Medicine & Science in Sports & Exercise

The Official Journal of the American College of Sports Medicine
www.acsm-msse.org

. . . Published ahead of Print

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Accepted for Publication: 11 July 2021

Medicine & Science in Sports & Exercise, Publish Ahead of Print
DOI: 10.1249/MSS.0000000000002755

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The authors have no external funding to declare and no competing interests to disclose. The results of the present study are presented clearly, honestly, and without fabrication and do not constitute endorsement by ACSM.

ABSTRACT

Purpose: We aimed to identify the underpinning physiological and speed/mechanical determinants of different types of 800-m running time trials (i.e., with a positive or negative pacing strategy) and key components within each 800-m time trial (i.e., first and final 200-m).

Methods: Twenty trained male 800-m runners (800-m personal best time (min:s): 1:55.10±0:04.44) completed a maximal 800-m time trial (800_{MAX}) and one pacing trial, whereby runners were paced for the first lap and speed was reduced by 7.5% (800_{PACE}) relative to 800_{MAX}, while the last lap was completed in the fastest time possible. Anaerobic speed reserve, running economy, the velocity corresponding with VO_{2peak} ($_{V}VO_{2peak}$), maximal sprint speed (MAX_{SS}), maximal accumulated oxygen deficit and sprint force-velocity-power profiles were derived from laboratory and field testing. Carnosine content was quantified by proton magnetic resonance spectroscopy in the gastrocnemius and soleus and expressed as a carnosine aggregate Z-score (CAZ-score) to estimate muscle typology. Data were analysed using multiple stepwise regression analysis.

Results: MAX_{SS} and vVO_{2peak} largely explained the variation in 800_{MAX} time (r^2 =0.570; P=0.020), while MAX_{SS} was the best explanatory variable for the first 200-m time in 800_{MAX} (adjusted r^2 =0.661, P<0.001). Runners with a higher CAZ-score (i.e., higher estimated percentage of type II fibres) reduced their last lap time to a greater extent in 800_{PACE} relative to 800_{MAX} (adjusted r^2 =0.413, P<0.001), while better maintenance of mechanical effectiveness during sprinting, a higher CAZ-score and vVO_{2peak} was associated with a faster final 200-m time during 800_{PACE} (adjusted r^2 =0.761, P=0.001).

Conclusion: These findings highlight that diversity in the physiological and speed/mechanical characteristics of male middle-distance runners may be associated with their suitability for different 800-m racing strategies in order to have the best chance of winning.

Key words: PACING, ANAEROBIC SPEED RESERVE, MUSCLE FIBRE TYPE COMPOSITION, RUNNING TACTICS, MIDDLE-DISTANCE RUNNING

INTRODUCTION

In elite 800-m running competitions (i.e., World Athletics Championships and Olympic Games), championship races can be won with either a positive pacing strategy (i.e., faster first lap), which typically results in faster overall times (1), or with a negative pacing strategy and a faster second lap (2, 3). For example, in the London 2012 Olympic Games 800-m final, David Rudisha won the gold medal in a world-record time of 1:40.91 (min:s) which was characterized by a positive pacing strategy with a faster first lap (49.28 s) compared to the second lap (51.63 s). In contrast, in the Beijing 2008 Olympic Games 800-m final, Wilfred Bungei adopted a negative pacing strategy with a much slower first lap (53.40) compared to the second lap (51.25) to win the gold medal in 1:44.65. Bungei's performance was characterized by an extremely fast final 200-m time of 25.10 s, compared to Rudisha's final 200-m time of 26.61 s in the London 2012 Olympic Games 800-m final. This raises the question as to whether 800-m runners who possess different physiological and/or speed/mechanical characteristics would be better suited to either controlling the race as a front runner with a positive pacing strategy or holding back the pace in order to execute a fast final surge?

During men's 800-m championship races that are characterized by a positive pacing strategy, the fastest 100-m split of the race occurs in the first 200-m and may exceed 9.0 $m \cdot s^{-1}$ (1, 4). In more conservative 800-m races, a slow first lap (typically >53.0 s) is followed by an increase in speed from the 500 to 600-m mark; while medallists tend to further increase their speed to the finish line over the final 200-m, with the fastest 100-m split (~8.0 - 8.3 $m \cdot s^{-1}$) occurring in this final sector (2). These divergent pacing strategies may require varying deterministic physiological and/or speed/mechanical characteristics, but this has not been investigated experimentally. We have previously shown that the determinants of last-lap speed during 1500-m trials differ when trials are performed with a sustained pace from the start compared to trials with either moderate or slow-paced initial laps, but an all-out last lap (5). In this previous study, the velocity corresponding with VO_{2peak} ($_{V}VO_{2peak}$) and running economy (RE) were the key determinants of 1500-m running performance with a sustained pace from the start. In contrast, a higher estimated proportion of type II muscle fibres and the maximal accumulated oxygen deficit (MAOD) became more influential for last lap speed in 1500-m trials with slower initial laps (5). Identifying whether the underpinning physiological and or speed/mechanical characteristics would differ when 800-m trials are completed with different pacing strategies could inform racing strategies for middle-distance athletes and provide greater insight for coaches and sport scientists as to the training requirements in order to maximise performance in different types of 800-m races.

Previous research has reported that the contribution of aerobic metabolism to the total energy produced during simulated and track 800-m trials ranges from 60-70% (6, 7). Other research reports that parameters associated with aerobic metabolism are key determinants of 800-m running performance, such as RE (8), VO_{2peak} (8), peak incremental treadmill velocity (9) and critical speed (CS) (10). One caveat of these studies (6-10) is that there is a bias towards quantifying parameters associated with aerobic metabolism. As highlighted by Sandford et al. (2), it may be necessary to revisit this paradigm and investigate whether characteristics limited by mechanical effectiveness and/or anaerobic metabolism may also be deterministic for success in 800-m racing. More recently, Bachero-Mena et al. (11) showed strong associations between 800-m performance (national and international standard runners) and sprint times over 20-m (r =

