Sports Medicine (2019) 49:843–852
https://doi.org/10.1007/s40279-018-1010-5

CURRENT OPINION

Maximal Sprint Speed and the Anaerobic Speed Reserve Domain: The Untapped Tools that Differentiate the World's Best Male 800 m Runners

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Abstract

Recent evidence indicates that the modern-day men's 800 m runner requires a speed capability beyond that of previous eras. In addition, the appreciation of different athlete subgroups (400–800, 800, 800–1500 m) implies a complex interplay between the mechanical (aerial or terrestrial) and physiological characteristics that enable success in any individual runner. Historically, coach education for middle-distance running often emphasises aerobic metabolic conditioning, while it relatively lacks consideration for an important neuromuscular and mechanical component. Consequently, many 800 m runners today may lack the mechanical competence needed to achieve the relaxed race pace speed required for success, resulting in limited ability to cope with surges, run faster first laps or close fast. Mechanical competence may refer to the skilled coordination of neuromuscular/mechanical (stride length/frequency/impulse) and metabolic components needed to sustain middle-distance race pace and adjust to surges efficiently. The anaerobic speed reserve (ASR) construct (difference between an athlete's velocity at maximal oxygen uptake [$\mathrm{v}\dot{V}\mathrm{O_2max}$]—the first speed at which maximal oxygen uptake [$\dot{V}\mathrm{O}_{2\mathrm{max}}$] is attained) and their maximal sprint speed (MSS) offers a framework to assess a runner's speed range relative to modern-day race demands. While the smooth and relaxed technique observed in middle-distance runners is often considered causal to running economy measured during submaximal running, little empirical evidence supports such an assumption. Thus, a multidisciplinary approach is needed to examine the underpinning factors enabling elite 800 m running race pace efficiency. Here, we argue for the importance of utilising the ASR and MSS measurement to ensure middle-distance runners have the skills to compete in the race-defining surges of modern-day 800 m running.

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Key Points

Modern day 800 m running may require development of both ends of the anaerobic speed reserve equation (maximal sprint speed [MSS] and velocity at maximal oxygen uptake [$v\dot{V}O_{2max}$]—the first speed at which maximal oxygen uptake [$\dot{V}O_{2max}$] is attained) in order to negotiate race surges and minimise associated energetic consequences.

The traditional measure of 400 m best time as an indicator of an athlete's speed capability may be misleading due to its poor association with MSS capability in 800 m athletes.

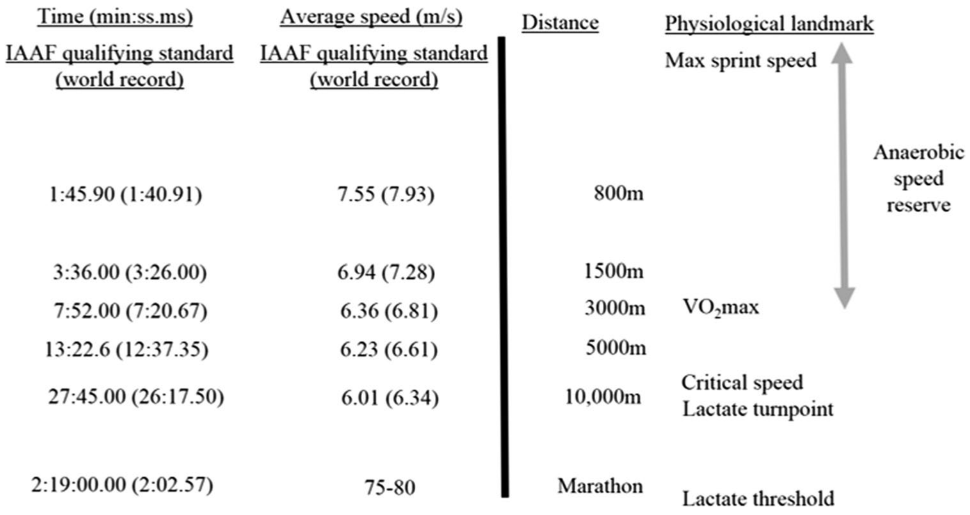
As running economy (16–20 km/h) is not representative of 800 m race pace efficiency (~ 27 km/h), future research should use a multidisciplinary approach to examine and define the individual mechanical requirements of the race pace-specific running motion.

