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CURRENT OPINION

Anaerobic Speed/Power Reserve and Sport Performance: Scientific Basis, Current Applications and Future Directions

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Abstract

Many individual and team sport events require extended periods of exercise above the speed or power associated with maximal oxygen uptake (i.e., maximal aerobic speed/power, MAS/MAP). In the absence of valid and reliable measures of anaerobic metabolism, the anaerobic speed/power reserve (ASR/APR) concept, defined as the difference between an athlete's MAS/MAP and their maximal sprinting speed (MSS)/peak power (MPP), advances our understanding of athlete tolerance to high speed/power efforts in this range. When exercising at speeds above MAS/MAP, what likely matters most, irrespective of athlete profile or locomotor mode, is the proportion of the ASR/APR used, rather than the more commonly used reference to percent MAS/MAP. The locomotor construct of ASR/APR offers numerous underexplored opportunities. In particular, how differences in underlying athlete profiles (e.g., fiber typology) impact the training response for different 'speed', 'endurance' or 'hybrid' profiles is now emerging. Such an individualized approach to athlete training may be necessary to avoid 'maladaptive' or 'non-responses'. As a starting point for coaches and practitioners, we recommend upfront locomotor profiling to guide training content at both the macro (understanding athlete profile variability and training model selection, e.g., annual periodization) and micro levels (weekly daily planning of individual workouts, e.g., short vs long intervals vs repeated sprint training and recovery time between workouts). More specifically, we argue that high-intensity interval training formats should be tailored to the locomotor profile accordingly. New focus and appreciation for the ASR/APR is required to individualize training appropriately so as to maximize athlete preparation for elite competition.

1 Introduction

Human locomotor performance is fundamentally limited by the generation and transmission of external forces to the environment [1, 2]. The generation of all-out high-speed/power efforts of 0–300 s that occur at intensities beyond the minimal speed/power that elicits maximal oxygen uptake (commonly referred to as s/pVO_2max when expired gas measures are possible, or more simply as the end incremental test speed as maximal aerobic speed or power, MAS/MAP) arise from a complex interaction of metabolic, neuromuscular, and mechanical capabilities [3–5]. Remarkably, the sustainable level of all-out efforts across various modes of locomotion can be estimated from just two key landmarks—the MAS/MAP and the maximal sprinting speed (MSS)/peak power (MPP) [5–8]. The differences between these speed/power landmarks represent the anaerobic speed or power reserve (ASR/APR).

As a re-emerging concept in the scientific literature, the ASR and APR represent a time-efficient, practical field-based construct, with numerous underexplored benefits [4,

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Key Points

From just two landmarks (maximal aerobic speed or power [MAS/MAP] and maximal sprinting speed or peak power), the anaerobic speed and power reserve (ASR/APR) can be used to estimate athlete tolerance to high-intensity exercise. What likely matters the most, irrespective of athlete profile or locomotor mode when exercising at intensities beyond MAS/MAP, is how much of the ASR/APR is used, rather than the relative intensity in relation to MAS.

Underpinning differences in athlete biological profile (e.g., muscle fiber typology) can be quasi-estimated from the ASR/APR. The locomotor profile differences can be used to guide both macro (annual training plan) and micro (weekly training workout design) decision making to reduce non-responder occurrence through upfront tailoring of training content relative to the athlete's physiology.

Training prescription as a proportion of ASR/APR is an important future research direction needed to determine whether individualizing, by accounting for ASR/APR differences, leads to more uniform physiological stress and subsequent adaptation across diverse athlete profiles on a longitudinal basis.

9, 10]. In this current opinion, we aim to describe the history and scientific basis of the locomotor profile, before putting forward potential current and future practical applications for both individual speed (running) and power (rowing, cycling, kayak) sports that operate within the 1- to 5-min range, as well as team sports where the requirements for high-speed running bouts (e.g., continuous 1–3-min periods of high-intensity work [11–13]) continue to increase [14–16].

