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Predictors of long-distance race performance in master runners

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Abstract

Peak aerobic power ($V·O_{2peak}$) and parameters related to training are associated with long-distance running performance in master athletes. Running economy (RE) predicts performance in younger runners, but its relationship to racing ability in older athletes is unclear. Allometrically scaled RE (allo$V·O_2$; ml kg $^{-0.66}$ min^{-1}), energy cost (EC; kcal kg^{-1} km^{-1}), and percent of $V·O_{2peak}$ (%$V·O_{2peak}$) required in a submaximal bout represent RE more accurately than $V·O_2$ does. The VDOT score, estimating $V·O_{2peak}$ and RE, can be used to compare races of different distances.

Purpose: To determine predictors of temperature-converted VDOT in master runners training for a long-distance race (10-26.2 mi).

Methods: Twenty-three master runners (age 57±9 years; eight females) performed treadmill marathon-intensity-effort (MIE) and $V·O_{2peak}$ tests within four weeks of their goal race. The MIE occurred at 88% of predicted maximum heart rate, which corresponds to estimated marathon intensity. Participants completed online training-history surveys. Forward stepwise multiple linear regression was used to find key predictors of VDOT. The alpha level for significance was .05.

Results: Converted VDOT was significantly associated with three-year peak weekly training distance (3YP) ($r = 0.454$, $p = .039$), $V·O_{2peak}$ ($r = 0.845$, $p = .000$), allo$V·O_2$ ($r = 0.623$, $p = .005$), and EC ($r = -0.528$, $p = .018$). The best-fitting model included $V·O_{2peak}$ and 3YP ($r = 0.898$).

Conclusion: Physiological and training factors are related to race performance in master runners. The best predictors of VDOT are $V·O_{2peak}$ and 3YP. Training to enhance these variables may improve distance-running performance in masters.

Keywords

$V·O_{2peak}$; Running economy; Training

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INTRODUCTION

Peak aerobic power ($V \cdot O_{2peak}$) is a notable predictor of performance in long-distance running events (Basset & Howley, 2000). Differences in $V \cdot O_{2peak}$ can account for interindividual differences in race times from one mile to the marathon (Foster, 1983). Among master runners, defined as runners aged 40 years and older, $V \cdot O_{2peak}$ is an important predictor of distance running performance (Wiswell et al., 2000). As endurance athletes age beyond their mid-twenties, their $V \cdot O_{2peak}$ decreases (Reed & Gibbs, 2016). Race times in long-distance events, i.e. 10 km to the marathon, increase by approximately 6-9% with each decade of age beyond the mid- to late thirties. Performance decrements tend to become steeper after the late 50s and again after age 70 (Brisswalter & Nosaka, 2013; Brisswalter, Wu, Sultana, Bernard, & Abbiss, 2014; Joyner, 1993; Reaburn & Dascombe, 2008; Tanaka & Seals, 2003, 2008).

Several studies have shown that training factors may play a role in maintaining $V \cdot O_{2peak}$ with age, or slowing its decline (Dehn & Bruce, 1972; Dill, Robinson, & Ross, 1967; Pollock, Foster, Knapp, Rod, & Schmidt, 1987; Rogers, Hagberg, Martin, Ehsani, & Holloszy, 1990; Sultana et al., 2012). Dill and colleagues (1967) tracked elite male distance runners from youth through middle age and found the lowest rate of decline in $V \cdot O_{2peak}$ in the athlete who had kept up a high level of training throughout the study period. In non-elite populations, study participants with greater activity levels consistently demonstrate higher $V \cdot O_{2peak}$ and a slower rate of decrease than their sedentary counterparts (e.g. (Dehn & Bruce, 1972)). The frequency, volume, and intensity of training required to mitigate age-related declines in $V \cdot O_{2peak}$ among runners remain unclear.

