Preparing for 2024 Sydney Marathon World Championships

Age-group amateur marathon runner aiming for sub-3 finish

Department of Public Health, Neuroscience, Experimental and Forensic Medicine
Exercise Physiology and Endurance Performance
Academic Year: 2023/2024

Author: Csaba Tarnai (530814)

Mentor: Prof. Cosme Franklim Buzzachera

Word Count: 18'881

I don't run with my legs. I run with my heart and mind

(Eliud Kipchoge, 2nd May 2022)

Abstract

Amateur marathon runners desire to excel at their chosen sport and to use the correct and latest research on how to optimise training and competition outcomes. Yet they do not have access to professional team of sport scientists, nutritionists, psychologists, and a well-equipped sports lab. This paper intends to review from the perspective of a self-coached 50-year old sub-3 marathon runner for the marathon world championships in Sydney what is the latest research, what tools and technologies are available and how can they be integrated into the training of such amateur athletes.

We will construct an Annual Training Plan; our starting point is the current level within a multi-year plan, the race ambitions for current year, and overall longer-term athletic goals. With an amateur runner, five years of experience, and a desire to diversify into middle-distance triathlon for current athletic year we will use a traditional training plan with a single peak for Sydney.

We now need to assess the athletes fitness, based on VO_{2max}, LT, and RE. Based on this, the desired race outcomes, and the training phase we construct the weekly running workouts. Generally speaking VO_{2max} is best supported by HIIT, LT by long-runs, and RE by running volume and strength workouts. The initial stages focus on volume which is gradually replaced by intensity. To help recovery within the week we need to vary training intensity and include lower-intensity weeks. To reduce injury risk from high running mileage we will focus only on four high quality run workouts and enhance the overall aerobic system with cross-training (cycling and swimming) and strength training.

Training intensity needs to be distributed in a polarised way with 80% of volume in moderate aerobic zones and upto 20% in severe zones. Strength training is 3 session in the general stages, becoming 2 in competitive stage and completely removed in final pre-race weeks.

To "Dose & Response" running intensity we will use critical power as measured by Stryd and benchmark against gold-standard laboratory tests. Other measures we will track with TrainingPeaks and WKO5 are key internal and external load for stress management (CTL, RHR, HRV), recovery management (sleep duration, time awake, and sleep quality), injury prevention (weekly running mileage and perceived injury for injury prevention), body composition (caloric expenditure, BMR, BM, and skinfold measurement), and polarised weekly running volume (hours of run training by intensity domain).

Nutrition needs to be aligned to daily workloads mostly by varying levels of CHO, while guaranteeing a steady and well-distributed level of protein, mostly in the form of EAA. Nutritional needs are aligned with phases in the training plan, most notably in later pre-competition stages where glycogen stores need to be topped-up while keeping body mass as low as possible. This is also supported by 1-2 LSD in fasted state to help use fat as substrate.

In addition to physiologic adaptations, training also needs to hone psychological skills. Mental fatigue can be detrimental to competition as central and peripheral muscle fatigue. We will train the psychology by focusing on setting goals, dissociation from fatigue, association with the flow of the exercise, attentional focus which we will also train through yoga, visualisation of the event, positive self-talk, and flow & prayer.

With 12 time zone difference and 24-hour long flight we must minimise travel fatigue and jet lag with melatonin, nutrition, recovery, easy workouts, and pre-taper psychology. Moreover we need gut training to assume 90 g/CHO/hour with 40mg caffeine.

If all this is executed well we anticipate a sub-3, fastest Hungarian running outcome for Sydney 2024 world championships.

Table of Contents

Introduction

According to the most recent report on the State of Running 2019 (Andersen, 2023) there are 1.1 million marathon runners worldwide who finished an official race in 2018. Compared to the other running distances where global participation is in decline marathon remains at an albeit slow but continued growth trajectory. Moreover participation in marathons by age category shows that the 40-50 year olds are the fastest growing age group (AG).

Surprisingly there is limited recent, scientifically-backed, and actionable guidance for age group amateur runners (Boullosa et al., 2020):

- No consensus on best practice for endurance performance
- Plethora of anecdotal guidelines without robust scientific support
- Non-validated algorithms like the 10% rule for weekly training load increments
- Use of different types of shoes to reduce injury rates
- Imitation by recreational runners of professional athletes, who have high weekly mileage and leads to injury
- As the source of scientific evidence derives from professional athletes it is unclear how this can be applied to recreational runners

The desired outcome would be a practitioner's guide / 360-degree preparation plan on how the latest sports science insights help recreational marathon runners prepare for their "A" race. As this research is aimed at supporting a wider community of amateur runners we will also establish what areas such amateur runners would like support with.

We start with a brief overview of the key elements to focus on for a successful AG marathon event from various perspectives. This includes key scientific direction, popular science, coach tools, insights from runners' community, the target marathon and the athlete. These key elements will then help narrow down the investigation in the literature review.

Next we will summarise the latest and most relevant scientific papers, often infused with anecdotal evidence and opinions from key speakers during the EPEP lectures (Speakers). Where such lectures have left questions email-based clarification was requested (Questions).

With laboratory-grade tools, professional sports equipment, and high-end training-specific mobile apps becoming available and affordable for AG athletes we will also investigate their relevance and role in training.

We are now ready to apply these findings to an integrated ATP which includes tune-up races, training cycles, testing, recovery, nutrition, and tapering for the race.

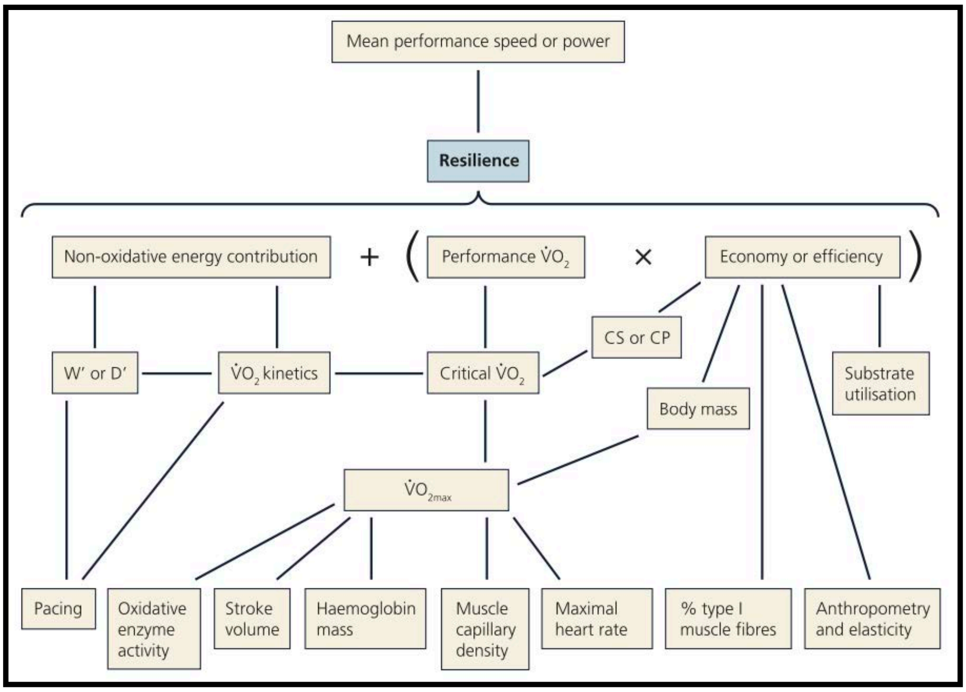
We will conclude with future areas of suggested academic research and areas where AG athletes can experiment individually while scientific evidence is building.

Focus Areas

This chapter will introduce the key topics we need to investigate in the literature study to build a strong foundation of the main drivers for successful age-group marathon running. The objective is to create a list of topics to investigate while reviewing literature. However as we want to prioritise broad over deep we will investigate based on scientific papers, popular application of science, anecdotal insights from renown coaches, and the running community. As our focus is one specific race we will also introduce that race and what challenges we will need to overcome for a successful completion in addition to the athletes motivation and medical background.

Scientific background

For elite endurance running the key physiological variables have been introduced by Joyner: VO_{2max}, Lactate Threshold, Running Economy (Joyner, 1991). Jones has recently proposed the addition of Physiological Resilience (Jones, 2023).



Physiological determinants of endurance exercise performance (Jones, 2023)

The academic community in it's most recent view on current and future trends in the evolution of world-class endurance training (Sandbakk et al., 2023) highlights:

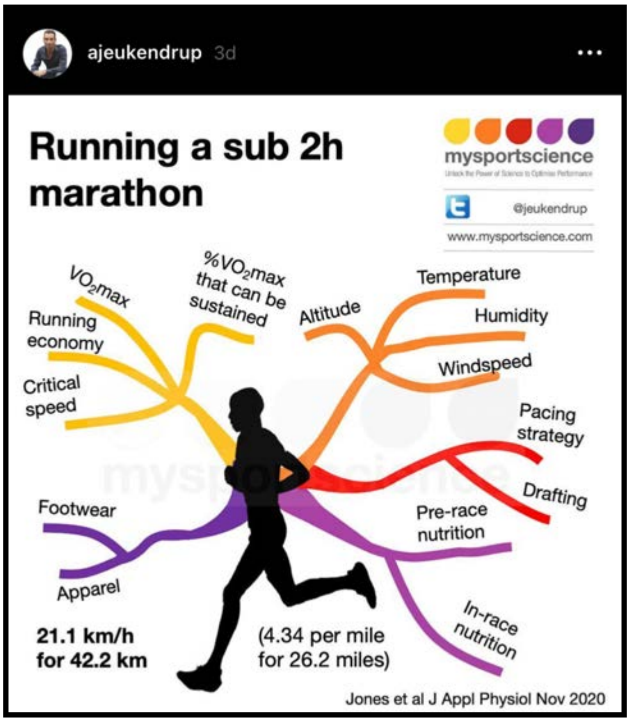
- Better understanding of sport-specific demands
- Improved competition execution
- Larger, more specific, and more precise training loads
- Improved training quality
- More professional and healthier lifestyle

The main areas expected to drive future improvements were associated with:

- Extensive use of advanced technology for monitoring and prescribing training and recovery
- More precise use of environmental and nutritional interventions
- Better understanding of athlete–equipment interactions
- Greater emphasis on preventing injuries and illnesses

Popular science application

Asker Jeukendrup is a well established sports scientist who often simplifies research for practitioners. In figure below he summarises and enriches Andy Jones' work by considering race conditions, pacing, nutrition, and athlete equipment.



Running a sub-2 hour marathon
(based on Jeukendrup)

Coach tools

Marathon running requires a long-term preparation and many professional runners plan on a multi-year career (Stellingwerff, 2018). One of the most referenced sports books for preparing such long-term view is (Bompa & Buzzichelli, 2019) which introduced the Annual Training Plan (ATP). The key components are:

- Competition scheduling
- Training phases
- Strength, endurance, speed training
- Periodised nutrition plans
- Medical and performance testing

	January	February	March	April	May	June	July	August	September	October	November	December
Domestic	London Winter Run											
International			Lisbon Superhalf						Sydney			
Location												
Training Phase	Preparatory					Competitive				Transition		
Strength	AA	M x S	P	Maintain								
Endurance												
Speed												
Nutrition												
Testing Dates												
Medical Dates												

Example Annual Training Plan (Bompa & Buzzichelli, 2019)

Community insights

To ensure the topics covered in this paper have a wider relevance a survey was conducted with the "Sub 3 Marathon" Facebook community. This private group is open to any amateur runner who can demonstrate at least one sub-3 marathon. There are 20.8k members.