-0.72) and 200-m (r = -0.84), while Sandford et al. (4) reported that a greater maximal sprint speed (MAX_{SS}) was associated with faster 800-m times (r = -0.74) in elite 800-m runners (800-m PB times ≤1:47.50). While these studies (4, 11) have demonstrated that speed capabilities may be important for 800-m performance, similar to previous studies (6-10), 800-m performance was assessed under conditions where athletes are attempting to run the fastest time possible such as a maximal time trial (6, 9, 10), simulated maximal time trial on a treadmill (7), or a "gun-to-tape" recent best performance (4, 8, 11). It is conceivable that the underpinning determinants of performance may differ when 800-m trials are completed with a positive pacing strategy compared to a slower first lap, but with an all-out last lap. Furthermore, previous studies (4, 6-11) have quantified the association between various physiological and speed/mechanical characteristics and overall 800-m time, which may mask the contribution that some of these qualities make to decisive components of an 800-m race such as a fast-start by a front-runner (i.e., first 200-m) or the final surge to the finish line (i.e., final 200-m) which differentiates medallists from non-medallists (12). In the present study, we aimed to identify the underpinning physiological and speed/mechanical determinants of different types of 800-m performances (i.e., positive and negative pacing strategies) and components of an 800-m race (i.e., fast start or final surge)in male 800-m runners. We hypothesize that parameters across the entire spectrum of speed and endurance capabilities will be deterministic for 800 m running performance. Given the speed requirements of 800-m trials undertaken with a positive pacing strategy, we hypothesize that MAX_{SS} will be deterministic in these trials, while vVO_{2peak} will likely be important given the contribution of aerobic metabolism to total energy production during 800-m running. Of particular interest are the underpinning characteristics associated the ability to produce a final surge to the finish line and the relative improvement in this ability in more conservatively paced

800-m trials. We hypothesize that mechanical/speed characteristics that underpin speed endurance will be deterministic during the final surge to the finish line in 800-m trials a slower first lap, but with an all-out last lap.

METHODOLOGY

Participants

Twenty trained male middle-distance runners (VO_{2peak}: 69.7 ± 5.5 mL·kg·min^{-1}, age 20.8 ± 2.5 yr, stature 179.0 ± 6.7 cm, body mass 66.6 ± 5.1 kg) participated in the present study. All runners had a consistent training history of at least 4 yr in the 800-m event and were without major injury interruption for the previous 6 mo. The runners had career best performance times during outdoor 800-m track competition of 1:55.10 ± 0:04.44 (1:48.25 – 2:06.40) and at the time of the study had a mean running training volume of 82.3 ± 10.5 km·wk^{-1}. All runners provided written informed consent prior to participating in this study which was approved by the Griffith University Human Research Ethics Committee.

Study design

Participants completed an 800-m time trial in the fastest time possible (800_{MAX}) with 200-m split times determined, and one pacing trial (800_{PACE}) on an outdoor athletics track. In the pacing trial, runners were paced for the 0 – 400-m, whereby speed was reduced by 5.0% (0 – 200-m) and 10% (200 – 400-m) relative to 800_{MAX}, while the last 400-m was completed in the fastest time possible. In addition, participants completed laboratory treadmill running tests to determine RE, VO_{2peak}, $_{V}VO_{2peak}$ and the MAOD. Participants also completed additional outdoor time trials (1500-m and 2000-m) for the quantification of CS and *D’* and a maximal 40-m sprint for the determination MAX_{SS}, anaerobic speed reserve (ASR) and sprint force-velocity profiles. All trials were conducted on separate days across a 5-wk period. Carnosine content was quantified by proton magnetic resonance spectroscopy in the gastrocnemius medialis muscle and soleus and was expressed as a carnosine aggregate Z-score (CAZ-score) to estimate muscle typology (13-15).

Running time trials

The running time trials were conducted on an outdoor 400-m synthetic athletics track. All running trials were preceded by a standardized warm up that consisted of a 10-min self-paced jog, a 5-min bout of submaximal running at a rating of perceived exertion of 5 (CR-10 scale) (16) and four repetitions of 10-s strides, with a walk-back recovery (~60 s). Strides were defined as bouts of fast running which were to be completed at each participants perceived 800-m race pace. Participants also completed a longer 150-m stride. The warm-up procedures were followed by 15-min of recovery. Air temperature, relative humidity and wind speed/direction were recorded using a thermal environment monitor (Questemp-15 Area Heat Stress Monitor, Quest Technologies, WI). Testing was conducted at an identical time of day (6:00 – 8:00 am) for all participants which assisted in achieving relatively consistent atmospheric conditions (air temperature range 22.4 – 25.4 °C; relative humidity 65.7 – 70.0%; wind speed 4.8 – 8.0 $km \cdot h^{-1}$).

800_{MAX} time trial

During 800_{MAX}, participants ran individually and were not permitted to view their race split times and were instructed to complete the trial in the fastest time possible. Electronic cameras (TG320, Olympus, Japan) were placed at the start and at the 200-m mark of the first lap in order to obtain each 200-m split time. Both cameras were synchronized by filming a clap from one of the researchers. Videos were analyzed using the KINOVEA software (version 0.8.15, USA) with resolution of 0.005 s.

800_{PACE} time trial

In the paced trial (800_{PACE}), runners were paced for the 0 – 400-m, whereby the 0 – 200-m split was prescribed to be run 5% slower and the 200 – 400-m split 10% slower, relative to 800_{MAX}. Participants were instructed to complete the final 400-m in the fastest time possible. These speed reductions were chosen following the pacing analysis (i.e., 200-m splits) of the gold medal winner from each 800-m championship race (i.e., Olympic Games and World Championship 800-m male final) since the year 2000 (5 Olympic Games and 10 World Championships) using readily available footage from YouTube. Videos were downloaded via YouTube and analyzed using frame-by-frame playback in Kinovea analysis software. We compared the 0 – 200-m and the 200 – 400-m split time of the gold medal winner from the five fastest (2012 and 2016 Olympic Games and 2001, 2013 and 2019 World Championships) and five slowest (2000 and 2008 Olympic Games and 2007, 2009 and 2015 World Championships) 800-m championship races from this period. From this analysis, we determined that the 0 – 200-m and 200 – 400-m split times were 4.74% and 10.14% faster, respectively, in the five fastest compared to the five slowest 800-m championship races (figure 1A). To assist with pacing from the 0 – 400-m mark in 800_{PACE}, each runner had access to target split times and a wristwatch (Garmin Forerunner 235, Canton of Schaffhausen, Switzerland). Members of the research team also assisted with pacing by providing splits verbally as each runner approached the 200-m and 400-m mark. During 800_{PACE}, if a participant recorded a 200-m split time within the first lap that deviated from the prescribed split by ≥1.00 s, the trial was discarded and performed on another day. This occurred on only one occasion. Ten participants performed duplicate trials on separate days 2-wk apart in order to determine the test-retest reliability for the 800-m time trials. The coefficient of variation (CV) for 800_{MAX} performance time and 800_{PACE} last lap time were 1.8% and 2.4%, respectively.