Running economy (RE) quantifies the efficiency of running at a submaximal speed and is typically reported in $V \cdot O_2$ (ml kg^{-1} min^{-1}) (Saunders, Pyne, Telford, & Hawley, 2004). Among long-distance runners with similar peak aerobic capacities, RE may account for differences in race performance (Saunders et al., 2004). As with $V \cdot O_{2peak}$, training may be important in maintaining RE as age increases (Trappe, Costill, Vukovich, Jones, & Melham, 1996). However, in trained master runners, age does not appear to have negative effects on RE, measured as $V \cdot O_2$ (Evans, Davy, Stevenson, & Seals, 1995; Quinn, Manley, Aziz, Padham, & Mackenzie, 2011).

Notably, the traditional units of RE may be flawed, as oxygen consumption does not increase linearly with body mass: a lighter athlete will use more oxygen per kg of body mass than a heavier person at the same relative intensity (Barnes & Kilding, 2015; Berg, 2003). Therefore, some have proposed that RE should be evaluated as ml O_2 kg $^{-0.66}$ min^{-1} or ml O_2 kg $^{-0.75}$ min^{-1}, using allometric scaling to account for size-based differences in $V \cdot O_2$ (allo$V \cdot O_2$; in the present study, scaling body mass to the −0.66 power) (Barnes & Kilding, 2015; Berg, 2003).

Additionally, evaluation of the energy cost of submaximal running might incorporate a measurement of calories (kcal) expended. With endurance training, lipid oxidation during exercise increases (Holloszy, Rennie, Hickson, Conlee, & Hagberg, 1977), which raises submaximal $V \cdot O_2$ and would make an endurance-adapted individual seem less efficient based on $\dot{V}O_2$ alone (Berg, 2003). The energy cost of submaximal running (EC) can be calculated using the respiratory exchange ratio (RER) at a submaximal speed (Péronnet & Massicotte, 1991). Due to the metabolic adaptations that occur as a result of chronic endurance exercise, EC may be a more useful measure of submaximal running ability than submaximal $\dot{V}O_2$ is.

A third alternative to $\dot{V}O_2$ is the percent of $\dot{V}O_{2peak}$ (%$\dot{V}O_{2peak}$) that a submaximal effort elicits. A competitive runner will use approximately 75-85% of $\dot{V}O_{2peak}$ in a marathon and 90-100% of $\dot{V}O_{2peak}$ in a 10-km race (Basset & Howley, 2000; Costill, Thomason, & Roberts, 1973). Running economy determines the percent of $\dot{V}O_{2peak}$ at which a person can run for a certain time or distance, thus setting his or her top speed for those parameters (Barnes & Kilding, 2015; Basset & Howley, 2000; Costill et al., 1973). A more economical runner will use a lower percent of $\dot{V}O_{2peak}$ at a given speed than a less efficient person will.

Comparing runners' performances at different distances requires more than calculation of pace, as athletes naturally run faster in shorter races. The VDOT score allows for such comparison. The formulas on which it is based take into account the time it takes for an individual to complete a race. This duration is related to a % $\dot{V}O_{2peak}$ value, while the runner's velocity corresponds to a given $\dot{V}O_2$. This information is then used to predict $\dot{V}O_{2peak}$ (Daniels & Gilbert, 1979). For example, if a runner completes a marathon race in 180 minutes, that person is predicted to require approximately 80% of their $\dot{V}O_{2peak}$ to do so. A 180-minute marathon equates to a running speed of 234.25 m min^{-1}, which corresponds with a predicted $\dot{V}O_2$ of 43.8 ml kg^{-1}. Thus, if 43.8 ml kg^{-1} is 80% of $\dot{V}O_{2peak}$, then the runner's VDOT score (or predicted $\dot{V}O_{2peak}$) is approximately 54.75 ml kg^{-1} min^{-1} (Daniels & Gilbert, 1979). The VDOT score may also be adjusted for temperature, as hot conditions can cause distance runners' pace to slow (Cheuvront & Haymes, 2001; El Helou et al., 2012). Therefore, a VDOT score can be a useful tool to evaluate races of varying distances held in different environmental conditions.