There were 139 votes on 17 research questions (FB survey) to investigate with sports science community. Following questions received >10% of votes:

- How to optimise cross-training for performance benefits in long-distance running (what sports, duration and intensity, timing) (18%)
- What is best way to determine marathon fitness (e.g. CP, CV, LTHR, VO_{2max}) (16%)
- What are best S&C exercises and rep and intensity range (x% of 1RM) for injury prevention and running economy (15%)
- What is best duration and training regime for tapering in preparation of A race (12%)

Target race

Main considerations preparing for a marathon race are (Jones, 2013):

- Temperature
- Humidity
- Elevation and vertical profile
- Course specifics
- Time zone difference
- Participants / field depth

Specific to Sydney (Weather and Profile) we anticipate that the main topics are: course profile, jet lag, and travel fatigue.

Athlete

The athlete has recently demonstrated ability to run sub-3 marathons. Sydney appears to be similar to previously competed marathons in terms of track, humidity, temperature, and field depth. Hence with proper preparation and adjustments to this race a sub-3 outcome appears a valid aspiration.

Finally it is worthwhile noting that author in addition to consuming a mostly plant-based diet has a long history of injuries, most notably plantar fasciitis, REDS, bone stress fractures, and osteoporosis.

Key investigation areas

We will focus on following areas during the literature research:

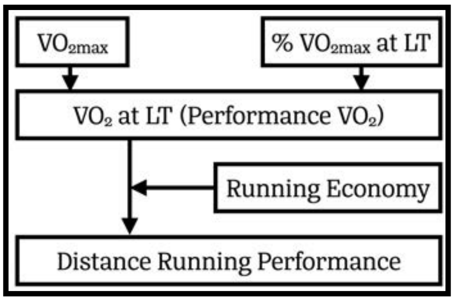
- Physiological parameters
- Psychological parameters
- Training Process & Run training
- Strength & cross-training
- Training and racing tools & equipment
- Recovery & Lifestyle
- Injury prevention
- Physiological and medical testing
- Nutrition and supplementation
- Race considerations

Literature Research

Thanks to the focus provided by key scientific papers, practitioners' insights, AG community and applied to the specifics of the Sydney race and the author in this chapter we will focus on these areas.

Physiological parameters

Training for endurance performance aims to improve the primary determinants of performance (Sandbakk, 2023)(Joyner, 1991)(Jones et al., 2021):



Key physiological parameters for running performance (Bassett, 2000)

- Maximal oxygen uptake (VO_{2max})
- Fractional utilisation of VO_{2max} (lactate threshold or critical power)
- Running Economy (Gross Efficiency / mechanical efficiency)

In literature these physiological parameters are sometimes referred to as:"the big three". The "fourth" dimension or physiological resilience as proposed by Jones (Jones, 2023) requires further research to be useful for our purposes.

Maximal oxygen uptake

Maximum oxygen uptake (VO_{2max}) is defined (Bassett & Howley, 2000) as the highest rate at which oxygen can be taken up and utilised by the body during severe exercise. It is one of the main variables in the field of exercise physiology, and is frequently used to indicate the cardiorespiratory fitness of an individual. In the scientific literature, an increase in VO_{2max} is the most common method of demonstrating a training effect. In addition, VO_{2max} is frequently used in the development of an exercise prescription.

VO_{2max} is measured mostly in laboratory environments. The test protocols usually consist of an incremental increase in intensity until voluntary exhaustion is reached after approximately 3 to 8 mins.

Cardiac output, total body haemoglobin, muscle blood flow, and muscle oxygen extraction constitute the primary limiting factors; however pulmonary function can also serve as a limiting factor (Sandbakk, 2023). For VO_{2max} the main limiting factor which can be trained is stroke volume, so at the same heart rate more volume of blood is circulated. For athletes this can be up to 35 l /min (vs. 22 l/min in untrained). According to Canepari, this can increase with 50% in two years and 15-25% in 3 months.

As shown later VO_{2max} can be trained mostly with HIIT and to lesser degree with overall training volume. It is uncertain if IMT-induced increase in pulmonary capacity and power has a significant impact on VO_{2max}. As this is one of the key indicators for running performance we will compare current level of VO_{2max} with AG averages and focus training interventions to increase it.

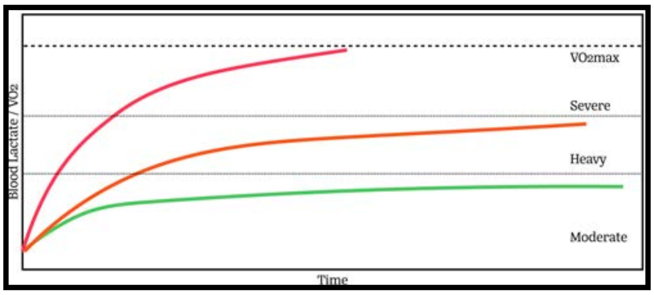
Fractional utilisation

The main factor used as an indicator of fractional utilisation of VO_{2max} is the so called lactate threshold (or respiratory compensation point or critical power). This can range from 60-90% between untrained and elite athletes (Sandbakk, 2023).

Although endurance training does lead to structural changes in the lungs there is limited research that fractional utilisation for elite athletes can be enhanced with pulmonary training (Sandbakk, 2023). Moreover fractional utilisation will increase from high volume of endurance training as it affects mitochondrial capacity, capillarisation, and aerobic enzyme activity.

In typical lactate profile tests, the points where lactate starts to rise above resting values and where it increases exponentially are used to estimate the first and second lactate thresholds. Again this is most typically carried out in a laboratory environment. However there is a strong association with Critical Speed (CS) which is easier to measure (Jones & Vanhatalo, 2017). Similarly (Jones et al., 2019a) establish that CP represents the genuine boundary separating exercise in which physiological homeostasis can be maintained from exercise in which it cannot, and should be considered the gold standard when the goal is to determine the maximal metabolic steady state.

In a response to academic critique (Jones et al., 2019b) establish that CP is preferable to MLSS because it permits a more accurate estimate of the boundary separating the heavy and severe exercise intensity domains which produce discrete physiological response profiles relevant to fatigue development, exercise prescription and adaptations to training.



Three exercise intensity domains

As such while it is recommended to establish a LT baseline in laboratory there are now alternative measures and tools which AG athletes can test more easily. Finally targeted training interventions will help increase fractional utilisation.

Running Economy

The steady-state oxygen consumption (VO_2) at a given running velocity, which is often referred to as running economy (RE), reflects the energy demand of running at a constant submaximal speed (Barnes & Kilding, 2015a). Runners with good economy use less oxygen than runners with poor economy at the same steady-state speed. RE interacts with the performance VO_2 to determine the speed or power achievable for a given distance. The oxygen cost of enduring running, expressed in mL/kg/min at a certain speed, may exhibit up to 30-40% variation among individuals (Sandbakk, 2023). In the marathon, RE is a critical factor in performance. (Berger et al., 2023)

There is debate about the key factors to determine RE; however it appears that RE depends mostly on the percentage of slow twitch / type-I muscle fibres. Hence RE can be improved with the inclusion of endurance-appropriate strength training. In fact Bompa states that HIIT might significantly improve RE and VO_{2max} (Bompa & Buzzichelli, 2019). Barnes (Barnes & Kilding, 2015b) found that resistance training, plyometric training, and explosive resistance training to be the best training interventions.

Other interventions for increasing RE are:

- Beetroot (BR) juice (Barnes & Kilding, 2015b)
- Shoes incorporating a carbon plate and lightweight, energy-returning foam can improve running economy by ~4% (Jones, 2023)

Running biomechanics has also been researched to increase RE; however the evidence is light and changes to running gait are mostly favourable from an injury prevention perspective.

In addition to BR, strength training and HIIT should be included in an endurance program and carbon-based shoes, at least for racing, should be considered for enhanced running economy.

Psychological parameters

Fatigue

Prolonged exercise will reduce physical performance due to neuromuscular fatigue in central, peripheral, and motor pathway (Sandbakk, 2023). In addition to this physiological / neuromuscular fatigue Marcora (Marcora et al., 2009) has demonstrated that also mental fatigue impairs physical performance. In fact later research (Staiano et al., 2018) demonstrates that perception of effort, rather than severe locomotor muscle fatigue is the cardinal exercise stopper during high-intensity aerobic exercise.

However it is shown (Lopes et al., 2023) that the field of mental fatigue in sport is still mostly at research level and that field applications are not yet ready for practitioners' use. Yet some, initial field recommendations can be made to reduce mental fatigue:

- Reduce mentally draining activities before and during competitions
- Self-talk and other psychological skills (Blanchfield et al., 2014)
- Legal psycho-stimulants like Modafinil to reduce perception of effort (Marcora, 2016)
- Caffeine supplements (increased doses) (Marcora, 2016)
- Brain endurance training (BET) (Staiano et al., 2023)

Exercise Tolerance

Simons (Simons, 2023) approaches the area of fatigue from a sport psychological perspective and states that exercise tolerance which is a psychological product of perceived exertion and pain, offset by the motivation to endure. Moreover as exercise tolerance is a psychological process it can be improved by training. In fact professional road cyclist were able to maintain performance and RPE during a 20-min cycle ergometer time trial compared to a control test.

Jones corroborates this finding that exercise tolerance can probably be trained as it is reported that senior cyclists with many years of accumulated training display excellent resilience. This may suggest that age and/or consistent, long-term, perhaps high volume, training may play an important role in exercise tolerance (Jones, 2023).

Simons (Simons, 2023) makes an interesting observation that recreational athletes seek task completion and their exercise tolerance is increased by applying dissociation strategies. This means they ignore pain / fatigue by focusing the mind away from discomfort or boredom. In contrast elite athletes use association strategies and focusing on pace, form, strategy, nutrition and the competition tactics.

Mental toughness

While fatigue and exercise tolerance are acute events psychology offers a more long-term view. Based on interviews with professional athletes it was found (Perry, 2015) that it's more than just resilience and bouncing back from adversity: there is a proactive element. Mentally tough athletes were more likely to seek out challenges and push themselves to get better. They were also very confident in their own abilities.

This resulted is the 4C model of mental toughness:

- Challenge - seeking out opportunities
- Commitment - make and keep promises
- Control - shape what happens to you and controlling associated emotions
- Confidence - inner strength to push through

The 4C model is the dominant model of applied sports psychology (Perry, 2015). It should serve as a guideline for athlete's and coaches on how to assess and enhance mental toughness. There are five practical interventions: positive thinking, visualisation, anxiety control, attentional control, and goal setting.

Motivation

Self-Determination Theory (SDT) tries to explain why humans choose behaviour beyond survival and procreation (Simons, 2023). Rewards can be extrinsic (e.g. payment, social pressure) and intrinsic (e.g. doing something for the love of it). External motivators as the major sources will ultimately fail. Focusing on intrinsic rewards there are three categories: competence (e.g. doing something you are good at and want to further excel at), autonomy (e.g. doing something good for yourself), and relatedness (e.g. belonging into a group of fast runners).

Practitioners' application

Fitzgerald (Fitzgerald, 2015) argues that brain training is part of the overall training for all athletes. Although more of a practitioner's guide and often based on anecdotal evidence Fitzgerald provides a comprehensive overview of mental interventions which can improve endurance performance:

- Brace: Acceptance of anticipated discomfort (compared to suppression)
- Flow: Direct attention externally to the task at hand (to distract from suffering)
- Self-believe: Believe in yourself and not on the outcome of a race
- Workaround: Embrace injury as it strengthens the mind to overcome
- Gift of Failure: Channel anger to increase pain tolerance
- Group Effect: Collaboration and communication with other athletes releases endorphins
- Audience Effect: When observed or cheered upon performance is boosted
- Success Effect: When athlete believes she or he is good at chosen discipline
- Is it Worth it: Find a strong personal motivation (includes prayer)

This is inline with recent research into ultra-endurance runners (Berger et al., 2023). It is reported that they are using a range of psychological strategies to cope with the demands, including goal-setting strategies, attentional focus strategies, positive self-talk, challenging negative thoughts, visualisation and seeking support from other runners and support teams.