2 Origins and Scientific Basis of the Anaerobic Speed/Power Reserve

Figure 1 illustrates the metabolic inputs and mechanical outputs that produce movement in an intensity- and duration-dependent manner. Within the 1–5-min time frame (beyond MAS), varying blends of (i) aerobic (ii) anaerobic, and (iii) neuromuscular and mechanical characteristics are implemented to achieve optimal performance for any individual athlete [4, 17]. This makes understanding the underpinning mechanical and metabolic interactions to workloads with the ASR/APR domain most challenging for scientific quantification [4, 18]. Some sports require athlete strengths along the full speed/power duration relationship (middle-distance events [4, 17]), while other sports require more focus on the top part (team sports [14, 15, 19, 20]) or on the bottom part (longer distance events [21, 22]) This interplay was in fact recognized by Hill with his observations of athletic world records [23]. For a given metabolic input, the mechanical output can vary from low to high power and speed depending on the continuity of force application, which determines the actual speed and power attained [24]. The muscular efficiency of any effort can be defined as the ratio between the energy input relative to the mechanical work completed [24]. At exercise intensities below the critical speed/power (CS/CP, for reviews see [25–27]), defined as the highest oxidative metabolic rate that can be sustained during continuous exercise [25], we can accurately measure both the mechanical speed/power and metabolic cost, and therefore economy of locomotion [28] and gross mechanical efficiency [29]. However, beyond this key intensity landmark, the anaerobic energy contribution cannot be accurately quantified [18]. Below CS/CP, the anaerobic contribution is so low that our inability to measure it does not impact the overall energetic evaluation, but when the anaerobic source represents 40% of the total energy, such as in the 800 m [30, 31], it is obviously a bigger problem. Despite numerous attempts to assess metabolic supply in the high-intensity domain, poor validity and reliability of the available measures (maximal accumulated oxygen deficit [MAOD]) [32], accumulated blood lactate [20], and specific tests such as the maximal anaerobic running test [33, 34] have limited application [35]. This is problematic for the field of sport and exercise physiology where the demands of many events (e.g., 1–5-min duration), as well as for many team sports, reside in this exercise intensity domain [10]. Figure 1 highlights this complex interaction, where performance determinants are duration-dependent, ranging from submaximal to high-intensity exercise domains. Reference to bipedal or instrument-based sports (cycling, kayak/rowing) refer to ASR or APR, respectively. For example, for APR, we refer to the power measured at the pedal crank (or boat oar), while in running we refer to what we can more practically measure, which is the speed of locomotion.

In the absence of accurate and reliable measures of anaerobic metabolism, we can advance our scientific understanding of the underpinning mechanisms of high-speed/power performance through the assessment of an athlete's overall locomotor profile. MAS/MAP measurement is highly dependent on the protocol used. Depending on the duration of the stage, the step increase in intensity used and recovery period between stages used (or not), end-test speed or power can be highly variable, thus impacting ASR/APR estimate. Practitioners and coaches should strive for consistency of protocol in longitudinal evaluation and application of the

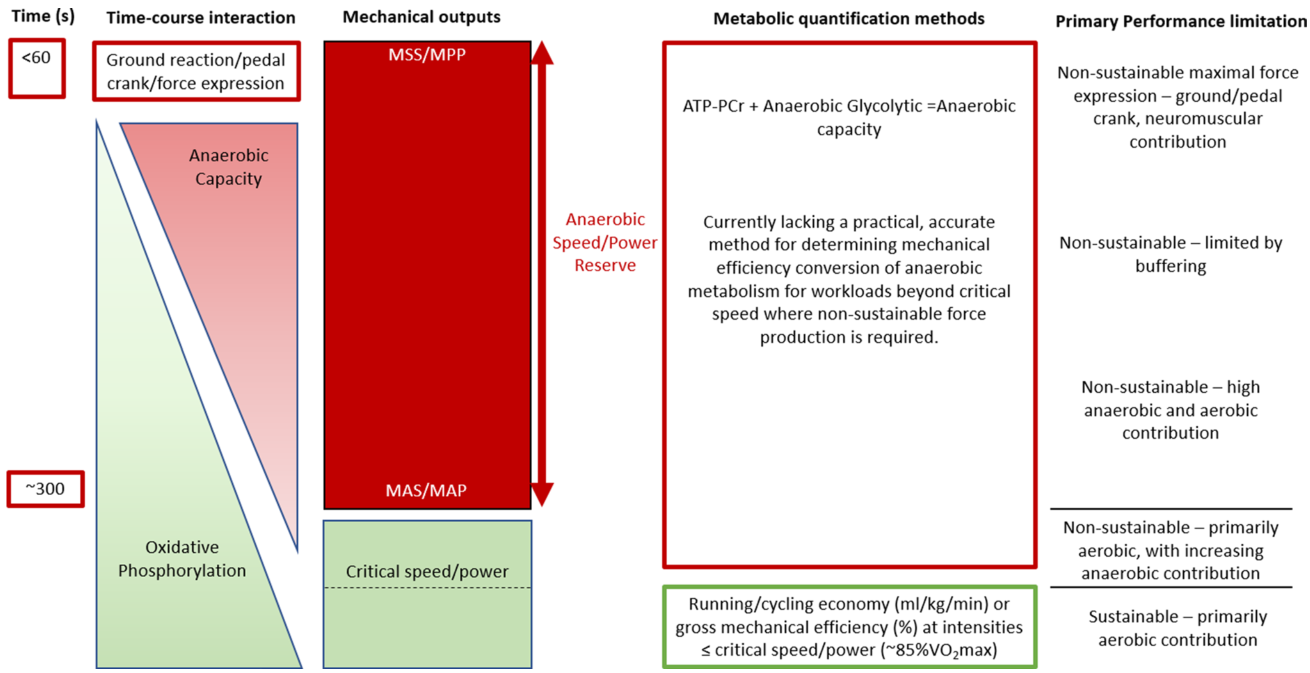

Fig. 1 Primary limitations across the performance–time continuum, including mechanical outputs and metabolic contributions. Performance in the anaerobic speed reserve domain arises from the complex interaction between metabolic inputs and mechanical outputs. *ASR* anaerobic speed reserve, *ATP* adenosine triphosphate, *MAP* maximal aerobic power, *MAS* maximal aerobic speed, *MPP* maximal peak power, *MSS* maximal sprinting speed, *PCr* phosphocreatine, *VO_2max* maximal oxygen uptake