In spite of the recent increases in participation and performance of master runners (Lepers & Cattagni, 2012; Lepers & Stapley, 2016), little is known about the training habits of older runners in preparation for long-distance races or whether training factors are related to race outcomes in this population. The relationship between RE and performance also remains uncertain, especially using more appropriate measures of RE, i.e. allo$\dot{V}O_2$, EC, and %$\dot{V}O_{2peak}$. Therefore, the primary purpose of this study was to determine the most important predictors of long-distance race performance (16.1 km to the marathon) in master runners. We hypothesized that both physiological and training-related factors would be significantly related to race performance.

MATERIALS AND METHODS

Participants

Participants were recruited from Minneapolis, Minnesota, USA and the surrounding area via an online running newsletter and emails to local running teams. To be eligible for the study, potential participants were required to be in training for a road race between 16.1 km and a marathon in distance. They were at least 40 years old and were thus classified as master athletes. These individuals were screened for eligibility via email prior to scheduling study visits. The University of Minnesota Institutional Review Board approved this study, and all participants provided written informed consent before enrolment. Twenty-three participants (eight females and 15 males) enrolled in the study. Descriptive characteristics of the participants can be found in Table 1.

Procedures

The present study employed a cross-sectional design. Study visits took place within four weeks of each participant's goal race. At the visits, runners completed a treadmill marathon-intensity-effort (MIE) running test to evaluate RE, followed by a $\dot{V}O_{2peak}$ test. To determine VDOT score, we used each participant's goal-race performance.

Peak aerobic power and RE are known contributors to distance running performance. We measured RE in a treadmill test in which athletes maintained a heart rate of 88% of their age-predicted maximum heart rate (MHR). This value was chosen because trained runners are predicted to complete a marathon at 75-85% of maximal aerobic power ($\dot{V}O_{2max}$) (Basset & Howley, 2000). According to works by Swain, Tanaka and colleagues (Londeree, Thomas, Ziogas, Smith, & Zhang, 1995; Swain, Abernathy, Smith, Lee, & Bunn, 1994), eighty percent of $\dot{V}O_{2max}$ corresponds to a heart rate of 88% of the MHR. Therefore, to simulate the $\dot{V}O_2$ required during a marathon effort, a target heart rate of 88% is appropriate.

Measures

Survey Questions—

Study participants completed a brief online survey within 1-2 weeks prior to their study visit and responded to the following questions:

- In the last three years, what is your approximate average weekly running mileage?
- In the last three years, what is your approximate peak weekly running mileage?
- In the last four weeks, how many high-intensity workouts have you done? (Threshold runs, marathon-pace runs, interval workouts, hill workouts, etc.)

In the present study, we analysed three-year average weekly training distance (3YA), three-year peak weekly training distance (3YP), and the number of intensity sessions completed in the four weeks prior to the study visit (4WI). Distances were converted from miles to km for analysis.

Testing Sessions—

Participants reported to a laboratory at the University of Minnesota for study visits. Testing procedures occurred in the order as described below. Participants were asked not to eat, consume caffeine or alcohol, or use tobacco within three hours of their study visits. We also requested that they not engage in strenuous exercise, defined as long runs, high-intensity workouts (e.g. interval training), or strength training, within 24 hours of their visits.

Anthropometric Measurements—Height was measured to the nearest 0.25 inch using a stadiometer (ACCUSTAT™ Stadiometer, Genentech, San Francisco, CA), and weight was measured to the nearest 0.1 pound on an electronic scale (Etekcity, Anaheim, CA). Body mass index (BMI) was calculated as mass (in kg) per height (in m) squared.

Running Economy Testing—An Ultima CPX metabolic cart and BreezeSuite software (MGC Diagnostics, St. Paul, MN) were used for collection and analysis of respiratory gas data throughout both the peak and submaximal exercise tests. The metabolic cart was calibrated prior to each testing session. Participants also wore a heart rate monitor (Polar, Bethpage, NY) throughout treadmill testing.