Conclusion

To help overcome fatigue and as part of the nutrition strategy we should explore caffeine and modafinil. However the main finding here are that the integrated ATP should seek to train performance psychology. The focus should be on: defining intrinsic motivation and increasing exercise tolerance with association strategies geared towards the exercise and competition. Interventions to be trained during exercise to be executed to perfection during racing needs to be: positive self-talk, visualisation, goal setting, and flow. Based on previous marathon experience there are examples of such positive self-talk (Mindfulness prayers).

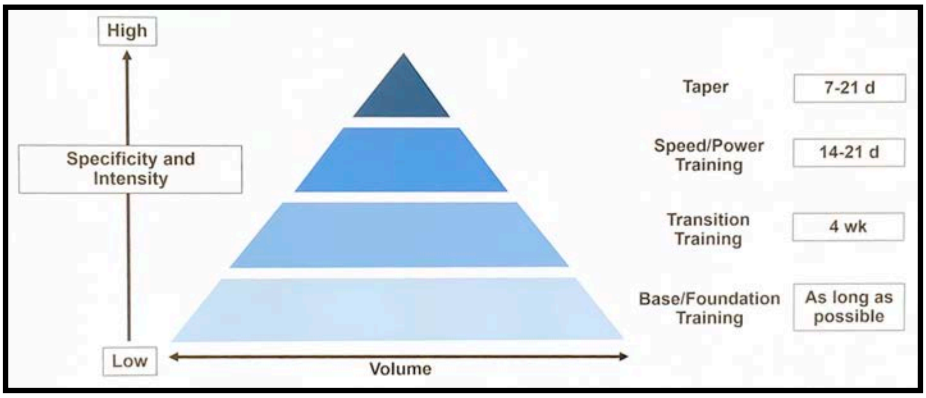
Training process

The holistic training process includes multiple stages where the overall aim is to close the gap between existing and desired performance level. These stages in sequence include: goal setting, knowledge of the sport-specific requirements, monitoring / determination of athlete capacity, gap analyses, planning and conduction of training (Haugen & Tonnessen, 2023). Moreover training needs to comprise of a long-term goal (e.g. Olympic Games) and annual goals. These need to be defined in tandem.

Long-term planning

A long-term training plan helps to define an overarching ambition or goal which requires multiple years to achieve. Quoting Solli's unpublished paper (Solli, 2020) Mujika provides a good insight into long-term training planning for endurance athletes:

- 400 to 900 hours / year - peak around 800 hours; this is in line with Seiler's 500-600 hours for long-distance runners (Seiler, 2023)
- Training intensity distribution (TID) should be: 10% high intensity, 5% mid intensity, 10% strength, 5% speed, 70% low-intensity
- Best performance only achieved after 7 years. István Balyi, who developed for Canada a long-term planning for performance in 1990:"Since it takes 6 to 8 years (and often more) of training to produce elite athletes, a well-established and monitored training plan must be in place early to best develop an individual's competitive talents".
- Only experienced (4+ years) athletes should have multiple performance peak events per year.



Components of an endurance training programme (source: Mujika)

Kataoka (Kataoka et al., 2021) reviewed over 100 periodised training studies out of which only 88 studies a 4-18 week period. Hence there is limited scientific evidence for training planning in excess of 18 week durations.

Hence while we consider a single "A" competition for 2024 it is worthwhile considering a longer-term investment into endurance training which should ensure limited injury risk, maintenance of overall health and a progression into an even stronger athletic year for 2025, possibly prioritising 70.3 races over marathon.

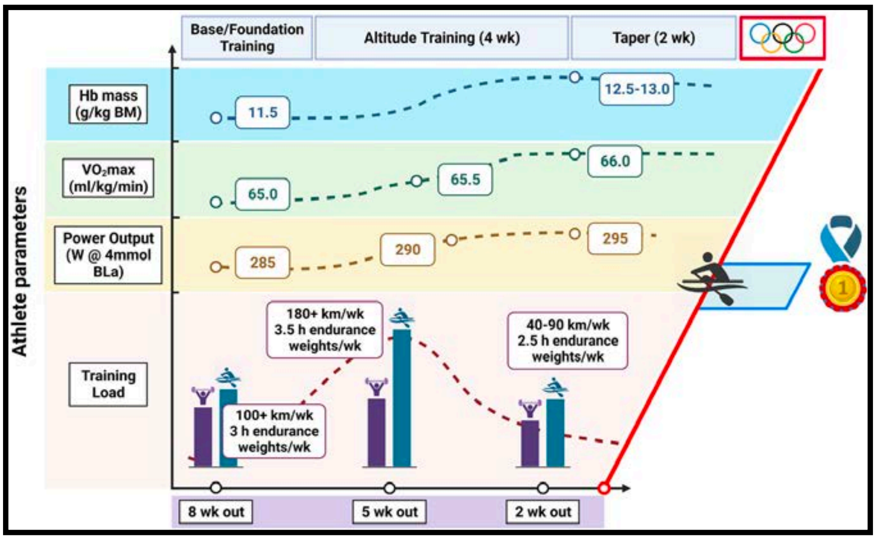
Annual Training Plan

Once the holistic long-term plan is created we define the key competitions for this year. This will guide what training adaptations are required, by when, to achieve what.

Bompa defines an ATP (Bompa & Buzzichelli, 2019) as: "An annual training plan (ATP) and its periodisation are the necessary methodological tools to maximise physiological adaptation, as they are the intrinsic foundation necessary to improve performance."

Building on these concepts (Kataoka et al., 2021) proposed three consequential phases:

- Preparatory phase with high volume / low load with an emphasis on general physical base to increase the athlete's ability to tolerate more intense training
- Competitive phase to prepare an athlete for the competitive season by increasing strength and power via increasing training load while decreasing volume
- Transition phase (a.k.a.active rest) provides lower workloads to recuperate before preparation for the next competitive cycle.



Periodisation of training for an elite athlete (Furrer, 2023)

These phases are broken down, based on duration, as suggested by Issurin (Issurin, 2010) into periodised training cycles: Multi-year preparation, Macrocycle (months), Mesocycle (weeks), Microcycle (days), and Workout (h/min).

Periodisation is an organisational approach to training that considers the competing stressors within an athlete's life and creates "periods" of time dedicated to specific outcomes (i.e., strength, hypertrophy or power). These designated periods are intended to manage the stress associated with exercise, while also creating potentiation in the subsequent training phases. Through proper stress management and program design this approach may also attempt to peak various performance measures at a specific time relevant to competition. (Kataoka et al., 2021). Periodisation may be categorised into two main models, namely, block periodisation (BP) and traditional periodisation (Issurin, 2010).

Periodisation methods

Traditional or linear periodisation involves different cycles in which different contents are present, but with volume decreasing proportionally to the increase of intensity throughout the season (Boullosa et al., 2018).

Several descriptive studies show that world-leading endurance athletes apply a progression in training volume and intensity according to the traditional periodisation philosophy. And while many top endurance athletes were victorious with this approach in the 60s and 70s with international athletes participating in more events through the year a new form of training planning, block periodisation, was introduced.

Traditional periodisation

The traditional periodisation proposes one-peak, two-peak, and three-peak designs reflecting key competitions.

Traditional periodisation provides an early emphasis on high training volume and a gradual shift towards higher training intensity with reduced volume as the competition period approaches (Haugen & Tonnessen, 2023). High volume of low-intensity is the preparatory phase creates a foundation for the subsequent mesocycles where more intensive training is performed. Most endurance athletes are therefore careful not to overuse race-pace training or introduce it too early in their annual cycle.

Traditional periodisation introduces the concept of "rhythmicity". With this there are intense mesocycles (typically on a 2-3 weeks or 4 weeks duration) followed by an easy week.

Another key concept is "specificity" under which the initial preparation mesocycles are more general fitness training which includes 2-4 strength and cross-training sessions a week. When entering competition this is reduced to 0-2 sessions a week.

Block Periodisation

The non-traditional model, called 'block periodisation', proposes a training system, where the sequencing of mesocycle blocks exploits the favourable interaction of cumulative and residual training effects. (Issurin, 2010). In contrast to the traditional periodisation where the training is focused on concurrent development of many abilities, BP intends consecutive stimulation of thoroughly selected finiteness components.

Block periodisation contains of three types of mesocycles:

- Accumulation - basic abilities such as general aerobic endurance, cardiorespiratory fitness, muscular strength, and basic coordination. It's duration is 2-6 weeks
- Transmutation - sport-specific abilities, strength endurance, proper technique and tactics. It's duration is 2-4 weeks
- Realisation- restore athletes and prepare them for competition. It contains drills for modelling competitive performance and quick active recovery. This ranges from 8 - 15 days.

These blocks of mesocycles are combined into an annual cycle with macrocycles around preparation and competition.

Although BP is relatively young it has been well researched. The key biological drivers for BP are: homeostatic regulation, stress adaptation and the law of super-compensation (Issurin, 2019). Concurrent training provokes conflicting physiological responses, where stressful intense workloads disrupt homeostatic reactions and suppress the impact of an aerobic program. By placing these workloads in separate blocks offers a solution for this methodological problem.

Optimal periodisation

Many coaches and literature imply that BP is the preferred periodisation model for elite athletes however there are quite some caveats:

- Furrer (Furrer et al., 2023) cautions that we still do not know what training really works best; as there is little longitudinal research and periodisation is scientifically on weak foundations.
- For all-year or multi-year training plans there is limited evidence whether the effects of block periodised training increase, maintain, or diminish over the long-term period of time (Kataoka et al., 2021).
- For strength training meta-analysis has determined that there is no benefit of block periodisation over linear periodisation (Harries et al., 2015).
- Marathon runners typically apply double periodisation centred around spring and autumn marathons (Haugen & Tonnessen, 2023).
- For most endurance sports traditional periodisation is used supported by block periodisation for specific adaptions like altitude camp (Haugen & Tonnessen, 2023).
- Mujika also suggested a general level of fitness all-year round followed by high fitness and peak performance as seen in traditional periodisation.

Conclusion

This paper is for AG athletes; not elite runners. Hence we do not have the strong multi-year training background to support multiple peaks, and there is only one "A" competition. Hence we would mostly benefit from an ATP based on traditional periodisation with one-peak.

Run training

The key components of the periodised ATP are the actual training exercises. Whilst cross-training and strength training are included into the ATP here we will focus on the run training.

Dose and Response

Run training creates physiological adaptations based on the type, duration, frequency, and intensity of the training session. Depending on the type of stimulus adaptions can lead to a delayed onset of fatigue, increased muscle power, or improved neuromuscular coordination (Lambert, 2023).

Ideally we should be able to provide the right "dose" of exercise to obtain the desired "response" (Lambert, 2023). Monitoring the training load (dose) can help make decisions regarding the load athletes need to be prepared for in competition, whether they comply with the prescribed load, and how they reported to that load.

For this we need to agree on how to quantify dose and measure response. Unfortunately there is no gold standard for defining the training load as it depends on sport and circumstances.

Yet where there is consensus is that we should have internal and external load measures. Examples of internal load measures are: heart rate, blood lactate concentration, and perception of effort. Examples of external load measures are: distance, time, speed, and power output. Impellizzeri (Impellizzeri et al., 2019) agrees to the use of external and internal load indicators for intensity monitoring. It is shown that once the external load from the training plan is applied it is actually the internal load to determines the training outcomes.

Anecdotally we learn that endurance coaches have a preference for monitoring the training load knowing the duration and type of training, the RPE, and personal remarks documented in athletes' training diaries (Lambert, 2023).

As a simple, yet valid method for quantifying training load during steady-state exercise Lambert (Lambert, 2023) advocates the use of session RPE (sRPE). Although the RPE assessment is athlete subjective in trained athletes on an individualised level it is still a good measure of the exercise intensity. Also Boullosa, albeit on a single case of a middle-distance runner recommends to record sRPE, RMSSD, and RR (Boullosa et al., 2021). RMSSD and RR are derivates of HRV.