1 Introduction

Winning a middle-distance race requires a unique blend of tactical decision-making and physical execution in the moment [1, 2]. Whilst characterisation of middle-distance events usually starts with global 'energetic demands' [3, 4], there are moments within races that define medal outcomes, such as surges in the first lap of the 800 m or the last lap kick in the 1500 m [5, 6]. To date, race-defining moments and their underpinning qualities have received little attention in the literature. Both 'sit and kick' and 'gun to tape' tactical approaches can occur (e.g. through championship rounds), meaning successful athletes require a robust armoury of abilities to negotiate both 'sit and kick' and 'gun to tape' scenarios, alongside the multitude of other possible surging scenarios [7]. Herein we define a surge as any timepoint after 100 m into the race where an athlete repositions by three or more places or noticeably raises the pace from the front.

In the men's 800 m, extreme surge demands (as fast as 11 s per 100 m) require substantial absolute speed (as fast as 10 m/s in world-class male 800 m runners [8]) alongside concurrent aerobic capability [5]. Recently, the anaerobic speed reserve (ASR), defined as the speed zone ranging from the velocity at maximal oxygen uptake ($v\dot{V}O_{2max}$—the first speed at which maximal oxygen uptake [$\dot{V}O_{2max}$] is attained) to the maximal sprint speed (MSS—the velocity at which an athlete can no longer accelerate when performing an 'all-out' sprint effort [9, 10]) (Fig. 1), was used to highlight the physiological and mechanical diversity of 800 m subgroup athletes [8]. As 'classic' coach education practices continue to prioritise the aerobic conditioning aspect of middle-distance running [11], these modern-day race demands clearly require significant concurrent speed capability [5], bringing forth the need to define the underlying speed qualities that constitute performance in an 800 m event [11]. Here, we therefore focus on the upper component of the ASR, namely MSS. Indeed, detailed reviews are available concerning the importance of $v\dot{V}O_2$max to middle-distance running (see Billat and Koralsztein [12] and Jones and Carter [13]).

Middle-distance coaching vernacular for a 'speed session' may refer to 150 m efforts, 400 m pace, race pace, maximal sprint speed (< 80 m) or sprint finish (pre-fatigued). Subtle prescription differences across discrete training paces (all of which may be termed 'speed') can lead to large differences in adaptation outcomes [10]. Therefore, clarification of the role of MSS (the speed ceiling) for 800 m running is needed to optimise training preparation for the event [15]. DeWeese and Nimphius [16] define speed application as "the skills and abilities required to achieve high velocities".



Time (min:ss.ms) IAAF qualifying standard (world record)	Average speed (m/s) IAAF qualifying standard (world record)	Distance	Physiological landmark	
			Max sprint speed	
1:45.90 (1:40.91)	7.55 (7.93)	800m		Anaerobic speed reserve
3:36.00 (3:26.00)	6.94 (7.28)	1500m		
7:52.00 (7:20.67)	6.36 (6.81)	3000m	VO_2max	
13:22.6 (12:37.35)	6.23 (6.61)	5000m		
27:45.00 (26:17.50)	6.01 (6.34)	10,000m	Critical speed Lactate turnpoint	
2:19:00.00 (2:02.57)	75-80	Marathon	Lactate threshold	

Fig. 1 Time and average speeds for the International Association of Athletics Federations (IAAF) qualifying standards for the London 2017 World Championships and world records, as they relate to physiological (maximal oxygen uptake [$\dot{V}O_{2max}$], crucial speed, lactate turnpoint) and mechanical/neuromuscular (maximal [Max] sprint speed, anaerobic speed reserve) markers (assuming even pace running). Modified from Billat [14] and Buchheit and Laursen [10], with permission

Indeed, how the skill component of speed is trained, taught and emphasised in distance runners is a topic of much debate [11]. Thus, in this article, we describe the ASR as it relates to the 800 m athlete, the transfer of MSS to race pace performance, and the factors that may underpin this transfer. Finally, we consider the topic of race pace efficiency for 800 m runners, and how this may be more motor skill—rather than running economy (RE)—driven.

2 Anaerobic Speed Reserve: A Framework for Faster Race Pace Running?

The application of the ASR may be considered complex as a result of its two moving parts; one largely limited by metabolism (v$\dot{V}O_{2max}$) [17], the other more by force orientation/mechanics (MSS) [18, 19]. The importance of the ASR is highlighted by its strong relationship with world-class 800 m running performance ($r = 0.74$ [8]), with likely implications in the 'last-lap kick' (1500–10,000 m) [6, 20]. Our recent study [8] showed that athletes running 1:44/1:45 (min:ss) for men's 800 m displayed a larger ASR over their 1:47 running counterparts, highlighting ASR as a likely differential characteristic between elite and sub-elite performers.