All treadmill tests were conducted on a Woodway Pro XL treadmill (Woodway, Waukesha, WI). Running economy was evaluated in a submaximal treadmill test designed to mimic a MIE. Each athlete was allowed to warm up for 2-10 minutes at a 1% incline and speed of their choice. They were instructed to select an intensity that felt like an easy run. Investigators gradually adjusted the treadmill speed to bring each runner to their target heart rate, which was 88% of their age-predicted MHR. To calculate predicted MHR, the following equation was used:

$$\mathrm{MHR} = 208 - (0.7 * \mathrm{age})\ (\mathrm{Tanaka, Monahan, \&Seals, 2001})\,.$$

Participants ran for five minutes in this target heart rate zone while investigators adjusted the treadmill speed as necessary so that the athletes maintained their goal heart rate throughout the five-minute MIE.

To determine $V\,{\cdot}O_2$ for the MIE period, we used the average $V\,{\cdot}O_2$ over the five-minute steady-state run. Rating of perceived exertion (RPE) was measured using a 6-20 scale (Borg & Noble, 1974) at the beginning and end of this five-minute MIE bout. The RPE for the bout was taken to be the mean of the initial and final RPE.

Peak Aerobic Power Testing—Participants performed an incremental treadmill test to exhaustion to determine their $V\,{\cdot}O_{2peak}$. This test occurred approximately 10 minutes after the end of the RE test. The speed for this test was based on participants' self-reported estimated current 5-km race pace (Braun & Paulson, 2012). Athletes began by walking for one minute at 1.39 m s^{-1} (3.1 mph) on a level treadmill. Treadmill grade was then increased to 1%, and speed increased to 75% of each person's 5-km race speed for three minutes. All subsequent stages lasted one minute. Over five stages, speed was increased to reach 5-km race speed. In the following stages, grade was raised by 2.5% each minute. Rating of perceived exertion on the 6-20 Borg scale (Borg & Noble, 1974) was recorded at the end of each stage. Participants ran to volitional exhaustion.

Analysis—Peak aerobic power was determined using mid five-of-seven analysis by the BreezeSuite breath-by-breath software. We used three methods to evaluate RE. To determine allo$V\,{\cdot}O_2$, the mean submaximal $V\,{\cdot}O_2$ from the MIE was converted to units of ml kg $^{-0.66}$ min^{-1}. To calculate EC, the average respiratory exchange ratio (RER) over the five-minute running test was used to determine a caloric equivalent value in kcal l $O_2{}^{-1}$ (Péronnet &

Massicotte, 1991). The caloric equivalent was divided by each athlete's average speed in m min^{-1} and multiplied by $\dot{V}O_2$ to find EC. Lastly, to find % $\dot{V}O_{2peak}$, mean $\dot{V}O_2$ from the MIE run was divided by $\dot{V}O_{2peak}$ and multiplied by 100%.

We collected the results for each participant's goal race from online race-result websites. The VDOT calculator is available online at http://runsmartproject.com/calculator/. The website also calculates predicted race times and VDOT scores based on race-day temperatures. We collected temperature data for each race from www.wunderground.com. We entered the race time, distance, and race-time temperature to calculate a temperature-converted VDOT score for each study participant.

Statistical Package for the Social Sciences (SPSS) was used for all statistical analyses. Forward stepwise multiple linear regression was used to determine the relationships between converted VDOT score and running performance variables. This method corrects for multiple testing. Independent variables included 3YA, 3YP, and 4WI (training factors); $\dot{V}O_{2peak}$; and allo$\dot{V}O_2$, EC, and % $\dot{V}O_{2peak}$ (measures of RE). In SPSS, the criterion to keep a variable in the final model was an F-statistic ≤ 50, while the criterion to remove a variable from the model was an F-statistic ≥ 100. To evaluate training parameters, means, standard deviations, and ranges were calculated for 3YA, 3YP, and 4WI.

RESULTS

Of the 23 participants enrolled in the study, we collected VO_{2peak} data from all runners and MIE data from 19 athletes. Therefore, the stepwise multiple linear regression analysis included 19 participants. Demographic characteristics of the participants are presented in Table 1. Survey data were obtained from all participants. Table 2 shows the self-reported training characteristics of the athletes.