After having reviewed and commented on the main internal and external load measures Lambert (Lambert, 2023) concludes the the Training Stress Score (TSS) may provide currently the best balance between practicality and accuracy for endurance monitoring. TSS was developed by Andy Coogan for cyclists and it takes the duration and intensity (power) of a workout to arrive at a single estimate of the overall training load. This approach is now also available for running based on run speed and lately also on running power.

Training Intensity Distribution

From a practitioner's perspective prescribing a training plan with frequency, duration and volume is simple. However the prescription of exercise intensity is non-trivial due to the lack of agreed framework for assessing the exercises intensity (Jamnick et al., 2020).

Based on the observation that humans have evolved relatively little in terms of activity and dietary patterns it is suggested (Boullosa et al., 2013) that athletes should train mainly in two zones: prolonged, low-intensity, aerobic-based activities interspersed with periodic, short-duration, high-intensity bursts of activity.

This observation is based on the three intensity domains already introduced (Moderate, Heavy, Severe based on LT/VT/VO_{2max}). In contrast to the pyramid TID which would provide the middle domain a training volume between moderate and severe, the polarised TID actually tries to limit this middle domain.

In fact a seminal paper by Seiler states that:"This study supports and provides the historical context for data from elite endurance athletes suggesting that the optimal training organisation for maximal performance is a polarised model of training with about 75% of training performance well below the lactate threshold and 15-20% well above that intensity" (Seiler & Kjerland, 2006).

Stoggl reported that when most training volume is below VT1, as little as possible between VT1 and VT2, and high-quality training of only around 20% of volume would be over VT2. Then this training resulted in the greatest improvement in most key variables of endurance performance in well-trained endurance athletes (Stoggl & Sperlich, 2014).

However the body is complex and even when strictly adhering to the prescribed intensity zones which target one physiological outcome also the not-targeted physiological benefits will be achieved. Seiler (Seiler, 2023) observes:"Endurance coaches and athletes often assume that only high-intensity interval training (HIIT) will improve cardiovascular performance and VO_{2max}, while low-intensity training only has value for inducing peripheral adaptations. In contrast, there is a quite compelling body of descriptive and experimental evidence indicating that cardiovascular performance and VO_{2max} respond to the interactive effects of both training intensity and overall training volume."

TID Measures

For coach-to-athlete communication the three-intensity-domain model is too coarse. Hence in different endurance disciplines we see practitioner models with 5 to 8 intensity levels. This helps communicate precisely what intensity is requested from the athlete. Yet these models always link back to the physiological intensity domains.

Also for on-field measurement purposes the three-intensity domains needs to provide simpler yet accurate measures. Hence is is substitute the physiological markers with CP and CS as these yield the strongest evidence to demarcate the heavy and severe domains of exercise. Yet the authors caution that these results need to be confirmed via on-transient VO_2 kinetics. (Jamnick et al., 2020)

We previously already stated that Jamnick proposed a mix of internal and external measures for best insight into prescription and determination of training intensity. Below is an example (Jamnick et al., 2020):

Aerobic training zone	Measure	L1 (recovery)	L2 (extensive endurance)	L3 (intensive endurance)	L4 (threshold training)	L5 (interval training)
Heart rate	(% of HR_{max})	65-75%	75-80%	80-85%	85-92%	>92%
Blood lactate	mmol/L	< 2.0	2.0 - 2.5	2.5 - 3.5	3.5 - 5.0	> 5.0
Rating of perceived exertion	RPE (6-20)	< 11	11 - 12	13 - 14	15 - 16	17-19
Relative to sub-maximal anchor		< LT1	LT1 < LT2	LT1 < LT2	<LT2	>LT2

Five aerobic training levels based on lactate threshold (source: Jamnick et al 2020)

In support of combined measures and the interaction between dose and response Seiler (Seiler, 2023) points out that we should consider training intensity more from the point of managing training stress.

Run workouts

Inside the periodised ATP we need to consider which forms of run workouts are most appropriate, based on what desired outcomes, based on existing stress, for what athlete and where inside the ATP phases. In the context of many sports, HIIT is likely the most powerful, controllable, and practical method we can use to achieve aerobic power development (Laursen & Buchheit, 2023). This was recently confirmed in a study with 84 participants on a 6-weeks study with various types of training types (Inglis et al., 2024):"Exercise intensity is a key component determining changes in VO_{2max} and sub-maximal thresholds and exercise intensity domain-based prescription allows for a homogenous metabolic stimulus across individuals."

HIIT works on three key physiological targets: Aerobic, Anaerobic, and Neuromuscular. Based on what combination of these three targets should be prescribed one of six possible training categories is selected. According to the selected category there are four major HIIT workouts which can be prescribed (Laursen & Buchheit, 2023):

- Long (Aerobic) intervals; 1+ min bouts (@ 95-105% CP) to induce acute metabolic and neuromuscular responses. For long intervals to be effective, they should be separated by short duration (1 - 3 min) of passive recovery. 2 times per week.
- Short (Anaerobic) Intervals; 10 - 60 sec bouts (@100-120% CP) repeated in a similar short relief time duration depending largely on the lactate response desired. 1-2 per week.
- Repeated Sprint Training; 3 - 10 sec bouts (all-out) with a variable but very short recovery to target high-end capacity.
- Sprint Interval Training; 20 - 45 sec bouts (all-out) for anaerobic lactate and neuromuscular training.

All these workout types can be configured on intensity and duration of the bouts, series of bouts, and recovery times between bouts.

In addition to HIIT Bompa (Bompa & Buzzichelli, 2019) suggests some other run workouts to be included:

- Long-slow distance (LSD) includes runs at 'conversational' speed. LSD is effective in untrained athletes but much less in elite runners. Yet for all athletes it is encouraged to be included for developing aerobic endurance and it should make up a large portion of the training volume, provided that HIIT is sufficient.
- Fartlek ("Speed Play") is used to develop endurance through unstructured intervals of fast and slow running. It may be most useful during the general conditioning or preparatory phase of ATP because it challenges the physiological systems of the body while eliminating the boredom and monotony associated with daily training.

Conclusions

Run training should follow a polarised TID which should be prescribed and monitored using a combination of internal and external load measures which are linked to physiological intensity domains but more practical to measure in the field. We will focus on CP, TSS, and sRPE. HRV will be considered in the context of recovery alongside RHR.

Based on the physiological adaptation required (aerobic, anaerobic, neuromuscular) the appropriate HIIT workout can be selected and adopted to athletes acute requirements. This may be enhanced with LSD to add volume and Fartlek for added variation and fun.

This is well-reflected by Boullosa's coach surveys (Boullosa et al., 2020).

- a combination of methods, including one to two HIIT sessions per week plus more sessions with moderate- and low-intensity continuous submaximal running
- Alternate sessions of high-intensity or sprint interval training with sessions of low and moderate-intensity continuation training, with > 75% of the volume at low intensity
- Complete 1-2 sessions of strength training per week to improve muscle strength and running economy

Strength and cross-training

Strength

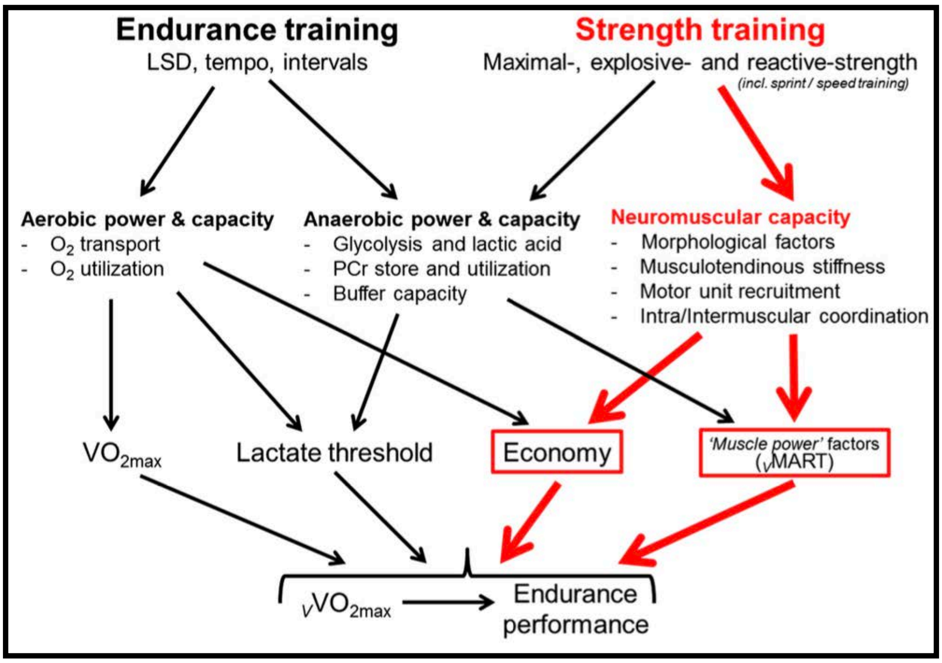
Strength training is defined (Andersen & Aagaard, 2010) as:"Training that in an efficient manner induces a measurable increase in muscle strength and/or hypertrophy." It works by improving neural function as well as tendon stiffness. Specifically for long-term endurance performance it also helps increase economy of movement (RE).

This is important also for endurance athletes as contemporary scientific data (Bompa & Buzzichelli, 2019) reveals that strength and power are important for sports with a large endurance component, such as long-distance running. Vernillo confirms as this helps increase muscle fatigue resistance.

Fitzgerald (Fitzgerald, 2023) claims that strength training is proven to increase performance, and improve body composition in endurance athletes. Strength training was found to improve muscular strength and RE in runners of very different levels, and performance in previously trained runners (Boullosa et al., 2020).

While Fitzgerald (Fitzgerald, 2023) and Maffiuletti claim that strength training is also good for injury prevention this has been put in doubt by a recent meta-study (Wu et al., 2024) which concludes that there is not enough evidence to support general exercise-based prevention strategies. However the same study does note a positive correlation when exercises included are targeted towards running.

One technique to improve neuromuscular efficiency in athletes is through strength training. This improves RE, vVO_{2max}/wVO_{2max}, muscle power, and performance. For long-term improvements in weak (neuromuscular inefficient) or non-strength trained endurance athletes, literature demonstrates that a general maximal-strength orientated programme may initially be the most appropriate and efficient method for improving maximal force, power and reactive-strength capabilities. Endurance athletes with high-force capabilities may need to place a greater emphasis on specific explosive- and reactive- strength training to gain further improvements in performance (Beattie et al., 2014).



Hypothetical model of the determinants for elite endurance performance and the potential benefits from strength training (Beattie et al., 2014)

In fact research by Sedano (Sedano et al., 2013) with eighteen well-trained male runners was conducted in three groups: endurance-only, plyometric strength, maximum strength. Plyometric and Maximum-strength training led to improved maximal strength, RE, and peak velocity with no significant effects on the VO_2 kinetics pattern.

Strength Periodisation

Volume of strength training in support of endurance sport will be different between key periodisation zones. However Bompa (Bompa & Buzzichelli, 2019) suggests for triathlon between 600 - 1'000 metric tons of volume per year. No data is provided for marathon running, however arguably long-distance triathlon is closely related to marathon running. Metric tons are a simple calculation of Sets x Reps x Load (kg) / 1'000

Strength training too needs to be periodised based on the training phase and the desired training effect. For distance running following phases are recommended:

- Anatomical adaptation (AA) (Preparatory) serves to strengthen the tendons, ligaments, and joints and to increase bone mineral content. This is achieved via tension time of 30 - 70 seconds. Most time is spent in eccentric phase
- Maximum Strength (MS) (Preparatory) without an associated increase in body weight supports central nervous system training. In this phase the concentric action should be explosive in order to activate the fast-twitch muscle fibers and to achieve the highest specific hypertrophy.
- Conversion to long muscle endurance (Preparatory) helps maximise rate of force development and is trained by engaging the nervous system via ballistic and plyometric training. Adapting the neuromuscular and cardiovascular systems physiologically, biochemically, and metabolically provides invaluable benefits to athletes in many endurance sports.
- Maintenance of maximum strength (SM) (Competitive) is important phase to retain the strength gains also during the competitive phase by continued strength training with at least one weekly session.
- Cessation (Competitive) phase is a period of 14 days, for long endurance sports, prior to the year's main race when the strength training is ended. This period might different by gender and body type.
- Compensation training (Transition) phase is the rest period between annual training plans. It should not last more than four weeks to avoid detraining for serious athletes.