measurement (we refer readers to [36–39] for further recommendations). In the first study on ASR, Blondel et al. [5] showed that time to exhaustion during repeated runs at 90–140% MAS (i.e., intensity range for events up to 8 min' duration [40]) was better explained by an athletes' ASR versus MAS. Specifically, 69% and 88% of the variance in time to exhaustion at 120% and 140% MAS was explained by the workload percentage of ASR. This experimental study was the first to suggest that what likely matters most when exercising at intensities beyond MAS is the degree of ASR used, rather than the relative intensity in relation to MAS (e.g., 120% vs 140% of MAS).

The practical importance of the ASR was then explained by a series of cycling [1] and running [7, 41] experiments using the intensity versus time to exhaustion relationship of various bouts of continuous exercises performed at intensities beyond MAS [1, 2, 7], which have been repeated more recently in professional cycling [6, 8]. Athletes with different absolute MAS and MSS who presented with varying times to exhaustion in fact showed very similar speed duration curves when their absolute running speeds were expressed relative to their locomotor profile (Fig. 2 [42]). These initial studies were also the first to show the importance of the ASR as a 'generic' (i.e., irrespective of locomotor mode and the athlete's absolute running or power performance) predictor of exercise tolerance in the very high-intensity exercise domain; the lower the percentage of the ASR used, the greater the exercise capacity.

These findings were confirmed during team sport-specific exercises, when Buchheit et al. [43] showed very large and large negative relationships between the percentage of the ASR used and the metabolic responses (%VO_2max and lactate) to a typical high-intensity interval training (HIIT) session (8 sets of 10 × 4 s on, 16 s off, with 2 min 20 s recovery between sets) [44]. Interestingly, players with the larger ASR also showed lower neuromuscular impairments and ratings of perceived exertion (RPE) during this session (due to using a lower % of ASR [43, 44]). These are pertinent findings with regards to ASR application in a team sport context, where a greater use of the ASR is associated with a greater rate of fatigue development, which in theory relates to alterations in neuromuscular co-ordination patterns and movement execution [45–48], both of which would directly impact decision making and technical performances [49, 50]. However, whether this concept can be directly transferred to the majority of team sport actions during matches and training remains to be elucidated, since the speed of movement often does not reach the 'ASR domain' during the majority of actions in team sports. For example, despite its very large energy demands, accelerated running over a few seconds often occurs at speeds lower than MAS [14]. Therefore, while the concept appeals in a generic manner (i.e., the more room for speed, the greater the tolerance for

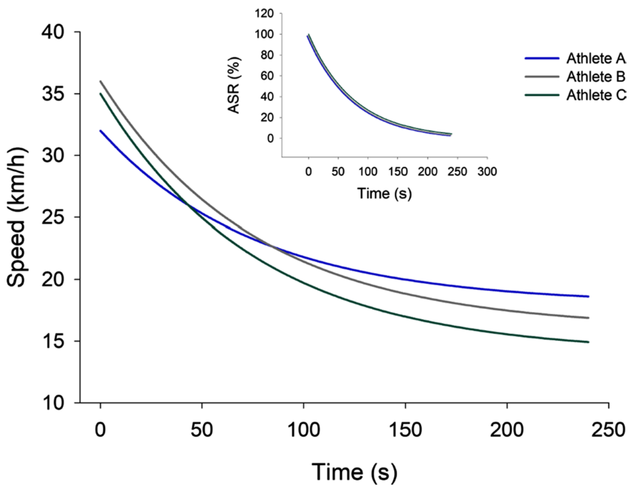

Fig. 2 Speed–duration relationships for three athletes, **A**, **B** and **C**. Athlete **A**: 32, 18, and 21 km/h for MSS (maximal sprinting speed), MAS (maximal aerobic speed), and VIFT (30–15 Intermittent Fitness Test), respectively; Athlete **B**: 36, 16, and 20.5 km/h; and Athlete **C**: 35, 14, and 18.5 km/h. Shown as absolute speeds and (inset) relative to the anaerobic speed reserve (ASR). Reproduced with permission (Buchheit & Laursen [42])

such types of efforts), how the ASR concept can be applied to high-intensity actions performed at low speed requires further research.

More recent evidence on mechanisms underpinning locomotor profiles and high-intensity exercise tolerance emerged from the study by Hodgson et al. [51]. Building on previous models of fatigue [52, 53], Hodgson et al. tested whether potential mechanisms of fatigue differed across locomotor profiles (small vs large APR) during high-intensity exercise. They showed differences in neuromuscular fatigue responses across APR profiles in healthy individuals performing step-test exercise protocols [51] and repeated sprints (e.g., maximal 6 s, off 30 s rest [54]), whereby individuals with a small APR had greater peripheral fatigue and reduced muscle endurance compared with those with a larger APR, suggesting fatigue mechanisms may differ between APR profiles [51]. In part, the differences in APR profiles may be explained by differences in buffering and glycolytic capacity [55]. For example, fast twitch fibers have higher baseline intracellular carnosine [56], increasing metabolic acidosis tolerance in those athletes with a large APR relative to their lower APR counterparts.