Critical speed and D'

Participants also completed additional outdoor track time trials of 1500 and 2000-m on separate days in order to determine CS and *D'*. These distances were chosen in order to yield finishing times between 2 and 12 min (17). These trials were performed with the same instructions as 800_{MAX} and CS and *D'* were determined using a linear distance-time model from the performance times of the three trials (800-m, 1500-m and 2000-m).

Maximal sprint speed and anaerobic speed reserve

Linear sprint speed was evaluated over 40-m using electronic timing gates positioned at the start line and at the 30-, 35- and 40-m intervals. Participants performed the standardized warmup procedure (without the 150-m stride), and also performed two 40-m running efforts at 75% and 90% of each participants perceived MAX_{SS}. All starts commenced from a static position and the upper body of each participant was positioned as close as possible to the inter-gate beam of the first timing gate which was placed on the starting line. MAX_{SS} was determined as the highest mean speed between either of the 5-m split times. Anaerobic speed reserve (ASR) was defined as the difference between the MAX_{SS} and the vVO_{2peak}, estimated from the submaximal and maximal incremental running test (see below).

Horizontal force velocity profile

Participants also performed a 30-m maximal sprint with electronic timing gates positioned at 5-m intervals. We used the distance-time data from the 30-m sprint to compute individual force-velocity and power-velocity profiles using a validated biomechanical model proposed by Samozino et al. (18). We also filmed the starting procedure for each participant using an electronic camera (TG320, Olympus, Japan) so that we could precisely determine the start of the movement time using KINOVEA software and add this to each split time to ensure that start time initiation was likely to coincide with the first rise of the force production onto the ground. We used the change in running velocity over time to estimate the acceleration of each participant's centre of mass in the antero-posterior direction and then used the aerodynamic friction of force and each participant's body mass and height to estimate the net horizontal ground reaction force. The theoretical maximal force (*F0*) and velocity (*V0*) were then identified from the force-velocity relationship as the x- and y-intercepts, respectively, and the theoretical maximal power output (*Pmax*) was determined as the apex of the power-velocity relationship (18). The mechanical effectiveness of force application (D_{RF}) was determined as the mean ratio of the estimated horizontally-oriented component to the total ground reaction force (19).

Laboratory tests

Across separate days, submaximal, incremental and supramaximal treadmill-running tests were performed to determine RE, the gas exchange threshold (GET), VO_{2peak}, vVO_{2peak} and MAOD as previously described (5). In brief, participants performed an incremental treadmill run to volitional exhaustion starting at 12 km·h^{-1} and 1% gradient with the speed increasing by 1 km·h^{-1} each minute until volitional exhaustion. Respiratory variables were measured using a Cosmed Quark b^2 (Rome, Italy), from which the gas exchange threshold (GET) was determined using the simplified V-slope method previously described (20) and VO_{2peak} was determined as the highest VO_2 value using a rolling 1-min average of breath-by-breath data. On a separate day, participants completed six, 4-min submaximal incremental stages (5% incremental speeds ranging from 85 – 110% of the GET) in order to construct a running speed-VO_2 regression. RE was determined as an energy cost using updated non-protein respiratory quotient equations (21) whilst running at 110% of the GET. The vVO_{2peak} was calculated by solving the regression equation describing the individual VO_2-running speed relationship based on the mean VO_2 values during the final minute of each 4-min submaximal incremental stage and VO_{2peak} measured from the maximal incremental running test using linear regression. On a separate day, participants performed a supramaximal constant speed treadmill test to exhaustion whilst running at a speed equivalent to 110% of vVO_{2peak}. Peak blood lactate concentration was determined from earlobe samples taken at 1, 3, 5, and 7 min after the completion of the test, with the highest value obtained considered the peak blood lactate concentration. MAOD was determined by subtracting the accumulated VO_2 uptake from the estimated VO_2 demand corresponding to the time to exhaustion at 110% of vVO_{2peak}.

Carnosine quantification via ^{1}H-MRS

Muscle carnosine content was measured by ^{1}H-MRS in the gastrocnemius medialis and soleus muscle of each participants right limb to estimate muscle typology (15). ^{1}H-MRS measurements were performed on a 3-T whole body MRI scanner (Philips Medical Systems Best, The Netherlands) as previously described (13, 14). The carnosine concentration of each muscle was converted to a gender-specific Z-score relative to an age-matched control population of active, healthy non-athletes, consisting of 40 men (i.e., control-men CAZ-score). The mean of the CAZ-scores of the gastrocnemius and the soleus was then calculated, and this CAZ-score was used for all analyses.

Statistical analysis

Results are expressed as mean ± SD. We performed a multiple stepwise linear regression to identify the physiological and speed/mechanical characteristics for which the majority of the variance in the overall time and first 200-m time of 800_{MAX} could be attributed to, as well as the final 200-m time of 800_{PACE} and improvement in last lap time relative to 800_{MAX}. A two-way analysis of variance with Tukey's post-hoc tests were conducted to compare split times (i.e., 0 – 200, 200 – 400, 400 – 600 and 600 – 800-m) across trials (i.e., 800_{MAX} and 800_{PACE}). Statistical analyses were performed using IBM SPSS Statistics (version 26.0, IBM Corp., Armonk, NY, USA).

RESULTS

Table 1 displays the mean and range of the physiological and performance characteristics of the participants included in the present study. The range in these values highlight the diversity in the physiological and speed/mechanical characteristics of this cohort of trained male middle-distance runners.

800-m trials

Table 2 displays the 200-m split times and first:second lap time ratio for the maximal (800_{MAX})

and paced (800_{PACE}) 800-m time trials, while figure 2B displays the 200-m split speeds. Given the manipulation in pacing, both the 0 – 200-m and 200 – 400-m split times were faster in 800_{MAX} compared to 800_{PACE}, while the 600 – 800-m split was significantly faster in 800_{PACE}. A similar pattern was evident when comparing the 200-m split speeds from the faster and slower championship races (figure 2A). Last lap time in 800_{PACE} was moderately associated with last lap time in 800_{MAX} (r = 0.710, P <0.001), but the improvement in last lap time in 800_{PACE} was not (r = 0.209, P = 0.376, Figure 2), suggesting that performance level did not moderate the magnitude of improvement in last lap performance.