Balancing hypertrophy with optimal body weight

There is some concern with endurance athletes that strength training induces muscle hypertrophy which in turn increases overall body weight. This in turn is considered unfavourable for longer-duration weight-bearing endurance events. However it has been found that hypertrophy plateaus out at approximately 25% of muscle expansion. Moreover there is big variation among athletes with some reporting 50% hypertrophy vs. 0% in others. Hence this element is highly individual. (Andersen & Aagaard, 2010)

Concurrent training

When strength training is included inside a periodised endurance training program it is often referred to as Concurrent Training. While it is recognised that both aerobic and strength training are beneficial for better competition outcomes these two training modes provide different training stimuli which are often in competition. This is also called interference (Laursen & Buchheit, 2023). According to Bompa (Bompa & Buzzichelli, 2019):"When resistance training is simply added to the pre-existing endurance training plan, performance usually is not improved. It is likely that adding the resistance training load to the overall training load results in excessive training stress which then elevates fatigue and decreases readiness." Moreover LIEE performance increase with concurrent resistance training typically requires a reduction of resistance training load.

As such concurrent training requires a different approach: Villanova has researched the most appropriate inclusion of strength training into endurance training and his main findings are:

- Endurance training earlier in the day then strength training with at least 8 hours of recovery. This is inline with the observation on human evolution by Boullosa (Boullosa et al., 2013) which recommends that enhanced strength and power were typically performed after aerobic activities.

- At least twice a week strength training with focus on sets of only 4 repetitions at 80% 1RM. In fact on maximum force development Fitzgerald (Fitzgerald, 2023) recommends that runners perform one set of 6-10 x 8-10 second sprints up a steep hill each week. This view is shared by Boullosa who considers sprint training as part of the strength section of the overall running training plan.
- There seems good scientific consensus with Mujika recommending the inclusion of 2-3 strength trainings per week in an endurance program. Similarly Fitzgerald (Fitzgerald, 2023) suggested to lift very heavy loads with low reps and workouts of 20-40 minutes are recommended two or three times per week.
- Focus on compound free-weight exercises and based on a meta-analysis of 17 studies with 510 participants it is suggested (Harries et al., 2015) to include variety into the training for stimulating strength development.

Training phase	Typical workout	Comments
Base training	•30 min-several h •70-75% VO_{2max} •75-80% HR_{max} •7-12 sessions/wk	•Non-competitive period for as long as possible (3-6 months) •High training volume •Low to moderate intensity •Prolongued continuous exercise
Transition training	•30-90min •85-90% VO_{2max} •90-95% HR_{max} •2-3 sessions/wk	•6 wk prior to competitive season for 3-4 wk •Moderate volume •Maximum steady-state/race pace •Continuous or intermittent exercise
Speed/Power training	•30-60min •Maximal intensity •2-3 sessions/wk	•2-3 wk prior to major competitions •Low volume •Faster than race pace •Intermittent exercise with long recovery between work bouts

Strength training as part of training phases (Hawley & Burke, 1998)

Cross-training

While considering how to improve training outcomes for long-distance runners Fitzgerald (Fitzgerald, 2014) states that training does not necessarily mean running more. In his experience increased mileage leads to an increased injury risk especially as running is a high-impact sport. Moreover he has observed that runners slow down with age at a steeper rate than other endurance athletes do. Based on anecdotal evidence he suspects this slow down to be the consequence of many years of high-mileage running which reduces the bounce of the runners' legs. There seems limited scientific evidence based on correlation between overall mileage in master runners and DNA deterioration.

Hence to allow for continued training adaptations for experienced runners past 35 years old he promotes cross-training with at least one workout per week ("Trust me: You will get a noticeable boost from this investment, yet your injury risk will change only marginally"). He actually promotes a more aggressive cross-training approach with three to six runs and thirteen total workouts per week.

Cross-training as a method for injury prevention is also promoted by Hobrough (Hobrough, 2016):"a good running programme should be underpinned by additional cross training, be it in strength and conditioning in the gym, or using body weight and stretches, aqua jogging, using the cross trainer or riding your bike."

Friel (Friel, 2015) suggests seven different cross-training activities for runners: antigravity treadmill running, bicycling, outdoor elliptical biking, indoor elliptical biking, pool running, slide boarding, and uphill treadmill walking. However based on French research in 2002

(Millet et al., 2002) cross-training which provides best adaptations for runners is cycling, while swimming does not contribute significantly to running performance.

Similarly Mujika mentioned that cross-training has endurance-enhancing effects; this is well documented in biathletes who exercise running and cycling during non-winter periods.

Boullosa cautions that we cannot achieve excellence in one sport and remain competitive in others. This is the principle of allocation.

In summary cross-training for AG runners with a history of injury is highly recommended with upto six runs a week and other cross-training which help increase endurance, mostly cycling. All this without expecting to achieving excellence in the cross-trained sports.

Conclusion

To develop a healthy and competitive long-distance runner strength and cross-training need to be fundamental components of the periodised ATP.

Strength training helps build stronger muscles which support the running with larger glycogen stores and overall power to help locomotion through improved RE. To benefit from strength it needs to be properly planned inside the ATP to avoid overexertion.

Due to the high injury rate from long-distance running physiological adaptations can be supported by cross-training in other endurance sports and further injury prevention comes from stronger supporting muscles. Hence running should be limited to 6 times a week. Cycling seems to have the best transferability for running. While swimming has low-transferability we will keep 2 sessions / week to keep IM-fit.

Training and racing tools and equipment

Carbon shoes

Since it's public launch in 2017 carbon-plated running shoes have changed the long-distance running world. In a recent research (Black et al., 2022) it was demonstrated that such carbon-plate footwear significantly enhanced time to the limit of tolerance and peak speed attained with reduced oxygen cost. Carbon shoes may improve maximal incremental running performance and positively influence oxygen cost (RE). As introduced before Jones (Jones, 2023) mentions a 4% increase in RE.

However later research (Tenforde et al., 2023) cautions that the introduction of carbon-plate footwear may increase injury risk from altered foot and ankle mechanics.

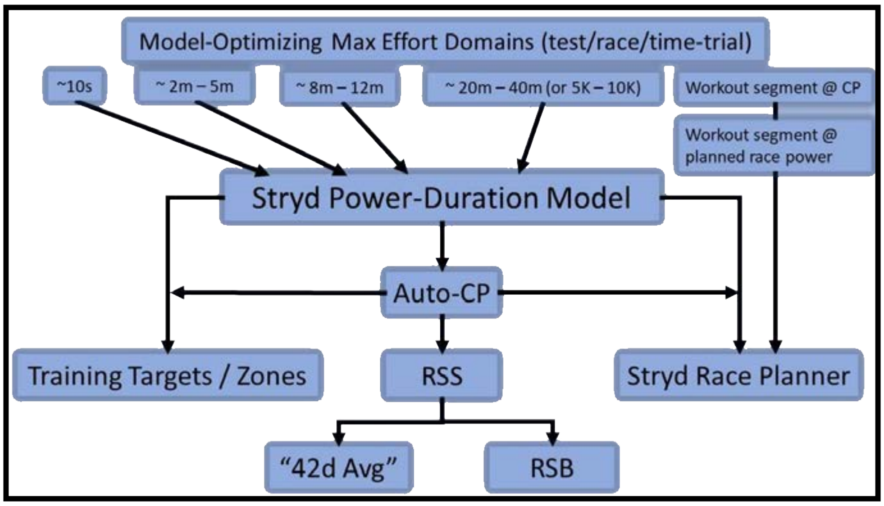
We conclude that carbon shoes are a must for key workouts and races by improving RE, but their use should be limited to reduce injury risk.

Stryd power meter

Stryd is a footpad-based power meter which measures during the run the actual power output from the legs incorporating wind resistance. It is considered the most precise power-meter on the market, especially in its latest product iteration which measures power on both legs and plots the relative position of the pods thereby providing a gait analysis based on an actual run activity (Footpath).

Stryd does auto-calibrate the Critical Power (CP) from the first runs. However a more precise and recommended initial assessment method is to do three runs with varying intensity and duration with a 30 second, 3 minute and 20 minute all-out segment during which the CP is determined. For continued, regular CP testing two all-out runs in same week with duration of 3 and 20 minutes are prescribed.

The Stryd power-duration model is based on three data points which is similar to the scientifically proposed method to determine CV/CP. As such Stryd provides a good proxy for fractional utilisation in a non-laboratory environment and should be used by AG athletes.



Stryd Power-Duration Model

We will use Stryd-based power to measure power for all run trainings and to regularly as part of ATP test increases in CP.

TrainingPeaks / WKO5

TrainingPeaks (TP) is an online training tracking and prescription platform which supports the interaction between coaches and athletes. Coaches can plan ATP with periodisation across multiple sport disciplines with a variety of custom-built workouts and the ability to individualise these to the athlete's need and stage in the training cycle. Athletes carry out workouts to this plan and log workouts alongside internal and external intensity criteria (e.g. distance, HR, power, RPE).

TP tracks athletes chronic training load (CTL), acute training load (ATL), and fitness stress balance (FSB). ATL indicates the load of the given day by combining the TSS of all workouts on that given day, CTL calculates a running 42-day weighted average of ATLs into one singe number, FSB is an indication of the chronic fatigue accumulated by the athlete. TP automatically imports data from key tools like FitBod, Garmin, Stryd, and others. Moreover TP helps administer training plans from companies like 80/20.

WKO5 is a data analysis tools to extract all data from TP and create custom reports. Reports (WKO5 consolidated report) are highly customisable and help to track KPIs identified throughout this paper.

We will use TP as the core tool to build and track our ATP; WKO5 will serve for more in-depth analysis on weekly performance.

FitBod

There is a need for concurrent / strength training. This should be based on reps with short sets of 80% 1RM. Moreover with training mostly in the evenings we need to work muscles which are not fatigued from early morning workouts. Finally as monotony is the enemy of progress we also need to provide a variety of training stimuli for continued strength development.

For this we have selected a mobile app called FitBod which provides AI-generated, daily, individualised workouts based on results from previous strength workouts, estimated muscle fatigue from previous strength and aerobic workouts, based on availability of strength equipment for each gym, and personal preferences around stacking exercises and overall workout duration.

Moreover FitBod estimates the TSS and includes it into TP's ATL for an accurate assessment of the overall training load and aggregated training stress.

FitBod includes strength assessment at muscle-group level as part of the regular workouts it generate and calculates a compound muscle-group score (mStrength). So instead of providing the 1RM for squat in kg it would aggregate all exercises which work the glutes and based on their relative contribution to strength development assess it's overall strength compared to all FitBod user base with 100 being top.

FitBod will provide the basic workout for 2-3 weekly strength training. Where required we will change the prescribed workout to be more run-specific and inline with physiological adaptions required in the ATP.

80/20 Training plans

80/20 Running is a company which provides a wide-range of workout plans to most endurance sports. 80/20's founder, Matt Fitzgerald, has done extensive research into the latest scientific papers. Hence these plans are based on the principles of periodisation, training cycles, gradual increase in mileage and intensity, train low and high, and tapering.

The company employs many experienced endurance coaches so in addition to the latest scientific insights they are also grounded in years of field experience training athletes.