2.1 What the ASR/APR (Locomotor Profile) Is and Is Not

The initial findings of Blondel et al. [5] and Weyand et al. [1, 2, 7] led to the early belief that ASR/APR represented a measure of anaerobic energetics, the so-called ‘anaerobic capacity’ [7]. However, the evolution of CS/CP research has provided strong evidence that whilst below the CS/CP, anaerobic contribution is quantitatively not important, beyond CS/CP intensity, the anaerobic energetic contribution substantially increases prior to attainment of MAS/MAP (Fig. 1) [26, 27]. Anaerobic energetic contributions to exercise intensity increase before attainment of MAS, dependent on the rate of peripheral fatigue development described by increases in lactate, ventilation, VO_2 utilization, and larger (and less efficient) fast twitch muscle fiber recruitment [57, 58]. Thus, MAS/MAP does not represent a consistent physiological landmark [57, 59]. However, this training intensity shows utility both as an important reference training pace for developing VO_2max and locomotor performance [20, 60, 61], and also a reference landmark for estimating sustainable proportions of oxygen consumption [62, 63] with subsequent potential for raising an athlete’s lactate threshold [63, 64]. To clarify understanding and interpretation for practical application, we offer clarification on common misinterpretations of what ASR/APR is and is not (Table 1).

2.2 The ASR in Relation to Absolute Locomotor Speeds

When looking at an athlete’s locomotor profile, consideration for the ASR/APR should not overlook the (greater) importance of the absolute locomotor speed/power values per se (Table 1). At the elite level, the absolute speed/power of the locomotor profile is what differentiates performance. For example, in elite 800-m runners (PB < 1:47.50), faster 800-m runners have a larger ASR, related to their higher MSS. Importantly, in athletes with similar MSS, differences in MAS or ASR showed no relationship with 800-m performance time [9]. In athlete populations with lower performance times, aerobic markers (VO_2max, running economy) were in fact related to 800-m performance [65], implying that determinants of performance may be different at the highest levels of elite sport.

In young soccer players, the best predictor of improvements in repeated sprint ability after periods of training (and growth) was not the increase in ASR per se, but the concurrent improvements of MAS, MSS, and the ASR together [66]. Indeed, an increase in ASR can artificially arise from aerobic deconditioning. Therefore, practitioners should avoid focusing on one element of the ASR alone—all are important (Fig. 3).

3 Practical Applications

Having covered the scientific basis for the ASR/APR, the second part of this current opinion will offer practical applications related to how knowledge of an athlete’s locomotor profile (Table 2) can help guide training prescription ([67],

Table 1 Common ASR/APR misconceptions

Misinterpretations	Correct interpretation
The APR/ASR range can be considered to reflect a combination of both maximal aerobic and anaerobic energetic capacities	**Why it is not this** The ceiling of the APR (MPP)/ASR (MSS) is limited by ground reaction/pedal crank/boat oar force application and not metabolism. Additionally, the anaerobic contribution between critical speed/power and MAS/MAP is not accounted for. Therefore, APR/ASR cannot represent anaerobic energetic capacity **What it is** ASR/APR represents the speed or power difference from MAS/MAP to MSS/MPP
The ASR represents a 'reserve' of running capacity left to the athlete once they have reached MAS/MAP	**Why it is not this** Time to exhaustion at high intensity is a complex interaction of neuromuscular, mechanical and metabolic factors alongside psychobiology and technical/tactical conditions, not simply the ASR **What it is** The speed range the athlete has access to above MAS. How fatigued the athlete is before arriving at that intensity will determine how much of the ASR can be used in a given moment
A combination of jargon such as 'anaerobic reserve, anaerobic energy reserve, anaerobic abilities' can be used to describe the ASR domain	**Why it is not this** Without valid and reliable measures of anaerobic metabolism, many of the tests estimating this capacity create their own terminology, which adds to the confusion, poor adoption, and incorrect exploration of the domain beyond MAS/MAP [48] **What it is** To describe the mechanical speed or power output beyond MAS, proportions of the ASR/APR should be used (Fig. 1) When considering the metabolic input alongside ASR, oxygen consumption (VO_2) should be described alongside anaerobic capacity. This best captures the anaerobic energetic exercise accounting for ATP produced from both glycolysis and ATP-PCr system
Athletes with the same ASR can be categorized in the same group for interpretation of training interventions, irrespective of an individual's MAS/MAP and MSS/MPP (Fig. 3c)	**Why it is not this** This approach does not take into account absolute variables of MAS/MAP and MSS/MPP, resulting in misleading categories [4] **What it is** The ASR can be used to group athletes, in conjunction with MAS/MAP and MSS/MPP, to determine 'similar' athlete types and interpret training interventions or performance outcomes (Fig. 3c)

APR anaerobic power reserve, *ASR* anaerobic speed reserve, *MAS* maximal aerobic speed, *MAP* maximal aerobic power, *MPP* maximal peak power, *MSS* maximal sprinting speed, *ATP-PCr* adenosine triphosphate phosphocreatine system

Fig. 4). Whenever possible, evidence-based recommendations are made, but in some instances the authors draw upon their practical experiences over many years working with elite athletes.