An 800 m runner presenting with a large ASR (with fast MSS) may have the opportunity to run faster relaxed race paces compared to an athlete presenting with a smaller ASR, assuming similar aerobic capability (e.g. Fig. 2). We propose this to be due first to a larger mechanical range across which one can adjust technique to apply more force as race surges demand [20]. Second, if the 800 m pace sits at a lower proportion of the ASR, the imposed physiological strain of that pace is reduced [21]. For example, Bachero-Mena et al. [22] recently demonstrated in national and international 800 m runners (1:43–1:58) that MSS measured using 20 m time was strongly related to 800 m performance ($r = 0.72$), with an even stronger relationship shown for 200 m speed ($r = 0.84$). Therefore, MSS may be an important prerequisite for an athlete to achieve faster paces over longer event distances and/or closing race sectors.

Tactical analysis of the men's 800 m from the 2012 Olympics [23] showed a 50% probability of qualifying by being in third place by 400 m. With remarkable individual 100 m sector speeds attained by world-class 800 m males between 100 and 200 m [5], athletes must possess an ASR to either meet these demands via a relaxed technique (and be in the top 3 by 200 m), or have a strategy to be in the race at the 400 m mark [23] (Fig. 3) by running a more even first lap of ~ 50 s (i.e. 25 s + 25 s, rather than 23 s + 27 s). A slow MSS when non-fatigued may prove costly in enabling a 50 s first lap, and subsequent tolerance of the second lap, if target race pace is at too high a proportion of their MSS [21]. Therefore, a key strength of the ASR determination for middle-distance athletes may be knowledge of the athlete's mechanical speed bandwidth to begin the process of optimising race pace selection [24]. Indeed, during all-out exercise, such as

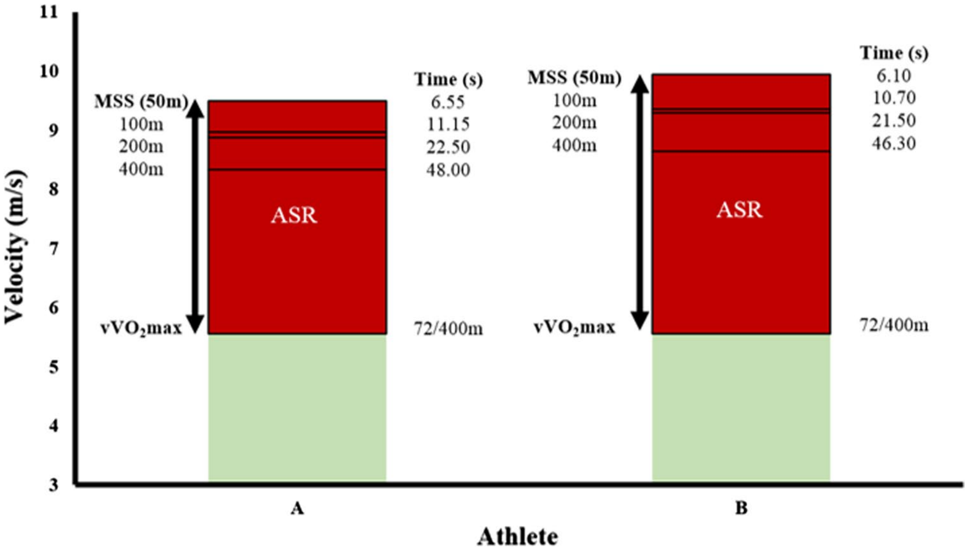


Fig. 2 Two hypothetical athletes (A and B) presenting with different maximal sprint speeds (MSS), but possessing the same velocity at maximal oxygen uptake (v$\dot{V}O_{2max}$). If the race demand of the fastest 100 m is 11.0 s, and an athlete's 100 m personal best is 11.15 s (athlete A), their anaerobic speed reserve (ASR) limits their ability to meet the event demands. The alternative approach for athlete A may be to perform a relaxed first lap of 50 s within their ASR limit. Importantly, however, relying on the latter approach may not be enough for a podium finish in the modern era [5]. The successful elite middle-distance athlete needs a high enough ASR non-fatigued to be competitive at race velocities under high metabolic perturbation in the closing stages of a race. Modified from Buchheit and Laursen [10], with permission