We used forward stepwise multiple linear regression to evaluate relationships between converted VDOT and 3YA, 3YP, 4WI, $\dot{V}O_{2peak}$, allo$\dot{V}O_2$, EC, and % $\dot{V}O_{2peak}$. Of these variables, converted VDOT had a significant relationship with 3YP ($r = 0.454$, $p = .039$), $\dot{V}O_{2peak}$ ($r = 0.845$, $p = .000$), allo $\dot{V}O_2$ ($r = 0.623$, $p = .005$), and EC ($r = -0.528$, $p = .018$). The best-fitting model for VDOT included $\dot{V}O_{2peak}$ and 3YP, after correcting for multiple testing. The r-statistic for the model including $\dot{V}O_{2peak}$ alone was 0.845, and the r-statistic for the second model, which also included 3YP, was 0.898. The respective r^2 values for these models were .713 and .807, and the standard errors were 5.4 and 4.6. The unstandardized beta weights for the first and second model, respectively, were 0.980 ($\dot{V}O_{2peak}$) and 0.915 ($\dot{V}O_{2peak}$) and 0.081 (3YP). The standardized beta weights were .845 ($\dot{V}O_{2peak}$) and 0.788 ($\dot{V}O_{2peak}$) and 0.311 (3YP) for the first and second model, respectively. For the model including $\dot{V}O_{2peak}$ alone, the p-value was .000; for the second model, $p = .000$ for $\dot{V}O_{2peak}$ and $p = .026$ for 3YP. Figure 1 displays the relationships between converted VDOT and $\dot{V}O_{2peak}$ (A) and 3YP (B).

DISCUSSION

In this cross-sectional study of master runners, we have shown that peak aerobic power measured within four weeks prior to a goal long-distance race, and the maximum weekly distance run in the three years leading up to that event, are correlated with actual performance in the race, as quantified through a VDOT score.

The VDOT score, similar to a predicted $V \cdot O_{2peak}$ value, was developed to facilitate comparison of race performances at different distances (Daniels, 2014). A race of a given distance is predicted to require a certain fraction of one's maximal aerobic power; a runner can use his or her time in a race of one distance to predict a time in a race of a different distance (Daniels, 2014). Notably, VDOT scores account for both RE and $V \cdot O_{2peak}$: a person may have a high measured $V \cdot O_{2peak}$ but, due to having a low RE, perform more poorly than expected on the basis of $V \cdot O_{2peak}$ alone (Daniels, 2014). Thus, VDOT scores can serve as a basis of comparison between athletes who have competed in races of various lengths. The strength of VDOT comparisons decreases as the discrepancy between race lengths grows (e.g. it may not be useful to compare a mile performance with a marathon time) (Daniels, 2014), but we believe that races from 16.1 km to a marathon in length are similar enough in a non-elite population to merit the use of VDOT scores.

Stepwise multiple linear regression showed that both physiological and training factors may influence race performance. In a group of people of different $V \cdot O_{2peak}$ values, peak power explains much of the discrepancy in running performance (Noakes, 1988). In the present study, participants had a wide range of $V \cdot O_{2peak}$ (38.5 – 66.1 ml kg^{-1} min^{-1}). Because $V \cdot O_{2peak}$ is a significant predictor of race performance in heterogeneous groups (Costill et al., 1973), it is logical that $V \cdot O_{2peak}$ was closely correlated with VDOT ($r = 0.845$, $p = .000$), a marker of race performance. Previous studies have found that $V \cdot O_{2peak}$ can predict performance in master athletes. In a group of male and female master runners, $V \cdot O_{2peak}$ was the best predictor of race times in 5-km, 10-km, and marathon distances completed in the past year (Wiswell et al., 2000). Among female distance runners aged 49-56, $V \cdot O_{2peak}$ explained nearly three-quarters of the differences in race times between runners (Evans, Davy, Stevenson, Reiling, & Seals, 1995). Our study corroborates these findings. Moreover, we have also shown that the relationship between $V \cdot O_{2peak}$ and race performance holds for master runners when they are tested within four weeks of a long-distance race.

