of this investigation revealed that vVO_2max was the best predictor of 3 km race performance in a group of collegiate distance runners with heterogeneous VO_2max values. However, when examined by sex, vVO_2max as the single significant predictor only held true for the men. For the women, vVO_2max and VO_2max were both significant predictors ($p < 0.05$) of 3 km race time. These results are in agreement with previous studies in male triathletes where peak treadmill velocity during their VO_2max test was the best predictor of 3 km time trial performance (Slattery, et al., 2006). Also in a group of untrained volunteers, following 6-weeks of endurance training, Stratton et al. (2009) showed final treadmill velocity during a VO_2max test was the best single predictor of 5 km run performance. Among well-trained male middle and long distance runners, Grant et al. (1997) found that vVO_2max was the third best predictor of 3 km run performance ($R^2 = 0.74$) behind velocity at LT and velocity at 4 mmol of blood lactate. As stated by Slattery et al. (2006), this close relationship between vVO_2max and 3 km race time may be due to the fact that middle distance races are completed at a velocity similar to that of VO_2max, whereas longer distance races may be completed at velocities closer to lactate threshold, and therefore vVO_2max may become a better predictor of performance in the middle distance events.

The correlational findings from this investigation are similar to the results in other studies examining vVO_2max or peak treadmill velocity and 3 or 5 km run performance. Correlation coefficients ranging from 0.86 to 0.91 have been reported in untrained individuals running 5 km (Stratton et al., 2009), and in 3 km performance in male triathletes (Slattery et al., 2006), and well-trained men (Grant et al., 1997). Similar results were seen in the present study where 3 km race time had a significant correlation with vVO_2max ($r = -0.949$). As Jones (1998) reported, the 3 km distance is run at an effort similar to VO_2max so it should be expected that measures reflecting aerobic qualities would have significant correlations. In the present study there was a strong relationship between VO_2max and 3 km race time for the group ($r = -0.865$, $p < 0.001$). This is similar to that seen in previous research at different distances or populations. In the studies by Grant et al. (1997) and Slattery et al. (2006), the correlation between VO_2max and 3 km performance was 0.70 and 0.80, respectively, which is similar to those seen in the present investigation of collegiate distance runners ($r = 0.865$). Baumann et al. (2012) showed a significant correlation of $r = 0.80$ between VO_2max and 5 km performance. When the present study group is separated by sex, the relationship for the men is no longer significant ($r = -0.523$, $p = 0.099$) however it is similar to that seen by Morgan et al. (1989) in their heterogeneous population of male runners and 10 km run time and the moderate correlation coefficient and low alpha statistic suggest trends towards significance. The women in the present study maintained a strong relationship between VO_2max and 3 km race time ($r = -0.971$, $p < 0.001$). The runners in the present study completed the 3 km race at 98.6 ± 3.1% of their vVO_2max.

In the present study, absolute RE at all of the running speeds did not correlate with 3 km run time when expressed in $ml \cdot kg^{-1} \cdot min^{-1}$ for the group or by sex at any speed. This is different than reported by Grant et al. (1997) who showed a significant relationship ($r = -0.53$) between RE at 14.5 $km \cdot hr^{-1}$ and 3 km run velocity in male endurance runners. However, when RE is expressed as a percent of VO_2max, at 14.5 $km \cdot hr^{-1}$ the findings of the present study are similar to that of Grant et al. (1997) who showed a significant relationship, $r = -0.860$. In the present study the correlation for the group was $r = 0.763$ and for the male runners $r = 0.680$. When examined by sex, only the women had significant relationships between 3 km race time and RE expressed as a percent of VO_2max at 9.7 and 12.9 $km \cdot hr^{-1}$. In the men, there were significant relationships between 3 km race time and RE expressed as a percent of VO_2max at 12.9 and 14.5 $km \cdot hr^{-1}$. As noted by Bragada et al. (2010), running economy may not be a significant factor in short duration races, but may play a role in longer distance races.

There were several limitations to the present study. During the data collection, a scientific-quality lactate analyzer was not available and therefore blood lactate was not measured. Lactate has been shown to be a predictor of endurance performance in middle distance efforts of 3 to 5 km (Grant et al., 1997; Slattery et al., 2006; Yoshida et al., 1990). RE and VO_2max testing were completed in a single test session in order to minimize the impact on academic schedules and training sessions for these student athletes. Additionally, a larger sample would have possibly affected the statistics, especially when broken down by sex.

CONCLUSION

There is limited data in the scientific literature examining collegiate 3 km race performance and the physiologic factors that impact that performance. The 3 km race distance is a standard race during the indoor track season and run periodically during the outdoor track season. The results of this investigation reveal that in a heterogeneous group of collegiate distance runners, vVO_2max was the best predictor of 3 km race time and this single predictor held true for the male runners. However, for the female runners, VO_2max was added to the prediction equation as a significant predictor variable along with vVO_2max in predicting 3 km race time. Future research should continue to examine these factors in an effort to better understand the variables that best predict middle distance performance in collegiate runners. In particular in men middle distance collegiate athletes, where in this investigation only 50% of the variance in 3 km performance could be explained by vVO_2max. Additionally, if vVO_2max is an important contributor to middle distance run success, determining what training methods provide the best stimulus to effect an improvement in this factor would be quite beneficial.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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