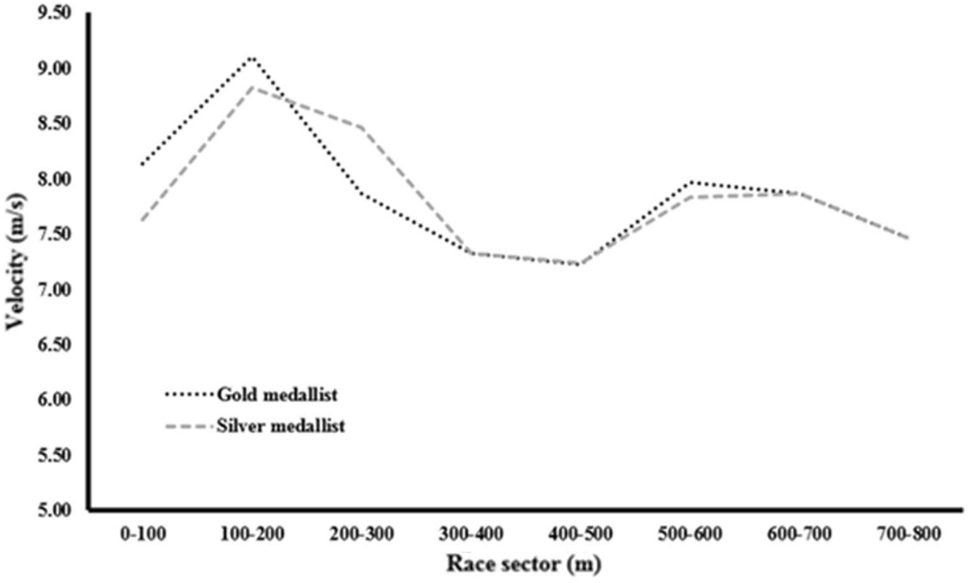


Fig. 3 Race profile of the Rio de Janeiro 2016 Men's 800 m final Olympic gold and silver medallists, illustrating the mechanical bandwidth of surges occurring during an 800 m middle-distance race (winning time 1:42.15 [min:ss.ms]). At the 200 m mark, the eventual silver medallist (800–1500 m subgroup) was 1.28 s behind the race leader (800 m specialist), shortening the deficit at 400 m to 0.37 s behind. Many speed transitions are shown within the race, requiring smooth mechanical coordination to avoid potentially disastrous increases in energetic cost. This figure represents the need for mechanical running literacy across the race pace bandwidths to maintain smooth technique at or above an even race pace strategy [28]

a gun-to-tape 800 m race, reliance on anaerobic metabolism will compromise force production [25], meaning compensatory strategies must be drawn upon by the athlete [25, 26]. The necessary recruitment of the larger motor units needed to sustain pace above critical speed (CS) [27] (e.g. 800 m race pace) presents a clear rationale for the need to maximise ASR (i.e. both v$\dot{V}O_{2max}$ and MSS) [25].

Importantly a large ASR does not mean athletes are instantly fast or efficient at all paces within the ASR domain (Fig. 4), but offers a potential explanation as to why some fast 400 m athletes struggle to transition to the 800 m (i.e. a new motor skill patterning is needed for efficiency at 800 m race pace; see Sects. 2.1, 3, 3.1 and 3.2).

2.1 Maximal Sprint Speed (MSS) Transfer to Race Pace

Improving understanding of MSS characteristics in 800 m subgroups provides a framework to further understand an athlete's 'split potential' in optimising their 800 m race strategy. 800 m race plans (splits) are usually cordoned into sectors, most commonly over 200 or 400 m [30]. An athlete's ability to run a first lap target time is often judged by their ability to run a specified 200 or 400 m split in training or racing (Gareth Sandford, unpublished observation). Without considering the athlete's MSS capability, these splits are used to establish the upper capacity for speed over any given race sector. The problem with this approach is that the transfer of MSS into 400 m season's best (SB) time is highly variable (Fig. 5). By comparison, in national US and Finnish 400 m specialists, Nummela et al. [31] revealed a very large ($r = 0.88$) relationship between 400 m time and maximum velocity (assessed over 30 m), whereas Fig. 5 reveals that MSS assessment only explained 35% of the variance in 400 m SB performance in elite and sub-elite 800 m runners. A commonly observed limitation in middle-distance runners during race surges may be their biomechanics (Gareth Sandford, unpublished observation). This element is often less accounted for in planning, and may explain part of the poor transfer of MSS to 400 m SB [10].

Further, the relatively high variation in 400 m SB time, despite similar MSS profiles (Fig. 5), highlights the limitation of using 400 m time alone as a representation of an athlete's 'speed capability' and could lead to inappropriate categorisation of an athlete into their event group specialisation. The alternative approach, through accurately determining MSS, may allow a more detailed analysis of the factors that may be limiting the transfer of MSS across the athlete's ASR bandwidth, and highlight opportunities for performance improvement.