800_{MAX}

Table 3 displays the multiple stepwise regression parameter estimates between the physiological and performance/mechanical characteristics and 800_{MAX} first 200-m time and overall performance time. MAX_{SS} and vVO_{2peak} provided the best model (adjusted r^2 = 0.570, P = 0.020; Figure 3), while MAX_{SS} was the sole best explanatory variable for the first 200-m time in 800_{MAX} (adjusted r^2 = 0.661, P <0.001).

800_{PACE}

Multiple stepwise regression analysis demonstrated that the CAZ-score was the sole best explanatory variable explaining the most variation in the improvement in 800_{PACE} last lap time relative to 800_{MAX} (adjusted r^2 = 0.413, P = 0.001; Figure 3), while the index of force application (D_{RF}), vVO_{2peak} and CAZ-score provided the best model to explain variation in the final 200-m time (adjusted r^2 = 0.761, P < 0.001; Figure 3). Figure 4 displays the individual CAZ-score values for the runners in the present study and the non-athlete control men.

DISCUSSION

The present study demonstrates that MAX_{SS} and vVO_{2peak} largely explain the variation in 800-m running performance when male 800-m runners attempt to run the fastest time possible. In particular, a greater MAX_{SS} was strongly associated with a faster first 200-m time during the 800_{MAX} trial. In paced 800-m trials with a slower first lap, we found that runners with a higher CAZ-score (i.e., higher estimated percentage of type II fibres), reduced their last-lap time to a greater extent relative to 800_{MAX} and were faster over the final 200-m. Furthermore, preservation of mechanical effectiveness during sprinting (i.e., D_{RF}) and vVO_{2peak} were important characteristics during the final 200-m of the paced 800-m trial. Interestingly, despite theoretical (22) and experimental (8, 10, 23) research supporting the importance of RE, CS, D' and MAOD for 800-m running performance, we did not find that these characteristics significantly contributed to the regression models explaining variation in 800-m running performance. Nonetheless, the present study highlights that diverse physiological and speed/mechanical characteristics are required in order to maximise 800-m running performance and that male athletes could adopt specific racing strategies that may best suit their physiological and/or speed/mechanical characteristics. Given that athletes have only limited control over how a race develops, a minimum level of both physiological and speed/mechanical capabilities would be required at the elite level for successful 800-m running performance.

In the present study, we found that a linear regression model containing MAX_{SS} and vVO_{2peak} explained the most variation in 800_{MAX} time. While previous research has shown that both VO_{2peak} (8) and peak incremental treadmill velocity (9), as well as MAX_{SS} (4), are associated with 800-m running time, this is the first study to demonstrate that both vVO_{2peak} and MAX_{SS} contribute to the explained variation in 800_{MAX} performance. The 800-m event is likely to elicit peak aerobic power (23, 24), while also requiring athletes to reach high sprint speeds (i.e., ~9.0 $m \cdot s^{-1}$) in the first 200-m of faster championship races (2). Indeed, a greater MAX_{SS} was strongly associated with a faster first 200-m time during 800_{MAX} and a greater MAX_{SS} is critical for athletes choosing to adopt a positive pacing strategy. This approach to racing the 800-m event allows for an athlete to dictate the pace of the race, run in the inside lane, and be at the front where the odds of winning improve (25). Interestingly, MAX_{SS} was a key determinant of 800_{MAX} time, but not 800_{PACE}. This finding may relate to the greater speed requirements of a "gun-to-tape" type pacing strategy (i.e., positive pacing). Indeed, the fastest 100-m split, which occurs in the first 200-m of positively paced 800-m championship races would appear to be 0.5 – 1.0 $m \cdot s^{-1}$ faster than negatively paced 800-m championship races, whereby the fastest 100-m split occurs in the final 200-m of the race (1, 4). As such, it could be suggested that an 800-m runner with a superior MAX_{SS} compared to another competitor may be best suited to adopting a positive pacing strategy to take advantage of their MAX_{SS} weapon and increase their likelihood of winning. These findings are supported by previous research that has demonstrated a strong association between a recent "gun-to-tape" 800-m performance and sprint speed over 20-m ($r = -0.72$) (11) and MAX_{SS} ($r = -0.74$) (4) in elite 800-m runners. A prominent concept that has been revitalised by Sandford et al. (4, 26) is the ASR, which is defined as the magnitude of difference between the MAX_{SS} and vVO_{2peak}, as originally described by Bundle et al. (27). In the present study, we did not find that the ASR contributed to any of the regression models explaining variation in the performance variables that we derived from the 800-m trials. In contrast, Sandford et al. (4) reported a strong univariable association between the 800-m season's best performance time of ten elite 800-m runners (≤1:47.50) and ASR (r = -0.74) which was of the same magnitude as the association between 800-m SB performance time and MAX_{SS} (4). Despite these associations being determined from partial correlations, the similar magnitude of correlation between MAX_{SS} and ASR and 800-m running time indicates that the athletes in this cohort (4) had extremely similar vVO_{2peak} values. Indeed, when a cohort of 800-m runners are matched for either MAX_{SS} or vVO_{2peak}, then the opposing characteristic may become the distinguishing performance determinant. Nonetheless, we suggest that both MAX_{SS} and vVO_{2peak} are important determinants of 800-m running performance.

Our analysis of the pacing strategy of the gold medal winner from the five fastest 800-m championship races (Olympic Games and World Championship male final) since the year 2000 demonstrates a substantially faster first lap (5.6% faster). In contrast, the gold medal winner of the five slowest 800-m championship races has adopted a negative pacing strategy (4.3% faster second lap). It is clear that when elite 800-m runners aim to run the fastest time possible, a positive pacing strategy should be adopted (1, 2, 12, 28). Experimental research also supports the employment of a positive pacing strategy in order to maximise performance during relatively short-duration trials (i.e., < 3 min). Turnes et al. (29) demonstrated that the run time to exhaustion was increased (125 s vs. 114 s), while the VO_2 mean response time was faster, with a positive compared to an even pacing strategy performed at a severe intensity that still allowed achievement of VO_{2max}. More specific to the 800-m event, the VO_2 attained during an 800-m race simulation treadmill run with a positive pacing strategy was significantly higher than that attained during a "square wave" type constant speed 800-m treadmill run. These findings are consistent with studies of a similar duration, pacing strategy and concomitant VO_2 kinetics in cycling (30, 31). Collectively, these findings demonstrate that athletes should employ a positive pacing strategy when the intention is run an 800-m race in the fastest time possible.