In addition to $V \cdot O_{2peak}$, we found that two measures of running economy are significantly correlated with the performance of master runners in a long-distance race. $AlloV \cdot O_2$ was positively related to VDOT score ($r = 0.623$, $p = .005$), while EC showed a negative association with VDOT ($r = -0.528$, $p = .018$). The positive correlation between $alloV \cdot O_2$ and VDOT is somewhat surprising. Faster runners are typically more economical than slower runners (Joyner & Coyle, 2008; Morgan et al., 1995) and would be expected to require less oxygen to run at a given intensity (e.g. half-marathon race pace) than slower runners do. However, we have shown that the faster runners in the present study—those with higher VDOT scores—also tended to have higher $V \cdot O_{2peak}$ values than the runners with slower performances. We did not find a significant association between VDOT and $\%V \cdot O_{2peak}$ elicited from the MIE. Assuming that actual races elicited a similar effort as the MIE in the laboratory, all runners may have been using a similar fraction of their $V \cdot O_{2peak}$ during their races, and those with higher peak capacities would consume more oxygen simply due to their greater $V \cdot O_{2peak}$.

The negative relationship between EC and VDOT score may be linked to the importance of efficiency during long-distance races. Energy cost is calculated using the respiratory exchange ratio during a submaximal running bout. The mean RER over this time period corresponds with a caloric equivalent value, in kcal l O_2^{-1} (Péronnet & Massicotte, 1991). When the caloric equivalent is multiplied by the average $\dot{V}O_2$, in ml kg^{-1} min^{-1}, and divided by the speed in km min^{-1}, the resulting energy cost has units of kcal kg^{-1} min^{-1}, a measure proposed by Berg (2003) and Barnes and Kilding (2015) to capture RE. Such a value reflects the actual demands of running better than $\dot{V}O_2$ does because EC accounts for energy from aerobic and anaerobic sources.

In long-distance races, energy supply is a limiting factor. Running gradually depletes glycogen stores in skeletal muscle, and runners must slow when energy supplied to muscle becomes insufficient to support their current pace (Coyle, 2007). Athletes with good RE have high activity of oxidative enzymes in their muscles, enhancing their ability to oxidize lipids, sparing carbohydrate stores (i.e. glycogen), and requiring less oxygen to produce ATP to fuel the maintenance of their pace (Saunders et al., 2004). A runner who can use less energy than another person can theoretically run faster and/or longer than the less economical athlete. This explanation supports our observation of a significant negative association between energy cost and VDOT score. Participants who required more energy for a given body mass and speed also had slower race times than athletes who were more energetically efficient. Furthermore, EC may increase with age. A study by Cavagna and co-workers (2008) found that older runners had to do more external work than younger runners did at a given speed. The older participants had a diminished ability to store elastic energy, possibly due to an age-related decrease in muscular strength (Cavagna et al., 2008). We did not include age as a predictor of VDOT in the present study, but age-associated changed in EC may contribute to the general slowing of long-distance race times that occurs in master runners (Brisswalter & Nosaka, 2013).

The reported top weekly training distance over the past three years was significantly and positively associated with VDOT score, whereas average weekly training distance and quality workouts in the past four years were not. Other investigators have found that training parameters can predict race performance in master runners. Among a cohort of master runners, weekly training distance was a key predictor of 5-km, 10-km, and marathon performance in both sexes (Wiswell et al., 2000). Training habits, such as weekly distance and average pace, have also been found to correlate significantly with $\dot{V}O_{2peak}$ (Eskurza, Donato, Moreau, Seals, & Tanaka, 2002; Pimentel, Gentile, Tanaka, Seals, & Gates, 2003; Pollock et al., 1997; Tanaka et al., 1997). Runners who better maintain their habitual frequency, volume, and intensity of training as they age may also exhibit smaller declines in $\dot{V}O_{2peak}$ than their counterparts who reduce their training (Pollock et al., 1997; Trappe et al., 1996). Training practices that contribute to the maintenance of $\dot{V}O_{2peak}$ may also help to mitigate declines in race performance.