3.1 Horses for Courses—Why Athletes with Differing Locomotor Profiles Should Be Treated Differently

One major (but not exclusive) mechanism underpinning the diversity of locomotor profiles seen in individual and team sports is muscle fiber type (Table 2) [4, 68, 69]. Fast twitch fibers are known to produce ATP at high rates [70], but at low capacity [55, 71], resulting in premature neural fatigue [72]. Recently, Lievens et al. [73] used a non-invasive muscle scanner (as a proxy of muscle fiber type [69]) to show that speed-dominant recreational athletes had a greater drop in knee extension peak power and took longer to return to peak power from baseline (up to 5 h post-fatiguing Wingate exercises) compared with the endurance-dominant athletes whose knee extension power returned to baseline after 20 min. In a longer-term overreaching study using the same non-invasive technique, Bellinger et al. [74] found that endurance-dominant athletes were able to better cope with higher training volumes, achieving superior performance adaptations compared with speed-dominant athletes who displayed delayed recovery and were at higher risk of overreaching. Together, these studies reveal differences in both short- and long-term training effects on athletes across locomotor profiles. By considering the underpinning differences

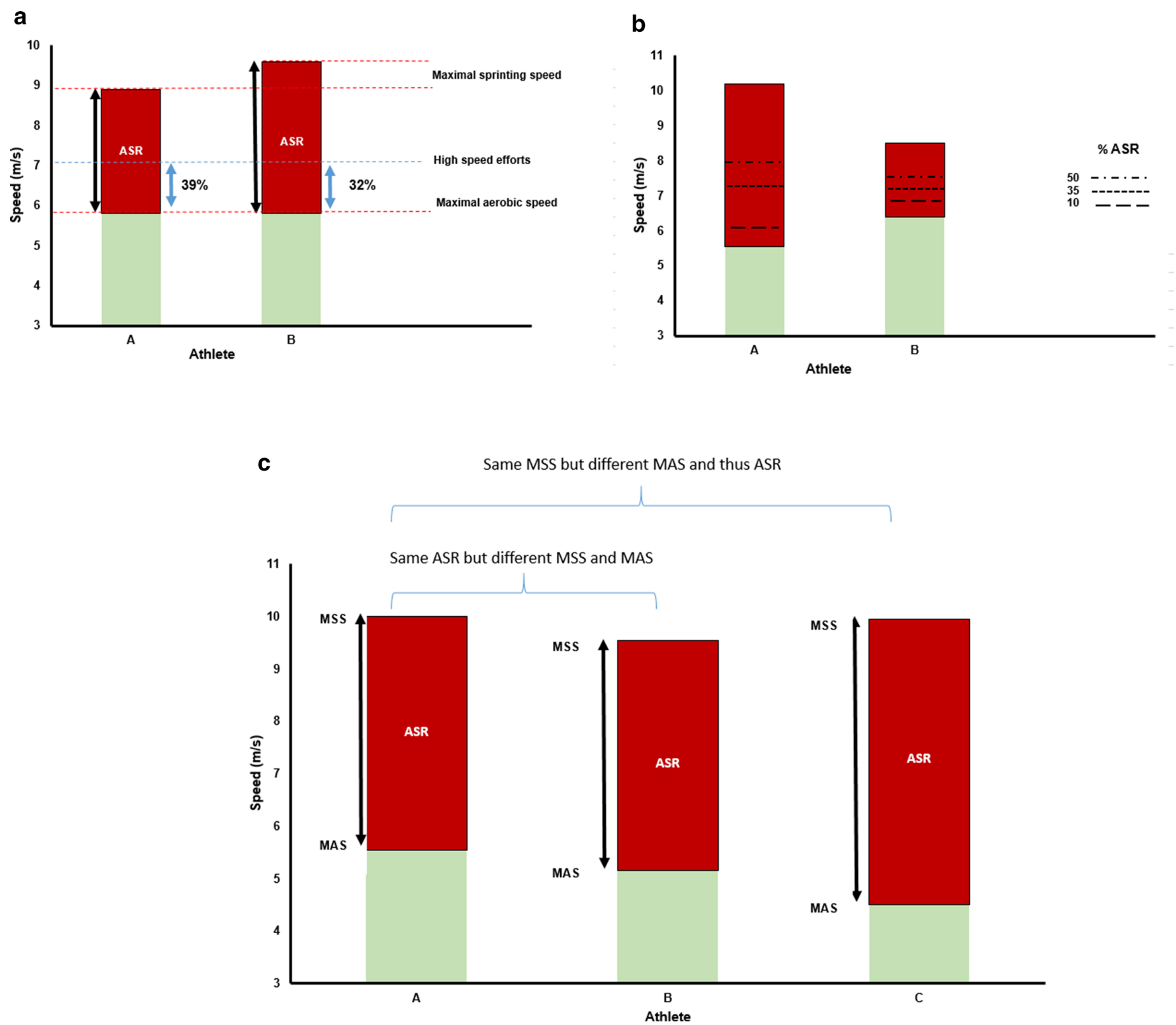

Fig. 3 (**a**) Athletes A and B have the same maximal aerobic speed (MAS) but differences in maximal sprinting speed (MSS). For Athlete A to perform the same high-speed effort as Athlete B, they must work at a 7% higher relative proportion of their anaerobic speed reserve (ASR) due to differences in MSS. (**b**) Prescribing high-intensity interval training workloads relative to Athlete A and B's