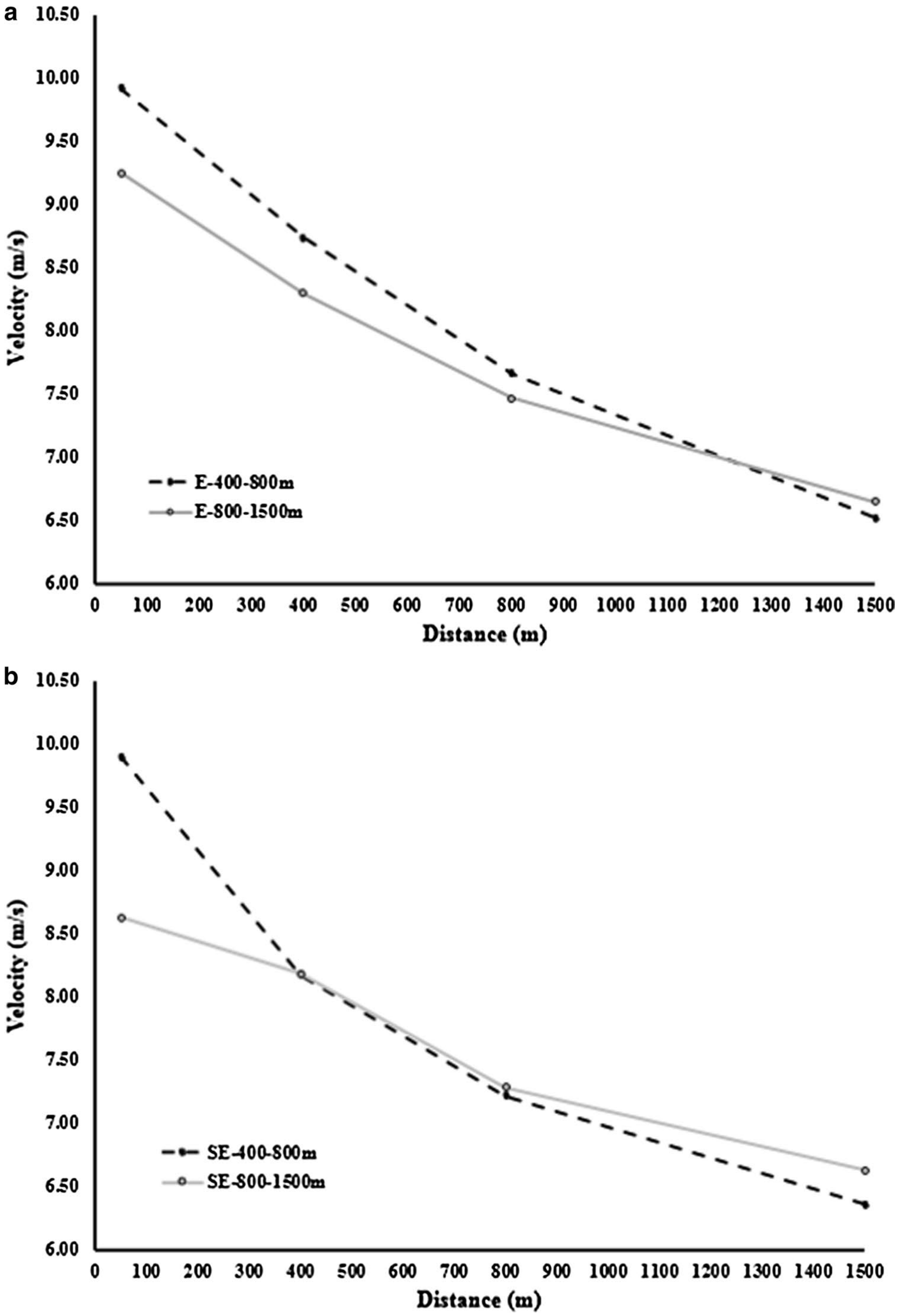


Fig. 4 Hypothetical speed profile of four 800 m athletes categorised per competitive standard: **a** elite (E): 800 m season's best time between ≥ 1:44 and < 1:47.50 (min:ss.ms); and **b** sub-elite (SE): 800 m season's best time between < 1:47.50 and < 1:51. Improvement in maximum velocity (50 m) or average velocity at a given race distance would be described by an upward shift of that marker on the speed profile to be used to identify mechanical/training/planning gaps in the athlete's profile, as illustrated by Quod et al. [29]. Data collected from methods described in Sandford et al. [8]

3 What Factors Limit the MSS Transfer to 800 m Race Pace?

Performance in maximal efforts < 60 s tend to be limited more by mechanical and neuromuscular aspects than metabolic components [17, 32], meaning these qualities represent important underlying characteristics for the surges that define race outcomes. Mechanical efficiency is defined as the ratio of work done (in this case, running velocity) to energy used [33]. Neuromuscular aspects refer to the nervous system and coordination of muscle contraction needed to perform the running task [34]. Importantly, having coordination across a mechanical bandwidth of speeds in and around race pace, and the ability to smoothly self-adjust, will enable efficiency for race surges under fatigue [35, 36]. Sections 3.1 and 3.2 discuss the neuromuscular, biomechanical and motor qualities that underpin race pace speed.