In the present study, the CAZ-score significantly contributed to the regression models explaining some of the variation in the final 200-m time during 800_{PACE} and the improvement in last lap time relative to 800_{MAX}. That is, runners with a higher CAZ-score (i.e., higher estimated percentage of type II fibres), reduced their last lap time and were faster over the final 200-m during 800_{PACE}, which was designed to reflect the requirements of a negatively-paced 800-m race. Furthermore, a larger vVO_{2peak} and better maintenance of effective force application (i.e., D_{RF}), contributed to the regression model explaining some of the variation in the final 200-m time during 800_{PACE}. It is important to note that in 800-m championship races, success (i.e., medallists) is not always demonstrated by an increase in speed during the final 200-m, but also by simply avoiding slowing down to the extent of unsuccessful athletes (i.e., non-medallists) (12). As such, it could be suggested that speed endurance is a more important quality compared to MAX_{SS} during the final 200-m, whereby athletes are required maintain speed despite the metabolic and neuromuscular demands of the initial part of the race. In the present study, 800-m runners who have a greater estimated proportion of type II fibres possess an advantage in the latter stages of negatively-paced 800-m races. In particular, type IIa fibres possess mechanical characteristics that underpin speed and power performance (32-34), and also have the ability to adapt to high oxidative demands which are not necessarily subservient to type I fibres in well-trained endurance athletes (35, 36). As such, type IIa fibres may possess an ideal blend of both speed and endurance capabilities given the mechanical and metabolic characteristics of these fibres, which may underpin elite performance in the final stages of a negatively-paced 800-m race.

Athletes with better maintenance of effective force application (i.e., D_{RF}) were faster over the final 200-m of 800_{PACE}, which suggests that superior mechanical effectiveness may preserve speed (i.e., speed endurance) during the latter stages of fatiguing running (i.e., final 200-m of an 800-m race). This is an interesting finding given that we determined this mechanical sprinting property during the acceleration phase of a maximal 40-m sprint performed in a non-fatigued state. Previous research has highlighted that a superior D_{RF} is associated with faster 100-m performance (mean and peak speed and 4-s distance) (19, 37). In addition, fatigue induced by repeated sprint running imposes a large decrease on the technical ability to orientate force (38, 39), whereby the individual magnitudes of change of D_{RF} were significantly more important than those of total force production (39). In well-trained 800-m runners (personal best time ranging from 1:43 to 1:56), stride length progressively decreases, and foot contact time increases from the first to the last 200-m repetition of a 5 × 200-m session with 4-min rest (40). Non-specialist runners produce lower peak braking and push-off forces, in turn leading to shorter stride length, during the latter stages of an 800-m running time trial (41). From these findings, it is clear that the technical ability to orientate force is impaired when runners are fatigued, and athletes with an enhanced ability to maintain effective force application during 800-m racing are likely to have superior performance in the latter stages of a race. We would highlight that 800-m runners should adopt appropriate training strategies to improve D_{RF} and speed endurance in order to maximise performance in the latter stages of 800-m races. Future research should investigate the individual factors that allow some athletes to better maintain effective force application during high-intensity running.

We did not find that RE contributed to the regression models that explained variation in either 800_{PACE} or 800_{MAX} trials. Our previous work (5) demonstrated that RE was a key determinant of 1500-m trials completed with a fast, sustained pace from the outset. Other research in elite middle-distance runners (8) demonstrated that RE, expressed as the relative oxygen cost during submaximal running (i.e., $mL \cdot kg^{-1} \cdot km^{-1}$), explained some of the variation in 800- and 1500-m running speeds obtained from a recent best track race. Interestingly, in the study of Ingham et al. (8) it appears that RE only becomes a significant explanatory variable for 800-m performance when it is coupled with VO_{2max}. This finding is actually supported by the present study whereby vVO_{2peak} significantly contributed to the regression models explaining the variation in 800_{MAX} performance time. vVO_{2peak} has been referred to as an "aerobic index" given that it manifests from the interaction between VO_{2peak} and RE (42). Indeed, vVO_{2peak} may explain individual differences in performance that VO_{2peak} or RE alone do not (43). In the present study, CS did not contribute to the regression models explaining the variation in 800-m running performance. Our previous work (5), and findings of the present study, demonstrate a high co-linearity between vVO_{2peak} and CS, which may render the association between CS and performance subservient to vVO_{2peak} in multiple linear regression analyses. Furthermore, mean 800-m running speed is considerably above vVO_{2peak} (115 – 130% vVO_{2peak}) (44) which would suggest that vVO_{2peak} would likely be more influential than CS.

In the present study, *D'* did not contribute to the regression models explaining variation in 800-m running performance. Fukuba and Whipp (45) and Pettitt (22) demonstrate theoretically through the hyperbolic speed-time relationship that both CS and *D'* may be important parameters related to pacing and performance in middle-distance running events. While these models have very good precision for estimating outdoor track running performance within ~2% for longer distances (i.e., 1600 and 5000 m trials), there is a substantially larger error observed for 800 m trials (95%CI: 5.2 – 18.9 s; ICC = 0.65) (46). This is likely due to the supramaximal speed (i.e., 115 – 130% VO_{2peak}) (44) and relatively short duration of 800 m trials which cannot be accurately estimated with the 2-component model (46, 47). We are actually unaware of any published literature demonstrating a strong association between *D'* and pacing or performance in middle-distance running events. In relation to MAOD, unlike our previous work assessing the underpinning physiological determinants of last-lap speed in paced 1500-m time trials (5), we did not find that MAOD was a significant explanatory variable for either 800_{MAX} or 800_{PACE}. This finding agrees with most (9, 48-51), but not all studies (23), that have investigated whether MAOD is associated with 800-m running performance. The latter study (23) actually quantified the AOD during the 800-m time trial compared to the other studies which determined a true MAOD during an exhaustive supramaximal constant speed treadmill test (9, 48-51). As such, the association between AOD and 800-m running performance in Billat et al. (23) may have manifested from the AOD determined during the actual 800-m running trial, rather than a true measure of MAOD which can only be determined from a separate exhaustive trial. It should also be noted that larger sample sizes and larger variation in the independent variables may be required to identify the deterministic potential of *D'* and MAOD to 800-m running performance.