individual ASR. By taking into account both the MAS and MSS, we normalize differences in the athlete's relative stress. (**c**) When using ASR to make macro and micro judgements on the effects of a training intervention on athlete profiles, important differences can be missed by using methods that do not consider the athlete's absolute MAS and MSS. For example, for grouping athlete caliber by ASR, it is recommended to consider all three metrics (MAS, MSS, and ASR), not just ASR in isolation (as similar ASR alone could represent very different caliber athletes). Note, whilst ASR is used in examples throughout the figure, these could be applied to the anaerobic power reserve

Table 2 Estimated locomotor profile and fiber type continuum for understanding athlete complexity

Name	Speed profile	Hybrid profile	Endurance profile
Locomotor profile	Low MAS/MAP High MSS/MPP	Moderate MAS/MAP Moderate MSS/MPP	High MAS/MAP Low MSS/MPP
Anaerobic speed/power reserve	Large	Moderate	Small
Estimated fiber type dominance	Fast twitch	Intermediate	Slow twitch

MAS maximal aerobic speed, *MAP* maximal aerobic power, *MPP* maximal peak power, *MSS* maximal sprinting speed

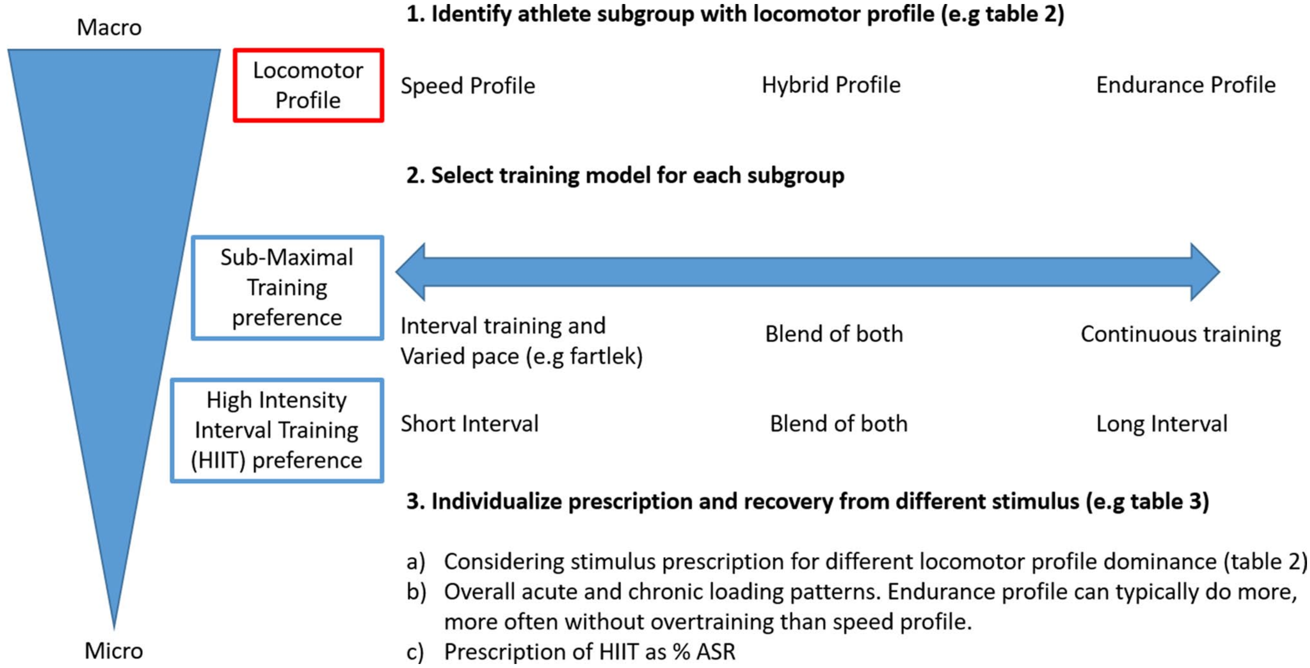

Fig. 4 A practical three-step process for applying the ASR/APR construct across macro and micro training planning perspectives for a squad of diverse athlete profiles. *APR* anaerobic power reserve, *ASR* anaerobic speed reserve, *HIIT* high-intensity interval training

across these varying locomotor profiles, coaches and practitioners may select more individualized training sessions to optimize training enjoyment and adaptive outcomes, whilst minimizing risk of all symptoms associated with 'forcing a square peg into a round hole' (Fig. 4, Table 3) [4].