In the present study, we did not find a significant relationship between VDOT and average training distance over the past three years, only with VDOT and peak weekly distance. This observation may be due to the wide range of weekly volumes that our participants reported (from 6.4 to 120.7 km $week^{-1}$), which is in keeping with other studies of training in master runners (e.g. (Wiswell et al., 2001)). However, we also saw great variation in reported 3YP: from 37.0 to 185.1 km week^{-1}. This result suggests that incorporating high training volumes may contribute to faster race times; conversely, faster runners may also be able to complete higher weekly distances than slower runners simply because it takes them less time to do so.

A limitation of this study is that the intensity that we chose to mimic a marathon effort, 80% of $V \cdot O_{2peak}$ (Basset & Howley, 2000), may have been greater than the actual proportion of $V \cdot O_{2peak}$ that our participants were able to sustain in their goal races. As Coyle (2007) notes, slower racers may use only 50-60% of their peak power. Most of the study participants who ran a marathon did so in three hours or greater, meaningfully longer than the 2:30 that Coyle (2007) cites for fast runners. Therefore, a more appropriate percent of $V \cdot O_{2peak}$ to target in the MIE bout may have been closer to 70% than 80%. However, of our 23 athletes, nine ran 16.1-km or half marathon races. With the shorter distance and time, they would be expected to be able to use a higher percent of their $V \cdot O_{2peak}$ than they would in a marathon. The discrepancies between % $V \cdot O_{2peak}$ elicited during the MIE could have been mitigated when considering the marathon runners (for whom the intensity may have been too high) and shorter-distance racers (for whom the intensity may have been too low) together. In addition, one participant misunderstood the survey question regarding intensity sessions and entered an improbable number. This point was excluded from analysis.

CONCLUSIONS

In conclusion, the present study has shown that $V \cdot O_{2peak}$ and self-reported 3YP are the most important predictors of VDOT score in master runners who are training for a long-distance race. Two measures of RE, namely allo$V \cdot O_2$ and EC, also show significant relationships with VDOT score. Our study is novel in that we have evaluated RE, $V \cdot O_{2peak}$, and training habits shortly before the goal races of our participants, thus gaining the ability to draw stronger relationships between these variables and actual race performance. Master athletes with higher peak aerobic capacities and recent peak training distances, but who use less energy to run at a marathon-simulation effort, may expect faster race times than runners who are less efficient, have completed lower peak running volume, and have lower $V \cdot O_{2peak}$ values. In practical application, master runners and coaches may be able to apply our findings to their training parameters, working to increase or maintain $V \cdot O_{2peak}$ and to reach a higher training volume leading up to a goal long-distance race.