The present study has demonstrated that diversity in the physiological and speed/mechanical characteristics of male middle-distance runners may relate to their suitability of adopting different racing strategies in the 800-m event. The influence that prior training has on the between-athlete variability in the broad range of physiological and speed/mechanical characteristics quantified in the present study was not determined. Furthermore, how training prescription can be manipulated in order to maximise improvements in vVO_{2peak} and speed/mechanical characteristics (i.e., MAX_{SS} and D_{RF}) simultaneously requires further examination. Indeed, to optimize adaptations across this spectrum of characteristics, future studies are warranted to investigate longitudinal effects of combined sprint, resistance, and endurance training on the critical determinants of 800-m performance. The findings of the present study should also be viewed in light of the specific cohort that was studied, whereby the male runners could be considered trained but not elite middle-distance runners. The findings that characteristics such as MAOD, CS and *D'* did not contribute to the regression models does not necessarily mean that they are not deterministic, and it is possible that these characteristics may be more important in other cohorts of trained athletes. We would also like to highlight that 800-m running is extremely tactical and a given athlete may not always be able to create a race scenario that favours the strengths of their physiological and speed/mechanical characteristics, nor would that necessarily guarantee them success in a race. For example, while some athletes would be best suited to a negatively-paced race, drafting and conserving energy for a surge in the final lap, leading the race and running on the rail is underappreciated by many athletes and coaches (12, 25) and this may be one strategy to reduce the likelihood of being in a poor position in the final lap (e.g., boxed-in) and being unable to make a final surge for the line.

In the present study, we aimed to identify the underpinning determinants of different types of 800-m running trials simulating aggressive front running or a slower initial lap, with a last lap surge in male middle-distance runners. We highlight that vVO_{2peak} and MAX_{SS} largely explain the variation in 800_{MAX}, while a higher estimated percentage of type II fibres and greater mechanical effectiveness were important for last lap speed in 800_{PACE}. These findings highlight that diversity in the physiological and speed/mechanical characteristics of middle-distance runners should be considered in light of maximising performance in different types of 800-m races. Coaches should also focus on how training prescription can be best manipulated in order to maximise training adaptations across the broad spectrum of characteristics that are important for 800-m running. Matching athlete characteristics with preferential racing strategies may be one avenue to increase the likelihood of success in male 800-m running competitions.

Acknowledgments

The authors have no external funding to declare and no competing interests to disclose. The results of the present study are presented clearly, honestly, and without fabrication and do not constitute endorsement by ACSM.

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FIGURES

Figure 1 – Panel A displays the 200-m split speed of the gold medal winner from the five fastest (2012 and 2016 Olympic Games and 2001, 2013 and 2019 World Championships) and five slowest (2000 and 2008 Olympic Games and 2007, 2009 and 2015 World Championships) 800-m championship races since the year 2000. Panel B displays the 200-m split speed of participants in the present study who completed the maximal (800_{MAX}) and paced (800_{PACE}) 800-m time trials.

Figure 2 – The association between last lap time in 800_{MAX} and 800_{PACE} (panel A) and last lap time in 800_{MAX} and the relative improvement in last lap time in 800_{PACE} (panel B).

Figure 3 – Determinants of overall time of 800_{MAX}, first 200-m time of 800_{MAX}, the final 200-m time of 800_{PACE} and improvement in last lap time relative to 800_{MAX} determined from stepwise linear regression models. Bars indicate the magnitude of explained variance (% r^2) with the combination of predictors presented at the top of each bar.

Figure 4 –Individual and mean (95%CI) carnosine aggregate Z-score values of the gastrocnemius and soleus of runners in the present study, as well as the non-athlete control group. The absolute carnosine concentration for the runners was converted to a sex- and muscle-specific Z-score relative to an age-matched control population of active, healthy male non-athletes (n = 40) and the aggregate of the carnosine Z-scores was used for all analyses.

Figure 1

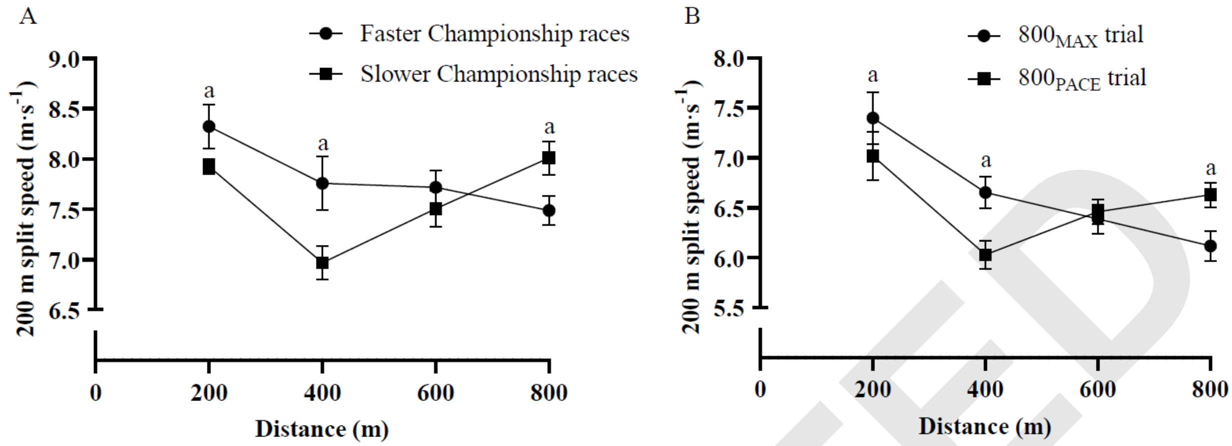

A
Faster Championship races
Slower Championship races
200 m split speed (m·s⁻¹)
9.0
8.5
8.0
7.5
7.0
6.5
a
a
a
0
200
400
600
800
Distance (m)
B
800MAX trial
800PACE trial
200 m split speed (m·s⁻¹)
8.0
7.5
7.0
6.5
6.0
5.5
a
a
a
0
200
400
600
800
Distance (m)