We will use 80/20 training plan as a starting point for our periodised ATP, while we understand that many of the workouts prescribed lack scientific evidence. Hence we will take the liberty to modify the standard plans according to AG athlete's needs. In addition to ready-built 14-18 week plans 80/20 also provides access to a vast library (Example run trainings) of power-based run exercises which can easily be inserted into TP while creating the ATP.

80/20 provides all run workouts listed above. As such 80/20 will provide the basis training plans for the ATP; however we will use judgement on modifying individual workouts, intensities, and their order.

Powerbreathe

Powerbreathe is a cost-effective and computerised Inspiratory Muscle Training (IMT) tool. Based on a marathon training regime (Protocol) it helps increase lung volume and pulmonary power. Early research suggested that IMT helps improve exercise tolerance (McConnell, 2012). Recent meta-analysis (Fernandez-Lazaro et al., 2022) now demonstrates that IMT increases maximal inspiratory pressure and significantly increase sports performance.

However if endurance performance is mainly limited by heart and not lungs, as Cardinale states, then how important is it to strengthen lungs? Moreover can lung capacity be enhanced and is this beneficial? According to Porcelli anecdotally IMT like PowerBreathe can increase lung volume with up to 10% and increase power. There is limited research which seems to confirm this, albeit not for marathon running:

- In a 2021 research by Chang on 800-meter track runners (Chang et al., 2021) IMT training shortened 800-m trial from 163s to 157s while increasing maximum inspiratory pressure from 113 cmH_2O to 131 cmH_2O.
- Similarly in a more recent research (Salazar-Martinez, 2024) eighteen amateur cyclists completed 6 weeks of inspiratory muscle training (IMT). IMT improved the strength of inspiratory muscles by 39% as measured by maximal peak inspiratory mouth pressure (PI_{max}). These changes were not attributed to alterations in the response of the breathing pattern. Driving and timing analyses suggest that the nervous system adjusts ventilation to exercise intensity independently of respiratory muscle strength.

Despite limited scientific proof but considering that in maintenance phase only three 3-minute sessions per week are sufficient to retain an elevated lung volume and pulmonary power the use of Powerbreathe seems to be a good investment.

Calibre

Recently new devices which measure VO_{2max} and BMR have become commercially available at a price-point affordable to individual athletes. One of them, Calibre, showed overall a very low percentage error. Calibre is the only Cardio-Pulmonary Exercise Testing (CPET) device to employ machine learning to predict gas exchange variables from the measured values, which allowed it to achieve high accuracy, at a substantially lower cost than other (wearable) devices (Van Hooren et al., 2023).

Calibre is a promising new CPET which can help AG runners to assess their VO_{2max} and BMR. As this is a new tool it should be validated against laboratory-grade testing. However if there indeed is a low percentage error then this tool is definitely helping to track performance changes on key physiological parameters.

Brain Endurance Tools

BET have become an area of interest with athletes. There are now various BET mobile apps and training tools. Rewire's Neuro Performance System is probably the most complete system which integrates a mobile app based training schedule to train fatigue coupled with a simple gadget with coloured LEDs and buttons to continue brain training also in typical endurance settings.

However, when BET tools were tested extensively by Hutchinson with hands-on support from Marcora, in preparation of the Ottawa marathon (Hutchinson, 2018) it was concluded to be still too early to tell if it is beneficial. Moreover when considering the time requirements for BET training on top of traditional marathon training Hutchinson questions if BET provides best yield.

We will continue to follow developments in this field but not invest into specific BET tools. Instead we will focus on including elements of sports psychology and yoga to help with mental toughness.

Recovery & Lifestyle

Recovery from training and competition has become an integral aspect of the training program of elite athletes. Incorporating appropriate recovery aims to enhance subsequent training quality and improved competition performance through the restoration of physical and psychological processes. (Halson et al., 2023)

Halson introduces a recovery pyramid where sleep and nutrition are the basics. Once these are met other recovery interventions can be introduced.

Sleep

General advise on sleep is to prioritise it, esp. as athletes report on average 96 minutes less sleep per night than needed. Suggestions provided (Halson et al., 2023) are: sleep eduction, reduce screen time, encourage naps, pre-sleep routine (paper book, stretching), no caffeine after 14:00, and regular bedtime.

Recent research from Doherty (Doherty et al., 2023) on a group of 25 elite athletes demonstrates that the consumption of two kiwi fruit one hour before sleep improved sleep as evidenced by significant increases in Total Sleep Time (TST) and significant reductions in the number of awakenings. Also Friel (Friel, 2015) provides similar insights related to tart cherry juice. Both researchers assume this from melatonin release in either fruit.

The expert consensus statement on sleep and the athlete (Walsh et al., 2020) provides some guidelines:

- Experts speculate that athletes need more than 7-9 hours to recover from the physical and psychological demands of the sport
- Sleep measurement can be carried out using commercially available wearable devices (i.e. sports watch) as long as it is understood that sleep duration is overestimated while awakenings are underestimated
- Encourage nap opportunities (< 30 mins)
  Caffeine consumed in doses of 150–200mg just prior to a mid-afternoon nap (hence 'coffee-nap') has been shown to be an effective countermeasure to mid-afternoon sleepiness (the 'post-lunch dip')
- Banking sleep before a period of anticipated sleep loss may benefit performance

Friel (Friel, 2015) provides further suggestions for athletes over 50 years old specific to sleep:

- Try to avoid too early artificial waking up as the REM sleep-stage, during which testosterone release is most pronounced, occurs late in a night's sleep cycle, thus hindering full recovery.
- Chronically shortening your natural sleep cycle is likely to have a long-term effect on training quality and performance.
- The fewest sleep interruptions came after the high-protein meal; the high-carb meals produced the least restful sleep.

Cold Water Immersion

The protocol for CWI is (Halson et al., 2023) full body immersion for 10-15 minutes of cold water at temperatures of 10-15C.

Most notably Roberts (Roberts et al., 2015) has conducted primary research which demonstrate reduction in muscle mass and strengths from cold water immersion (CWI) for up to two days. The researchers do not recommend this recovery method to improve athletic performance. However this research did not consider endurance athletes who would use strength training for explosive power and reduction of injury risk, rather then pure muscle strength and hypertrophy. In fact it may be argued that countering the increased weight from hypertrophy is actually beneficial for endurance athletes.

A historic view is added by Friel (Friel, 2015) who remembers when in the 70s icepacks were being used on sore muscles to speed recovery, while science has now proven this to actually delay recovery.

Halson (Halson et al., 2023) is more supportive:"there is enough evidence demonstrating CWI can have a positive impact of the recovery of endurance performance over both acute and chronic timeframes. However the potential negative effects of CWI on strength adaptations suggests that the use of CWI should be well planned around different types of training sessions and periodised to ensure the bet training outcomes are achieved."

Compression garments

Current evidence suggests that compression garment use post endurance exercise is beneficial for perceptual and performance indices of exercise recovery, including muscle soreness (Halson et al., 2023). Similarly Friel (Friel, 2015) states that there are a few studies that if compression garments are worn during recovery muscle soreness is decreased and subsequent exercise performance is improved.

Yoga

Yoga is the control of thought-waves in the mind (Prabhavananda & Isherwood, 2022). Yoga means balancing and harmonising the body, mind, and emotions. It was always thought that growth does not cease with maturity of the physical body. Each one of us has unlimited potential for mental and physical growth to influence our personalities. (Anupama & Kumar, 2021). Yoga is a healing process of cleaning and toning the body, mind, and senses. This healing allows the body, mind and senses a be in a more fertile environment in which to function thereby operating at the utmost level off efficiency. (Swenson, 2021)

Although no formal research has focused on this, Mujika mentioned based on anecdotal evidence of coaching the Spanish women national water polo team, that yoga might be included as part of Recovery. Also the yoga meditation during the one-hour yoga sessions are a form of brain endurance training (attentional control by focusing for one hour on breathing) as described previously in Psychological parameters.

Other recovery mechanisms

Halson lists other recovery tools and mechanisms which are frequently used by practitioners. The only ones worthwhile considering for endurance athletes are hot-water immersion and far-infrared sauna mostly to benefit adaptations to hot weather racing. Also floatation therapy is suggested to be beneficial as a post-exercise strategy; however this may simply be from the napping during this therapy. Interestingly Active Recovery and Stretching are unlikely to help facilitate post exercise recovery. (Halson et al., 2023).

However Friel (Friel, 2015) adds a practitioner's dimension to recovery research by stating:" Basically, science knows less about non-sleep and non-nutrition recovery that appears to be the case … Your experience counts for a lot when it comes to recovery techniques"

Recovery Periodisation

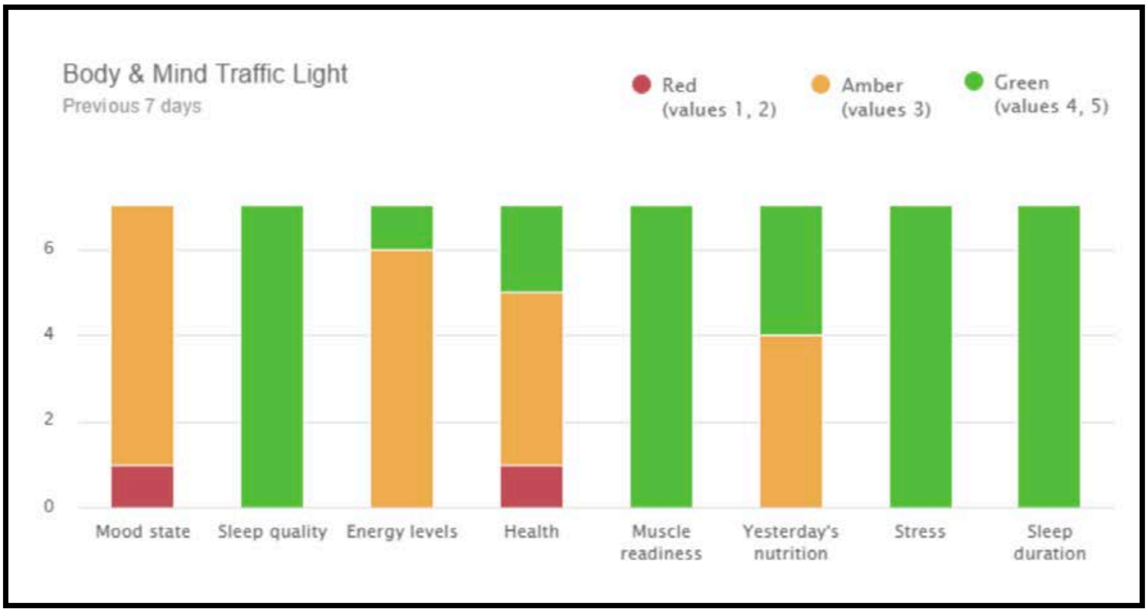
It is suggested (Halson et al., 2023) to insert recovery interventions into a periodised training plan. Key areas to consider are: training phase, desired adaptations, injury prevention, and psychological wellbeing. Interestingly avoiding recovery may be appropriate in early stage of a training plan to maximise stress adaptation.

In the context of periodisation, overtraining occurs when there is an imbalance between the recovery and the summation of all stress related to training and sports events (i.e., sport-specific practices and competitions). Considering that the periodisation of training was established to manage stress in conjunction with the sport, the management of overall stress plays a role to maximise performance outcomes (Kataoka et al., 2021).

Monitoring

Monitoring recovery is hard as highlighted by Kellmann (Kellmann et al., 2018):"To gain an understanding of the training load and its effect on an athlete, a number of training-load indicators have been introduced, but strong scientific evidence supporting their applicability is often lacking. Monitoring tools to quantify external loads include, for example, power-output-measuring devices and time–motion analysis. Internal-load measures encompass the perception of effort, oxygen uptake, heart-rate-derived assessments, blood lactate, training impulse, neuromuscular function, biochemical/hormonal/immunological assessments, questionnaires and diaries, psychomotor speed, and sleep quality and quantity. An incongruence between external and internal load units may reveal the current recovery–fatigue continuum of an athlete."