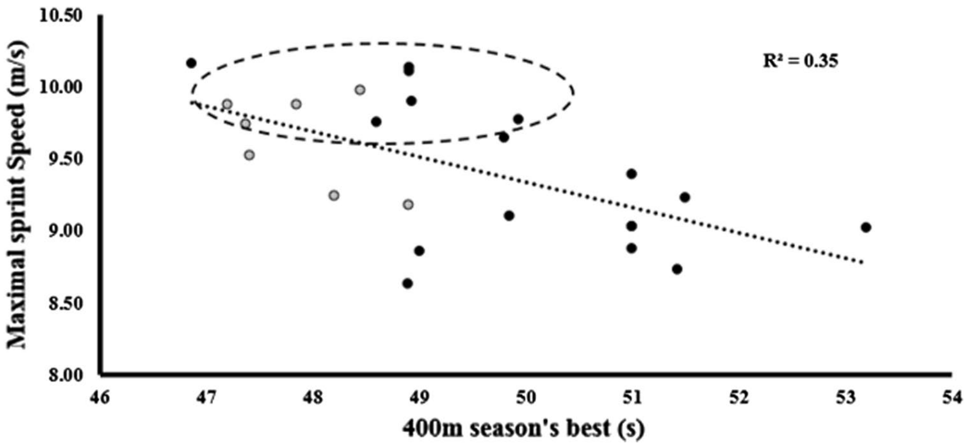


Fig. 5 Relationship between 400 m season's best (SB) and the maximal sprint speed (MSS) ($r = 0.60$, large correlation), as assessed by radar gun over a 50 m maximal sprint from a standing start during the 2017 outdoor competition season (northern and southern hemisphere) in seven elite (grey dots) and 17 sub-elite (black dots) 800 m runners [8]. 400 m SB was taken from the competitive race season. The dashed oval sector highlights athletes with a similar MSS of ≥ 9.75 m/s but with a large 400 m SB range (47.20–49.94 s)

3.1 Running Economy or Motor Skill Driven?

Commentators often refer to middle-distance runners' technique as smooth and relaxed [37, 28]. Physiologists, however, may incorrectly link this observation to RE. RE is defined as the energy demand for a given velocity of submaximal running, as determined by measuring the steady-state consumption of oxygen ($\dot{V}O_2$) and respiratory exchange ratio at submaximal speeds ≤ 85% $\dot{V}O_{2max}$ (for reviews see Barnes and Kilding [38] and Saunders et al. [39]). Of course, an 800 m event occurs above CS (e.g. even an 800 m race pace of 1:45 = 27.4 km/h), well above steady-state submaximal running speeds (Fig. 2), where the anaerobic contribution to exercise is substantial, thereby preventing accurate calculation of RE [40, 41]. Interestingly, Daniels and Daniels [42] demonstrated that elite 800 and 1500 m runners were more economical at speeds greater than 19 km/h, but less economical at slower speeds than marathon runners. However, in the absence of accurate measures of anaerobic metabolism [43], it is difficult to conclude that middle-distance runners are more economical at faster velocities than their longer-distance counterparts [39]. Nevertheless, Trowell et al. [44] showed no relationship between RE at 16 km/h and 1500 m race performance in national- and international-level female 1500 m runners (performance time 4:23.31 ± 9:65). Our speed type 400–800 m subgroup may appear remarkably inefficient at submaximal running paces yet show remarkable race pace efficiency (Gareth Sandford, unpublished observation). While we are not implying that RE is not important, particularly for the 800–1500 m subgroups, it equally does not indicate it should be a primary performance determinant for speed type and 800 m runner specialists. Although Ingham et al. [45] showed a moderate relationship ($r = 0.49$) between RE and men's 800 m speed, it is possible that the relationship was derived more from a subgroup of predominantly 800–1500 m athletes.