Figure 2

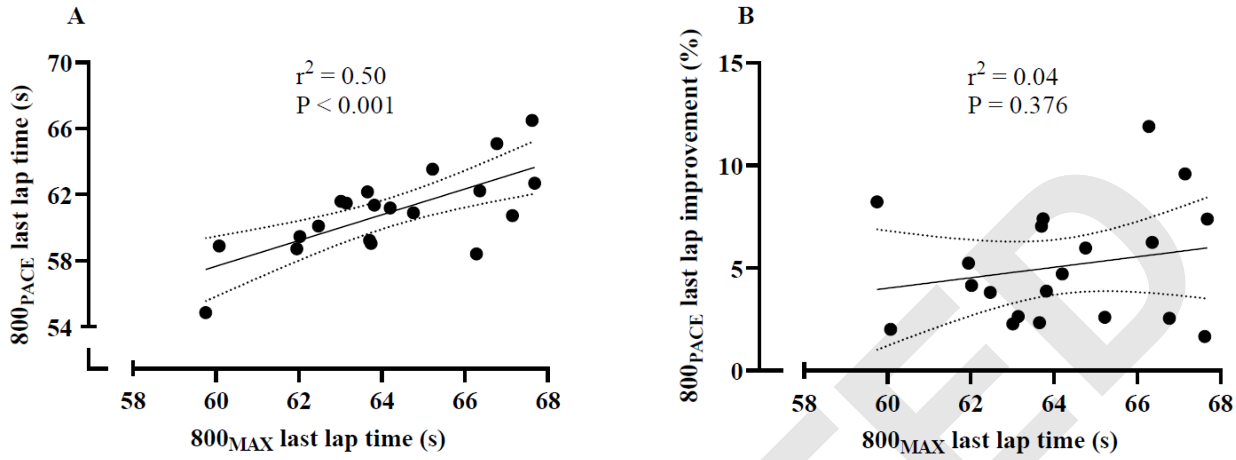
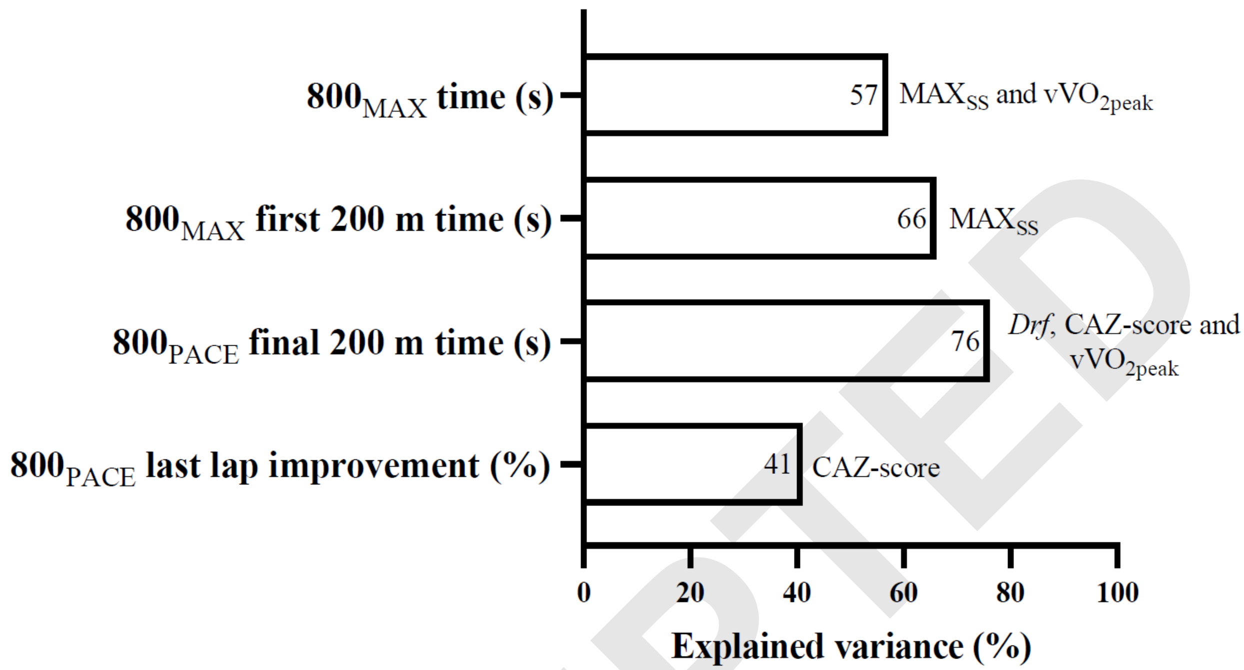

A
r² = 0.50
P < 0.001
70
66
62
58
54
800PACE last lap time (s)
58
60
62
64
66
68
800MAX last lap time (s)
B
r² = 0.04
P = 0.376
15
10
5
0
800PACE last lap improvement (%)
58
60
62
64
66
68
800MAX last lap time (s)

Figure 3



800MAX time (s)
800MAX first 200 m time (s)
800PACE final 200 m time (s)
800PACE last lap improvement (%)
57
MAXSS and vVO2peak
66
MAXSS
76
Drf, CAZ-score and vVO2peak
41
CAZ-score
0
20
40
60
80
100
Explained variance (%)