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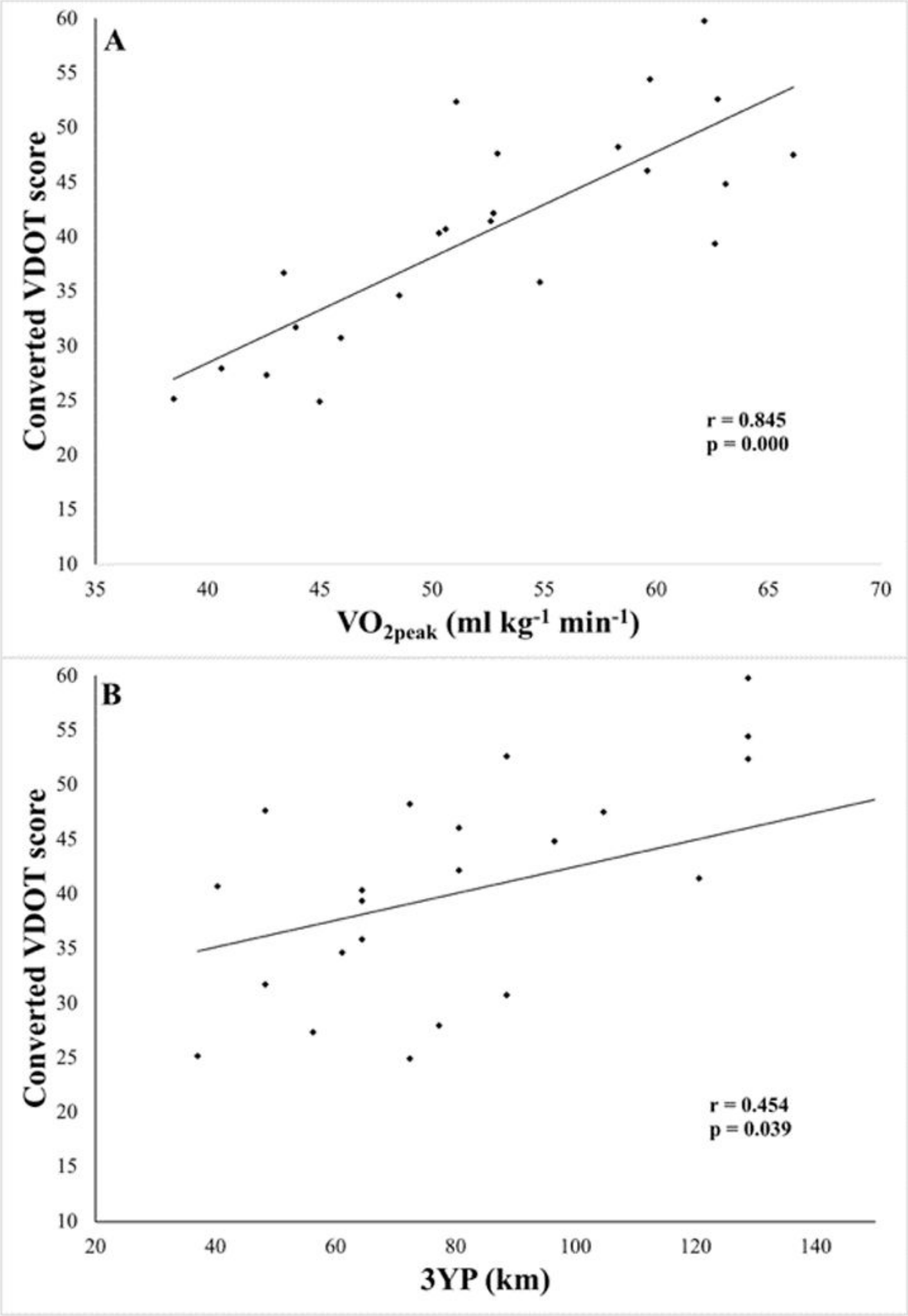

Figure 1.

Relationships between converted VDOT and $\dot{V}O_{2max}$ (A) and 3YP (B).

Table 1.

Descriptive characteristics of the participants.

N (% female)	23 (35)
Age (years)	57 ± 9
Mass (kg)	68.7 ± 11.2
Height (m)	1.75 ± 0.09
BMI (kg m^{-2})	22.4 ± 2.7
$\dot{V}O_{2peak}$ (ml kg^{-1} min^{-1})	52.5 ± 8.1

Values are mean ± SD unless otherwise indicated.

BMI: body mass index; $\dot{V}O_{2peak}$: peak aerobic power.

Table 2.

Self-reported training characteristics of the participants.

Training parameter (N)	Mean ± SD (range)
3YA (km) (23)	47.2 ± 23.0 (6.4, 120.7)
3YP (km) (23)	84.3 ± 35.4 (37.0, 185.1)
4WI (no.) (22)	7.2 ± 3.5 (2, 15)

3YA: Three-year average weekly training distance. 3YP: Three-year peak weekly training distance. 4WI: Number of intensity sessions completed in the four weeks prior to the study visit.