3.2 Mechanical Efficiency at 800 m Race Pace

Figure 6 shows an overview of the requirements for smooth 'surge' transitions between 800 m race pace and MSS. Smooth transitions refer to minimising the energetic cost of technical adjustments, primarily from changes in stride length (SL) and frequency (SF) that determine running speed [46, 47]. In distance runners these technical skills are less well-developed and rarely prioritised as a skill in training [11, 48]. Perhaps this may result from insufficient knowledge concerning SL, SF and contact time interaction at race pace [49]. Interestingly in elite sprinters, Bezodis et al. [50] demonstrated very large fluctuations in SF and SL (therefore, MSS) in response to different training phases. The implications this may have for target 800 m pace performance are unknown but may be important to consider in annual planning towards target races.

Whilst SL and SF ratios are usually self-selected [51], coordination of both SL and SF across ASR bandwidth has some important biomechanical underpinnings that require further resolution. Trowell et al. [52] showed that hip flexion/extension angle range during swing, the thorax flexion/extension angle at toe-off and the plantar/dorsiflexion ankle angle explained 94% of 1500 m race time in national and international male middle-distance runners (performance time: 3:49.66 ± 6:08). The authors acknowledged the individual variance in observed technique, meaning determination of individual biomechanical efficiency is paramount. Lussiana and Gindre [53] suggest this variance in part may

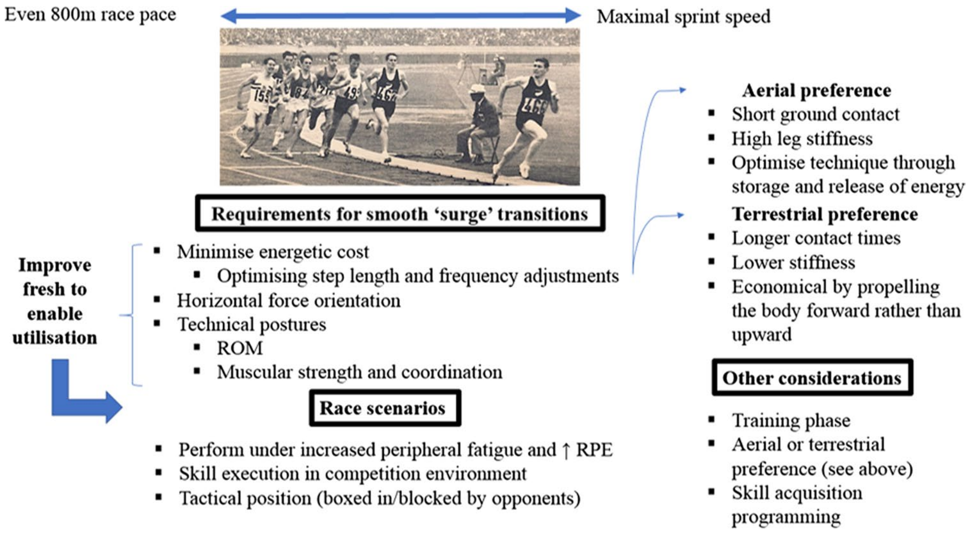


Fig. 6 Overview of the factors affecting transitions of pace both fresh (non-fatigued) and within a race scenario, including mechanical preferences (aerial or terrestrial) and other factors that can affect the mechanical/coordination variables involved in pace transition. *ROM* range of motion, *RPE* rating of perceived exertion

be due to preferential aerial or terrestrial gait cycle preferences. The 100 m world record holder, Usain Bolt, may be the perfect illustration of a terrestrial profile where the function of height and limb length create longer ground contact times, producing more impulse-per-step than in his aerial counterparts, thereby allowing approximately 10% greater impulse-per-step [54]. In the 800 m running context, even at race pace running velocities, terrestrial athletes with longer running contact times may produce the same impulse for a lower metabolic cost than their aerial, stiff and/or fast twitch counterparts. These presumptions offer many potential implications for optimising race pace/plan, strength and conditioning, as well as athlete mechanical cueing (internal or external preference [55]) that warrant further investigation. Importantly, however, despite the different preferences identified, the race demands of a fast opening, or closing, lap by nature of the required speed necessitates a minimum MSS ability to be efficient at shorter ground contact times [56].

With world-class 800 m data not being available to date, a biomechanical analysis of the men's 10,000 m final from the 2007 World Championships may be a good starting point for understanding how a small ASR and inability to increase force orientation restrict performance potential [18, 57]. In this race, Martin Mathathi (third-place athlete) elicited what appears to be "good technique to utilise mechanical energy effectively in the race's early laps, but was unable to speed up at the end of the race" [20]. One can speculate that Mathathi was an athlete with a good RE but with a small ASR and limited mechanical efficiency at faster race paces, unable to transition his SL and SF ratio at a faster speed at the end of the race (assuming he would have the metabolic capability to sustain this intensity). By contrast, Kenenisa Bekele, the gold medallist in that same race, was described as "maintaining a large SL during the race and changing his running velocity by increasing his SF, especially in the final sprint" [20]. Ten years later, the International Association of Athletics Federations (IAAF) report [58] on the 2017 London World Championships revealed that Mo Farah (first) and Joshua Cheptegei (second) displayed the same qualities as Bekele in maintaining a long SL and an increasing SF in the closing stages.