After having considered physiological, biochemical, performance, and subjective measures to monitor recovery for daily monitoring the most practical monitoring tool for recovery assessment is athlete self-report measures (ASRM) (Halson et al., 2023). Athlete self-report measures are paper-based or electronic records of an athlete's perceived physical, psychological, and/or social well-being, completed on a regular, often daily, basis. (Saw et al.,



Example of Athlete Self-Reporting Measures (source: Metrifit)

2017). However there are no standardised templates and it is suggested to create an ARSM based on utilisation purposes.

Altini (Altini & Plews, 2021) studied the correlation of heart rate and heart rate variability (HRV) with respect to individual characteristics and acute stressors. In particular, the relationship between heart rate, HRV, age, sex, body mass index (BMI), and physical activity in a large sample of 28'175 individuals. It was found that acute stressors revealed how HRV is a more sensitive marker of stress with respect to heart rate, as shown by larger relative changes. The paper's recommendation was that HRV-guided training may be to alter training intensity based on substantial changes in HRV and to prescribe full rest days based on substantial changes in resting heart rate. Similarly, and based on personal experience Mujika recommend to use both RHR as well as HRV to monitor recovery and training stress.

Conclusion

From all the recovery tools described in literature the most practical ones for AG athletes is sleep, nutrition, hydration. For the benefits of flexibility and attentional control we will also schedule one session of yoga per week. Compression garments will only be used where appropriate after races and to support long travel. CWI is an area to investigate better but will not be used. For recovery monitoring HRV and RHR will be considered as good indicators of recovery in addition to sleep KPIs.

Injury prevention

Running injuries

Runners suffer from the highest injury rates of all recreational athletes (Hobrough, 2016). This is confirmed by Boullosa:"Running-related injuries affect most runners with injury incidence even greater in marathoners. Endurance running is very challenging for muscle and connective tissues because it is a weight-bearing activity involving stretch–shortening cycles repeated over time" (Boullosa et al., 2020).

It seems that a high running mileage per week is the most important injury risk factor among recreational endurance runners. Hence progressive loading is suggested (Boullosa et al., 2020).

Recognising research which highlights runners' loss of performance directly following static stretching, Hobrough (Hobrough, 2016) cautions that:"It is important to note that static stretching still has its place and these few studies showing a reduction in performance are in no way suggesting we should abandon static stretching at others times as this will increase injury risk." Also Bompa recommends post-exercise cool-down to include 10-20 minutes of stretching in order to: bring muscle back to anatomical length, facilitate metabolic exchanges, and to speed up recovery process (Bompa & Buzzichelli, 2019).

As most injuries occur during last month before a major race, especial caution should be taken in final training mesocycles.

Running biomechanics

According to Tartaruga one of the key components of endurance exercise performance is the biomechanics of running which is comprised of: stride frequency, stride length, vertical oscillation, flight time, and ground contact time.

Cavanagh concludes that the preferred stride length is usually the most economical and anthropometric variables cannot be used to accurately predict or prescribe stride frequency or length on an individual basis (Cavanagh & Kram, 1989). Moreover Hunter (Hunter et al., 2017) found that:"Inexperienced and experienced runners are equally capable of matching preferred stride length to economical stride length, thus athletes and coaches do not need to alter runner's stride length when economy is the main concern".

Ground contact time (GCT) may be reduced using strength and explosive training programs which are capable of improving RE (Boullosa et al., 2020).

Other research (Boullosa et al., 2020) and (Ogueta-Alday et al., 2014) looked into various types of foot striking (front-foot, mid-foot, rear-foot). It was found that while some forms of injury may be alleviated (Giandolini et al., 2013) there is limited evidence that either strike has better RE.

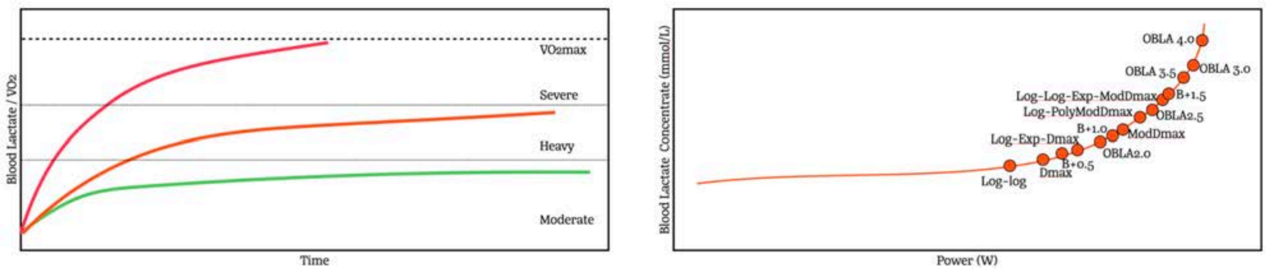
Conclusion

While running is injury prone there are suggestions to reduce risk: progressive increase in mileage, cross-training, static stretching and especially caution in final month before competition. Instead biomechanics as a way of injury prevention can best be modified with appropriate strength training while other aspect of stride should best left as is for an experienced runner.

Physiological and medical testing

Physiological tests

Recreational runners could use laboratory-based gold-standard tests like VO_{2max}, Aerobic threshold, and running efficiency. However the assessment of these maximal and submaximal variables is not accessible to all runners in terms of cost or availability (Boullosa et al., 2020). More accessible evaluations include: maximum aerobic speed, HR_{max} and CS. However the superiority of any method has not been demonstrated over others with respect to the validity and sensibility for training monitoring (Jamnick et al., 2020).



Translating physiological domains to intensity measures (based on Jamnick)

Hence for serious endurance athletes for monitoring of individual exercises a mix of measures with a minimum of CP and RPE are recommended, possibly enhanced with a regular check-point in a sports lab to relate this to VT1, VT2, VO_{2max} and RE.

A key indicator for training load is Chronic Training Load (CTL). Fitzgerald (Fitzgerald, 2023) recommends for elite athlete between 120-140. Sekiguchi (Sekiguchi et al., 2021) have researched acute:chronic workload ratio on division-I male soccer players and found that it may be a useful tool to achieve an appropriate balance between training and recovery to manage daily fatigue and soreness levels in athletes.

ATL and CTL when modelled separately are also indicators for injury risk (Bache-Mathiesen et al., 2024). Interestingly from two cohort of Qatari and Norwegian national league football players it has emerged that the highest injury incidence occurs with high ATL and low CTL. Although the authors suggest lots of future research this research might suggest CTL should remain elevated to avoid injury risk.

Body Assessment & composition

For athletes in weight-dependent sports, realising optimal body composition (e.g. power-to-weight ratio, lean muscle mass) is an important factor in obtaining the best possible periodised "peak." However, a periodised yearly and career approach will allow for this, while maximising training adaptation and long-term athlete health. Stellingwerff (Stellingwerff, 2018) goes on to show that in a multi-year assessment of body composition in middle-distance runners over time the total 7-skinfold quantity has decreased in female athletes from 84.7mm to 65.1 mm (-23%). The conclusion is that BF% was optimised for competition.

Yet the IOC states:"Although body fat is a drag it is also an integral part of the body. There is currently no universally accepted criteria to prescribe as gold standard the adult body composition". Also Burke (Burke, 2023) notes that while endurance athletes tend to be lean and light, there is no correlation found between physique and performance.

And if an athlete wants to change body composition there are limits deriving from interactions between genetic and environmental factors, with estimates of phenotypic heritability from epidemiological studies varying between 25% and 75%. Therefore, there will be a genetic limit to the extremes at which an individual can manipulate their phenotype and even more reason to create individualised body composition goals.

Although the study focused on aquatic sports there are general insights on body mass and body composition from Mujika (Mujika et al., 2014): it is desirable for a loss of BM to come as loss of fat rather than muscle. However, negative energy balance may result in a significant loss of lean BM. However it has been demonstrated that low-energy, high-PRO% diet (35%) will lead to loss of total body mass, but minimal muscle loss.

Fitzgerald (Fitzgerald, 2023) dedicates an entire book on achieving the 'right' racing weight. Recommendations and benchmarks are provided by sport, gender, and age group. The 'ideal' body fat for elite marathon runners is: 7.3% (men) and 12.4% (women). However for AG male athletes in 50-59 year bracket BF of 8.8% - 16.9% is considered gold standard for which no intervention is suggested.

Hence we conclude that while there may be typical characteristics by sport, there is no scientific evidence for the best body composition and there are mostly genetic limits to consider. During training focus needs to be on achieving training goals while keeping the athlete healthy. Only in the final stages of preparation for competition in weight-dependant endurance sports could body composition be considered by introducing a low-energy, high protein diet to reduce overall BM while retaining muscle mass.

Basal Metabolic Rate

Basal Metabolic Rate (BMR) is the energy requirements at rest (Porcari et al., 2015). It is also known as resting metabolic rate which refers to the bare minimum number of calories requires to keep you alive (Shorkey, 2020). BMR slows as age increases and weight decreases, but muscle gains increases it. Being able to assess BMR sets a minimum caloric requirement for any athlete.

$$MaleBMR = 88.362 + 13.397 * weight[kg] + 4.799 * height[cm] - 5.677 * age[years]$$

While this formula can be easily calculated BMR is best assessed in a laboratory. For AG practitioners CPET tools like Calibre might provide a more convenient method for regular testing once the baseline is set in laboratory conditions.

Regularly testing BMR and plotting against exercise caloric expenditure (as estimated by TP) can help fine-tune nutritional needs.

Blood test

Although there is no scientific recommendation for what blood tests and for which markers to check there is recommendation from Ferraris to test at least once every six months. TrainingPeaks for athletes ramping up training load recommends blood testing every 3 to 6 months and to test for Iron, Vitamin D, B_{12}, and LDL (White, 2023). Moreover for AG athlete based on age, high genetic cholesterol, low BMD, frequent stress fractures, and REDS in past, it was recommended by sports dietician to check following markers: B_{12} (Total and Active), Creatinine, Ferritin, Iron, Testosterone, T3/T4, Vitamin D, Cholesterol (HDL, LDL, Triglycerides).

Conclusion

We suggest that the base physiological and medical markers are tested inside the ATP. Blood tests should be taken 3-6 months to monitor how nutrition and training is impacting the overall AG athlete's health. BMR, VO_{2max} and aerobic threshold should be lab-tested at least at the beginning of the ATP to set a benchmark for future athlete-based assessments. Although body composition is not considered a key marker it is still recommended to assess regularly to regulate nutrition planning in conjunction with BMR and exercise caloric expenditure.

For AG Athlete we have an initial laboratory assessment of cardiorespiratory parameters as well as physiological measurements.

Nutrition and supplementation

While genes, talent, conditioning and coaching are key ingredients, nutrition plays an important role in the development and achievement of all endurance athletes (Burke, 2023).

Coyle (Coyle, 1999) prescribes intake of CHO, fat, and water based on physiological demands of the exercise. In addition to supporting exercise and recovery he also states that nutrition should prevent adverse effects such as dehydration and hyperthermia.