3.1.1 Step 1: Identifying an Athlete's Locomotor Profile

An athlete's locomotor profile reflects their individual propensity for dominance in speed versus endurance aptitude. Several studies in elite athletes reveal diversity of locomotor profiles exist within the same groups of individual [4, 9, 75] or team sport athletes [76–78]. Therefore, when beginning a training plan, locomotor profiling is recommended to calibrate the training approach relative to each individual athlete profile (Fig. 4, Sect. 3). This concept may be one of the strongest applications of the locomotor profile in sport.

3.1.2 Step 2: Selection of Training Priorities for Each Locomotor Profile

Coaches typically design an annual plan using insights taught by a previously successful coach [79], using a scientific basis, or both (e.g., polarized training [22]). Whilst there are merits for these approaches, a single model can often result in the outcome where some athletes benefit optimally from the prescription, while others do not [80–82]. Typically, the training model employed is the same for all athletes within a group. It is only at a micro (day-to-day) level where coaches more commonly individualize the specific training for a speed versus endurance athlete profile.

Table 3 Training stimulus application per sub-group

Stimulus description	Speed profile	Hybrid profile	Endurance profile
Slow continuous efforts	*	**	***
Short ~ critical speed/power	***	***	***
Long ~ critical speed/power	**	**	***
Repeated sprint efforts	***	**	*

Rating 1–3 (***) provided for stimulus distribution across subgroups (*** major consideration, * minor consideration). Application driven by context depending on sub-group; certain sub-groups will have different emotional responses to stimulus and this is a key consideration amongst training design

What we suggest is that the locomotor profile may help to better guide a coach in choosing an appropriate training model for their athlete. As shown in Fig. 4, endurance profiles (Table 2) may be best suited to continuous, higher volume-based programs (including long HIIT), with greater tolerance to overload training (e.g., capacity for double day sessions) with a sprinkle of intensity [21, 22, 74]. Conversely, giving a speed athlete profile such a program leads to risk of maladaptation or overreaching [74].

3.1.3 Step 3: Training Session Individualization by Sub-Group

After general training model selection, there are numerous day-to-day decisions that coaches make around training intensity, duration, frequency, and load (how much and how often). Given the variability in adaptation across athlete profiles [73, 75, 81, 83], we suggest a framework for targeting aerobic development across diverse locomotor profiles (Table 3).

Since sprint training methodology does not include extensive slow and continuous exercise [84], speed athlete profiles in transition to sports with concurrent aerobic demands may be less familiar or experience discomfort early on with this modality. Even during low-intensity exercise, fast-twitch–dominant athletes (speed profiles), particularly if glycogen depleted (e.g., under recovered/second training session of the day), may place increased reliance on fast twitch fiber motor units [85], which under a continuous low exercise intensity stimulus can increase the VO_2 slow component, making steady-state exercise unattainable [26, 86]. The increased dependence on anaerobic metabolism to meet the energetic requirements for the speed profile athlete, in addition to the increased neuromuscular loading with longer high-intensity work, can create unwanted fatigue in the unfamiliar athlete, lowering the quality of subsequent repetitions and potentially future training sessions [74].

For the speed profile athlete to develop aerobic adaptations and fatigue resistance, they need to recruit and adapt fast twitch muscle [87]. This is also mechanically, physiologically, and psychologically appropriate for the speed profile, until the time at which a foundation of the aerobic stimulus and gait motor patterns are advanced [20]. Consequently, using short intervals and repeated sprint training (RST) is likely a more appropriate approach in this population, and contrasts with the potentially more well-known long-interval prescription that involves efforts around MAS/MAP of 2–5 min, with 2–3 min of passive recovery [20] (Type 4 HIIT). Certain types of HIIT with short intervals (e.g., short work intervals 10–15 s, 20–30 s rest; run at 100–120% MAS/5–10% ASR; Type 1/2 HIIT) enable substantial exercise time at an intensity near VO_2max, while keeping lactate accumulation low [20]. There are four aspects to justify RST for aerobic development in speed profile athletes. (i) They tolerate these efforts well as they possess a greater proportion of fast twitch fibers, which contain higher baseline buffer muscle carnosine [69, 88] and more fast twitch enzymes that have larger glycolytic capability [89]. (ii) They have lower cardiorespiratory fitness levels compared with the endurance-based profile, therefore relying more frequently on anaerobic metabolism, so producing lactate during training is not that different, and they just preferentially use their anaerobic system more. (iii) There is an inverse relationship between fiber type cross-sectional area (larger in speed profile athletes) and fiber VO_2max, likely explained by the matching of muscle fiber oxygen demand and supply [71]. Time at VO_2max is inversely related to VO_2max during RST [20]; therefore, in individuals with a lower VO_2max, it is better to use a suboptimal format in relation to time accumulated at VO_2max (TVO_2max) that is well tolerated rather than an optimal prescription for TVO_2max that is not well tolerated by the athlete. (iv) There may be some peripheral acute responses linked to greater deoxygenation levels [90, 91] that can improve aerobic function (at the muscle level) independently of the actual TVO_2 of the session [19, 92]. This makes RST a well-tolerated format for speed-based profiles as their underpinning physiology suggests a greater tolerance to sustained high-intensity work in the ASR/APR domain. Therefore, these underlying profile characteristics may have important implications for training prescription. The literature has long considered the question "Is long better than short HIIT?", with the results always being It depends' [44]. A simple reason for this observation may be that HIIT formats have never been tailored to the locomotor profile. This idea warrants further investigation.