Under fatigue, on the second lap of an 800 m race, a decrease in running speed will align with decreases in SL and SF [59]. Therefore, to increase running speed under fatigue, an athlete must increase either SL or SF. Bridgman [60], in a cohort of regional, national and international distance runners, recommended an emphasis on extending SL to achieve high velocities, with more favourable energetic cost than increased SF, though this is contingent on being able to produce more force during ground contact [18, 57, 60]. Chapman et al. [56], supporting earlier observations [51], found that elite cohorts placed a greater reliance on increasing SF at higher speeds, suggesting SF capability is an important tool in the armoury of an elite distance runner, and a key quality underpinning the ASR.

Van der Zwaard et al. [61], in Dutch international pursuit cyclists, showed a long muscle fascicle rather than a large muscle cross-sectional area (CSA) as being beneficial for achieving both high peak power and strong 15 km time-trial performances, with an inverse relationship between CSA and $\dot{V}O_{2\max}$. Perhaps having both longer fascicles (with high contractile speed) and high percentages of slow-twitch muscle (for high oxidative capacity) may be optimal to optimise 800 m running pace in this event. In cycling, power profiles are used to assess a range of power outputs that may be experienced within a race, as well as optimising the pedalling frequency-to-gear ratio [29, 62]. A similar approach might be considered for middle-distance runners to optimise their mechanical efficiency in and around the race pace motor skills (Fig. 4), as small changes in gait lead to large differences in performance velocity [56, 60].

3.3 Acceleration: On the Fly Versus from Standing

Pace transitions from a rolling start have been shown to have a much lower energetic cost than from initial standing acceleration in cycling [63] and running [64–66]. The challenge in the 800 m event is the tactical importance and fast speed of the modern-day first 200 m [5]. This suggests that there is not just a need to hone the efficiency of being relaxed at race pace, but also for being efficient at accelerating for positions at the tactical break after 100 m, as well as ensuring tactical options on the first lap.

4 Perspective

The purpose of this article was to contextualise the role of MSS and the ASR domain in 800 m running with recent evidence of speed demands increasing in world-class men's 800 m running [5]. No longer should it be considered that distance runners cannot improve their MSS [67, 68], which has important implications for potential splits over longer distances. Having a faster MSS can be a performance advantage for an athlete, and ensuring that distance runners have the ASR framework required to handle surges in their event demand is an important coaching pursuit alongside the concurrent development of aerobic physiology.

Advancing knowledge concerning speed transfer into relaxed 800 m running, and its underlying components, is an important future research direction. Submaximal RE assessments are questionable for gaining insight into the capability of an athlete to perform the specific skill of 800 m race pace running. Focus instead should be turned towards understanding the technical requirements from a motor control and biomechanical perspective, and how this may differ between aerial and terrestrial preference athletes. Utilisation of a 'speed profile' concept (Fig. 4) akin to the cycling model may assist to understand these individual differences between both the mechanical and physiological subgroups discussed. Finally, better understanding of the strategies used to counteract fatigue and hold SL and SF during the closing stages of a middle-distance race are critical for limiting an athlete's deceleration at the end of a race [5, 6].

5 Conclusions

The aim of this article was to provoke interest in areas that are less frequently considered in developing a fast 800 m runner. While MSS is well-defined, the supporting paces within the ASR around 800 m race pace require further definition, better quantification and investigation. New focus is required to advance beyond merely quantifying RE and $\dot{V}O_{2\max}$. To do so requires an individualised, multidisciplinary subgroup focus to extend our knowledge of the middle-distance performance picture. Importantly, a new paradigm inclusive of these areas alongside the classic aerobic physiological determinants of endurance running [69, 70] is critical for producing well-rounded 800 m runners that can thrive in the modern-day cauldron of world-class competition.

Compliance with Ethical Standards

Funding We are grateful to the funding partners: High Performance Sport New Zealand, Athletics New Zealand and Sport Performance Research Institute—AUT University.

Conflict of interest Gareth Sandford, Andrew Kilding, Angus Ross and Paul Laursen declare that they have no conflicts of interest relevant to the content of this review.

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