Figure 4

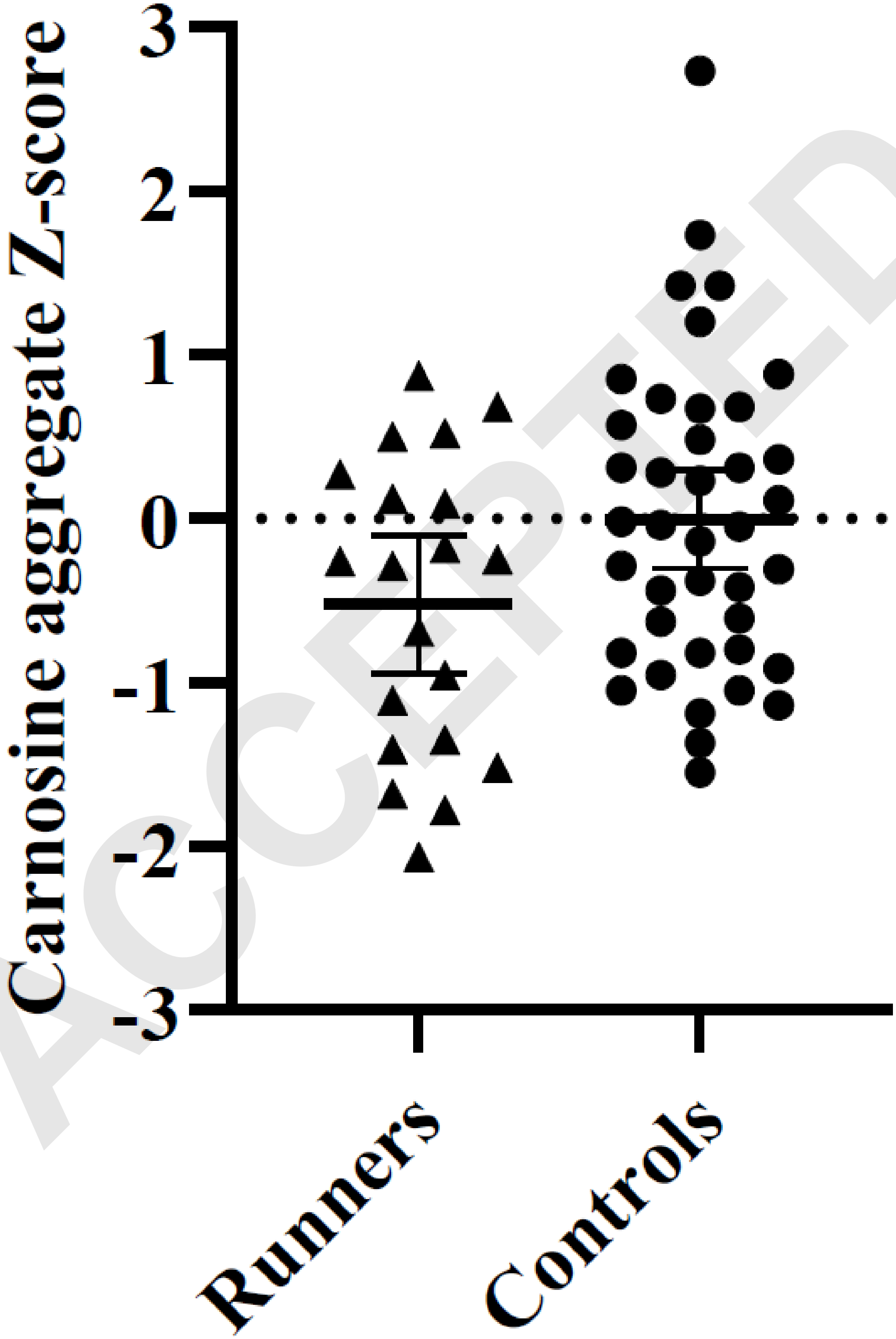


Table 1 – The mean (range) physiological and performance characteristics of the subjects derived from both laboratory and field testing.

Variable	Mean (range)
Submaximal laboratory treadmill test	
RE (Kcal·kg·km^{-1})	1.06 (0.99 - 1.16)
Maximal incremental laboratory treadmill test	
VO_{2peak} (L·min^{-1})	4.65 (3.31 - 5.46)
VO_{2peak} (mL·kg·min^{-1})	69.7 (60.4 – 77.0)
Peak HR (beats·min^{-1})	194 (181 - 213)
Submaximal and maximal laboratory treadmill test	
vVO_{2peak} (m·s^{-1})	5.67 (4.58 – 6.39)
Supramaximal laboratory treadmill test	
Supramaximal TTE (s)	171 (155 - 250)
MAOD (L^{-1})	3.11 (1.89 - 5.40)
MAOD (mL·kg^{-1})	47.6 (30.9 - 69.2)
Peak blood lactate (mmol·L^{-1})	15.4 (9.8 - 23.1)
Athletics track testing	
CS (m·s^{-1})	4.89 (4.25 – 5.56)
D' (m)	228 (115 - 346)
MAX_{SS} (m·s^{-1})	8.5 (7.58 – 9.86)
ASR (km·h^{-1})	10.8 (7.04 - 17.9)
Speed reserve ratio (AU)	1.52 (1.24 - 2.29)
V0 (m·s^{-1})	8.78 (7.36 – 10.36)
F0 (N·kg^{-1})	7.40 (6.15 - 8.63)
Pmax (W·kg^{-1})	15.6 (10.1 - 19.1)
Index of force application (*Drf*)	0.086 (0.063 - 0.106)
Proton magnetic resonance spectroscopy testing	
CAZ-score	-0.52 (-2.06 - 0.87)

VO_{2peak}; peak oxygen uptake, vVO_{2peak}; velocity at peak oxygen uptake, HR; heart rate, RE; running economy, CS; critical speed, D'; curvature constant, TTE; time to exhaustion, MAOD; maximal accumulated oxygen deficit, ASR; anaerobic speed reserve, MAX_{SS}; maximal sprint speed, *V0*; theoretical maximal velocity, *F0*; theoretical maximal force, *Pmax*; theoretical maximal power. CAZ-score; carnosine aggregate Z-score

Table 2 – The mean ± SD 200 m split times, first:second lap time ratio and total time for the maximal (800_{MAX}) and paced (800_{PACE}) 800-m time trials.

	Segment splits				1:2 lap ratio	Total time (s)
	0 -200 m (s)	200 - 400 m (s)	400 - 600 m (s)	600 - 800 m (s)		
800_{MAX}	27.17 ± 2.02[a]	30.14 ± 1.49[a]	31.39 ± 1.50	32.78 ± 1.71[a]	0.89 ± 0.05[a]	121.48 ± 4.86[a]
800_{PACE}	28.64 ± 2.09	33.26 ± 1.67	31.00 ± 1.26	30.20 ± 1.24	1.02 ± 0.04	123.11 ± 5.50

[a]indicates significant difference between 800_{MAX} and 800_{PACE}

NB: Each 200 m split time within each trial was significantly different from one another.

Table 3 – Stepwise linear regression model parameter estimates for the association between the physiological and performance/mechanical characteristics (independent variables) and the overall time and first 200 m time of 800_{MAX} and the final 200 m time of 800_{PACE} and improvement in last lap time relative to 800_{MAX} (dependant variables).

Statistic	800_{MAX} performance time	800_{MAX} first 200-m time	800_{PACE} last lap improvement	800_{PACE} final 200-m time
Predictors	MAX_{SS}[1] and vVO2peak[2]	MAX_{SS}[1]	CAZ-score[1]	Drf[1], vVO_{2peak}[2] and CAZ-score[3]
Adjusted r^2	0.570	0.661	0.413	0.761
P value	0.020	<0.001	0.001	<0.001
Standard error of the estimate	3.180	1.209	2.171	0.744
Variable 1				
Unstandardized coefficient	-5.800	-1.015	2.085	0.424
Standard error	1.442	0.171	0.550	0.151
Standardized coefficient	-0.614	-0.813	0.666	0.358
P value	0.001	<0.001	0.001	0.013
Variable 2				
Unstandardized coefficient	-0.891			-1.088
Standard error	0.346			0.251
Standardized coefficient	-0.393			-0.505
P value	0.020			0.001
Variable 3				
Unstandardized coefficient				-0.838
Standard error				0.212
Standardized coefficient				-0.498
P value				0.001

vVO_{2peak}; velocity at peak oxygen uptake, MAX_{SS}; maximal sprint speed, CAZ-score; carnosine aggregate Z-score, *Drf*; index of force application