3.2 Day-to-Day Training Session Prescription as a Fraction of ASR/APR: is it Appropriate?

For low-intensity exercise (below CP/CS), there are other models better suited to performance estimation and exercise prescription [22, 93]. The choice of focusing on the 1–5-min events here is based on the current evidence of strongest ASR/APR application that surrounds performance estimation and HIIT prescription in the context of workloads beyond MAS [6–8]. Despite the evidence showing ASR as a better tool for estimating time to exhaustion at workloads within the ASR/APR domain in individual [1, 7, 41, 94] and team sports [95] (Fig. 2), studies currently showing the efficacy of prescribing training interventions as a proportion of ASR/APR are limited [76]. Many studies still prescribe interventions using percentages of MAS/MAP, which do not account for differences in an athlete's ASR (Fig. 3) [96–101].

In rugby and middle-distance runners, Julio et al. [76] found lowered inter-subject variability of delta blood lactate concentrations and time-to-exhaustion using percentage of ASR compared with percentage of MAS. In addition, there is less variability in the acute heart rate response during HIIT when prescribed using the speed reached at the end of the 30–15 Intermittent Fitness Test (which accounts for some anaerobic/neuromuscular contribution) versus MAS [102]. Therefore, training prescription as a proportion of ASR is an important future research direction needed to determine whether individualizing HIIT by accounting for ASR differences leads to a more uniform physiological stress and subsequent adaptation across diverse athlete profiles on a longitudinal basis (Fig. 3) [4].

3.3 Meeting Within-Event 'Surge' Demands

Surge moments within sporting events are commonly cited as differentiating medal outcomes in middle- [103–106], and long-distance running [107], speed skating [108], and professional cycling [109, 110]. At the fundamental level, an individual must possess large enough MSS/MPP and MAS/MAP to be competitive within a homogenous elite competition field (e.g., Olympic final). Without acquiring a minimum locomotor profile level, emerging evidence suggests performance may be compromised in certain types of races [10, 104, 111].

3.4 Tactical Approaches and Position Specialization in Team Sports

Varying locomotor profiles can be found across team sport players, which can (i) directly impact the relative fatigue development between players during their high-speed locomotor performance during matches, and in turn, (ii) logically predispose players to certain playing positions in the team that fit with tactical models (Table 4). Naturally, improving both components of the profile (Figs. 2 and 3) can enhance an athlete's tolerance to (repeated) high-speed sequences, and may add a protective effect across dense periods of match play from an injury perspective [112, 113]. Importantly, however, any given repeated high-speed sequence is dictated, for the most part, by the tactical and strategic requirements of the match [114]. This means that improving physical capacities may affect the relative fatigue development (Fig. 3a) compared with a player's absolute running performance per se [114]. From an organizational standpoint, conditioning coaches may seek to group athletes by locomotor profile rather than by playing position only, especially when two athletes with divergent profiles (Table 2) may play the same position [115]. Better understanding of these player profiles and the physical limitations that exist may offer important information for coaches aiming to execute a particular playing style (e.g., counter attacking associated with high-speed running volume vs building up from the back and high possession strategies in soccer).

4 Conclusion

Many individual and team sports have event demands that meet or exceed an individual's MAS/MAP. In order to develop the qualities needed to tolerate repeated muscle contractions at these high speeds/powers, we recommend using locomotor profiling as a framework to guide training content. This framework can assist in understanding athlete profile variability, selection of an appropriate training model, selection of an appropriate training format, and between-workout recovery timeline guidance. From a performance perspective, by maximizing the training adaptation of both locomotor components, we can ensure we are meeting event performance demands. Within team sport events, positional preferences can be determined based on the locomotor profile, which can help to inform a coach's tactical selections. In the absence of valid and reliable measures of anaerobic metabolism, ASR/APR estimates provide many opportunities for the coaching and exercise science community to evolve their understanding of athlete locomotor profile development and how it fits into solving the performance puzzle.

Table 4 Three different ASR profiles related to positional roles in soccer

Locomotor profile	Sprinting ability	Repeating high-speed runs	Overall match workload capacity	Optimal pitch position	Coping with high fixture density*
Speed	+ + +	+ +	+	Central defenders or attackers	+ +
Hybrid	+ +	+ + +	+ + +	Full back	+ +
Endurance	+	+ +	+ +	Midfielders	+ + +

* Note difference vs overall match workload capacity—in addition to locomotor profile, coping with high fixture density is likely also related to the absolute overall positional playing demands, with the lower the demands, the greater the coping ability (although this remains very individual). This explains why central defenders (presenting reduced match demands) may be able to cope with congested fixtures as well as full backs, despite possessing less optimal locomotor profiles

ASR anaerobic speed reserve

Declarations

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