The general recommendation for macronutrients is:

- CHO-rich foods must provide the majority of the daily energy provision between 7-10g CHO/kg BM/day (Stellingwerff et al., 2007) and 3-12g CHO/kg BM/day (Mujika et al., 2014). This latter (3-12g CHO/day) is echoed by Burke (Burke, 2023) based on four different exercise intensity levels / day.
- Daily protein intake should be targeted at 1.5-1.7g PRO kg BM/day during periods of hard training
- During short-term recovery (<4h), to maximise glycogen re-synthesis rates, aim for ~1.2-1.5g CHO/kg BM/h

These recommendations are in line with practitioners' anecdotal suggestions (Fitzgerald, 2023):

- 4 servings fruit / day
- 4 servings vegetables / day
- Max 2 alcoholic beverages / day
- Eat before exercise
- Any workout lasting longer than two hours and any high intensity workout lasting longer than one hour will be aided by carb intake
- Carbs early in day to fuel exercises; protein late in day to help rebuild overnight

Carbohydrates

The importance of CHO as a substrate for exercise has formed a major principle of sports nutrition since the 60s (Burke, 2023). There are daily needs for macronutrient intake for exercise and recovery which may vary on training load and phase in ATP (Stellingwerff et al., 2007). A periodised ATP needs to be in line with nutritional aspects. Most notably the higher the training load the more CHO is required. Moreover low-CHO diets (3-15% energy) have

		General Prep		Specific Prep		Competition		Transition/R&R	
		Light	Heavy	Light	Heavy	Light	Heavy	Light	Heavy
Estimate weekly training volume	~km/week ~h/week	<100km 5-8h	>150km 10+h	<80km 4-7h	>130km 6-9h	<70km 3-5h	>90km 4-7h	<15km <2h	>50km 2-4h
Training intensity		low		moderate to high		tapered training volume and intense racing		very low to complete rest	
Recommended daily macronutrient intake ($g \cdot kg^{-1} \cdot day^{-1}$)	CHO FAT PRO	7 1.5 1.5	10 2 1.7	7 1 1.5	10 1.5 1.7	7 0.8 1.2	10 1.2 1.5	4 1 0.8	6 1.5 1.2
% of total daily energy intake	%CHO %FAT %PRO	~60% ~28% ~12%		~66% ~22% ~12%		~70% ~18% ~12%		~57% ~32% ~11%	
Total daily energy intake	kJ kcal	~13900 ~3300	~1900 ~4500	~12600 ~3000	~17600 ~4200	~11700 ~2800	~16600 ~4000	~8200 ~2000	~12400 ~2900

Nutrition recommendations for a 70kg athlete
(Adapted from Stellingwerff, 2007)

uniformly been shown to impair high-intensity and endurance-based performance (Stellingwerff et al., 2007).

Protein

Dietary proteins, are the crucial ingredient needed for building or rebuilding muscles during the recovery process (Porcari et al., 2015). Therefore, it could be hypothesised that protein intake after endurance exercise is necessary not only for the recovery and repair of damaged myofibrillar proteins, but also for the optimised synthesis of mitochondrial and possibly sarcoplasmic proteins. (Stellingwerff et al., 2007)

In support of increased protein consumption for exercise in AG athletes Friel (Friel, 2015) states:"While the number of studies on the topics of food, recovery, and aging is small, all of those studies seem to indicate that older athletes need more protein, especially during recovery, than younger athletes do. There is evidence to suggest that we don't synthesise protein as well as we get older, especially for the restructuring of the slow-twitch endurance muscles."

Athletes should consume protein intakes of 1.2 - 1.6 g/kg BM/day, however optimal intakes may be even higher up to 2.2 - 2.4 g/kg BM/day under scenarios such as lean mass maintenance during periods of energy restriction or injury disuse / rehabilitation (Burke, 2023). In fact protein intakes at the higher end of the recommended range generally maximises muscle remodelling and recovery outcomes regardless of other characteristics.

It is also suggested to spread protein intake over 4-6 meals / day. This includes post-workout and pre-sleep protein intakes (Burke, 2023).

Essential Amino Acids (EAA) are a portion of protein which the body is unable to produce. The latest position statement from the International Society of Sports Nutrition on EAA (Ferrando et al., 2023) provides strong arguments to prioritise EAA supplementation over other forms of intact protein:

- Supplementation of EAA increases muscle protein synthesis more than intact protein
- There is no upper limit to safe EAA supplementation although 15-18g / day seems plateau
- Repeated supplementation throughout day does not diminish effect of anabolic meal intake
- EAA requirement rise with caloric deficit and help preserve anabolic sensitivity
- EAA timing should be immediately before or after exercise

In conclusion protein and especially EAA should be supplemented to support recovery and muscle protein synthesis especially in AG athletes and particularly with a caloric deficit.

Fat adaption

A countermeasure to strategies that increase CHO availability is to promote other oxidative substrate sources that can extend of replace their finite contribution as muscle fuels (Burke, 2023). Ultramarathon runners report (Berger et al., 2023) that chronic high-fat diets markedly increase fat oxidation and negatively impact cost of running compared with high-carbohydrate diets during prolonged submaximal exercise. This may be true for ultra-running and other sporting events in which rates of energy production are low enough to be provided by fat oxidation or in which the athlete is unwilling of unable to support optimal CHO use, while for other sports the evidence from current performance-focused studies suggest that success is determined by better economy of ATP production from optimised CHO availability / oxidation (Burke, 2023).

Mujika recommends for marathon training, based on the mesocycle of the annual plan, to have at least one training session per week with low-CHO-availability to stimulate fat adaptation and simulate race-day fuelling. This is echoed by Casiraghi, based on recommendations from the European Sport Nutrition Society as a concept called “Train Low”. Under this concept it is promoted to train in Z2 in fasted state once a week for a duration less than 90 minutes (Hawley et al., 1997). The caveat is to avoid this concept if an athlete is often injured.

Stellingwerff (Stellingwerf, 2012) specifically for marathon runners suggests that even maximally adapted athletes may need to periodically undertake low-CHO-availability training to fully exploit endurance-training responses. These sessions were mostly morning training sessions. Jones who has worked extensively with Eliud Kipchoge also shared unpublished details on his training protocol which includes fasted runs in the morning; including a weekly 30km long run.

Stellingwerff (Stellingwerff et al., 2007) suggests that a fat-adaptation/CHO restriction protocol while training for 5 days, followed by a CHO loading day, resulted in a decreased use of CHO. According to Burke (Burke, 2023) robust retooling of the muscle to enhance the availability, transport, uptake, and utilisation of muscle lipids can occur in as little as 5-10 days of adaptation to a low CHO, high fat (LCHF) diet. However based on a case study (Stellingwerff, 2012) the portion of running at low-CHO-availability was very individual (10-35%) or 1-5 times per week as individually tolerated.

Nitrate

Already demonstrated in 2009 by Bailey (Bailey, Winyard, et al., 2009) beetroot juice (BR) reduced the O_2 cost of submaximal exercise and enhance the tolerance to high-intensity exercise. This finding is confirmed repeatedly and most recently by Tan (Tan et al., 2022):"During prolonged, constant-work-rate exercise, an upward drift in pulmonary O_2 uptake is typically observed. The oxygen cost of such exercise may increase with time due to a shift in substrate utilisation toward fat oxidation, a progressive recruitment of type II muscle fibers, or a decline in skeletal muscle mitochondrial and/or contractile efficiency. Ingestion of nitrate during exercise preserves elevated plasma nitrite and negates the progressive rise in O_2 uptake during prolonged moderate-intensity exercise. In conclusion, BR supplementation during exercise can modulate plasma NO_3 and NO_2 dynamics and attenuate the progressive rise in $\dot{V}O2$ during prolonged moderate-intensity exercise."

Not surprisingly NO_3 is classified as a nutritional supplement that can directly enhance athletic performance, a stance supported by the International Olympic Committee (IOC).

It was recently also researched if co-ingestion of beetroot with caffeine, CHO, citruline, and arginine might have additional beneficial effects (Ferrada-Contreras et al., 2023). Although there might be some benefits for endurance athletes of BR with citruline which would provide a performance boost in high-intensity exercise and reduced muscle soreness the evidence is still weak.

However despite limited research there is some caution on beetroot supplementation as it is known to be carcinogenic and that may also induce several other adverse effects. (Zamani et al., 2021)

Caffeine

The most recent international society of sports nutrition position on caffeine and exercise performance states: (Guest et al., 2021):

- Aerobic endurance has most consistent moderate-to-large benefits from caffeine use
- Caffeine has consistently been shown to improve exercise performance when consumed in doses of 3–6 mg/ kg BM
- The most commonly used timing of caffeine supplementation is 60 min pre-exercise

In Marcora's editorial (Marcora, 2016) the use of caffeine as a psychoactive drug helps to reduce the perception of effort and improves exercise performance.

Stellingwerff adds that CHO ingestion is supported by caffeine:"to maximise fuelling and hydration plan by consuming ~15 g CHO every ~15 min during the race, along with a total of ~3 mg caffeine/kg BM" (Stellingwerf, 2012). Casiraghi too confirms that caffeine with a dose of upto 40 mg /hour helps the absorption of CHO.

Iron

Iron helps us lift more in the gym. Specific to endurance sports iron contributes to oxygen transport in the blood (haemoglobin) and muscle (myoglobin) (Burke, 2023). In long-distance running the repeated, high-impact footfall, called foot-strike hemolysis, is suspected to damage blood iron. Moreover during endurance events gastrointestinal bleeding might occur. Hence iron deficiencies in ultrarunners are reportedly common and are also possible manifestations of undereating and relative energy deficiency (Berger et al., 2023).

Iron is amply available in legumes (e.g. lentils, soybeans, tofu, tempeh), grains, nuts, and other vegetables. Yet while plant-based diets actually have a higher iron content than meat-based diets the plant-based version of iron (nonheme) is less well absorbed.

Iron absorption is reduced when consumed with phytates, oxalates, and polyphenols, (present in tea and coffee) and calcium (Burke, 2023). Iron absorption can be increased by using a cast-iron skillet and by cooking greens in coconut or olive oil (Shorkey, 2020).

As long as legume-rich meals are consumed, spread over the day, and considering factors to increase and reduce absorption, supplementation is not recommended (Frazier et al., 2021).

Calcium

Calcium is most associated with the formation, strength and metabolism of bone. Bone health is a major concern for endurance athletes with low bone density and stress fractures being a common problem and serious injury (Burke, 2023). Although bone-loading exercise is associated with a chronic stimulus of bone formation there have been recent observations of a sudden decrease in blood ionic calcium concentration at the onset of acute exercise. A resection in such bone resorption may be achieved by consuming calcium-rich food or supplements in the pre-exercise period. The recommended dietary intake is 700 - 1300 mg / day.

Other Micronutrients

Other common supplements for athletes are:

- Creatine monohydrate is a safe and useful supplement to promote muscle strength. The general recommended dose is 3-5 g/day and will not lead to water retention or increase in fat mass (Antonio et al., 2021). Emerging evidence (Ribeiro et al., 2021) suggests greater benefits when creatine is consumed after exercise compared to pre-exercise. According to Guglielmetti it is recommended to do 4 weeks of wash-out after 8-10 weeks of supplementation.
- Latest research quoted by Casiraghi promotes inclusion of polyphenols to help oxygenise muscles. It is suggested to use cacao nibs or other nutrients with cacao.
- Fruit-based anthocyanin (e.g. Acai, blueberry) supplements have potential benefits for endurance to reduce muscle soreness and inflammatory damage (Burke, 2023) and require more investigation for endurance sports.
- Acute and multi-day bicarbonate supplementation has been shown to have performance benefits in middle-distance runners (Stellingwerff et al., 2007). However this seems not to have any impact on marathon running.
- Beta-alanine has also been studied and it leads to an increase in muscle carnosine. However the subsequent performance effects have not been obvious (Stellingwerff et al., 2007).

Although a varied plant-based diet provides the highest quality and well absorbed nutrients, for fully plant-based athletes there are some vitamins which are recommended (Frazier et al., 2021):

- Vitamin B_{12} promotes creation of DNA; it is manufactured by microbes in the soil and is plenty available in earth-based vegetables. However the cleaning process in modern food industry effectively removes this and it should be artificial reintegrated into a healthy diet. RDA: 300-1'000 µg / day
- Vitamin D is created by the body when exposed to sufficient direct sun shine; athletes living at higher latitudes and spending lots of time indoor are at risk of getting a Vitamin D deficiency. Vitamin D helps prevent muscle pain, bone loss and fatigue. RDA 1'000 - 2'000 IU
- Omega-3 fatty acids are crucial for brain function, help better mental focus, and are a powerful anti-inflammatory. RDA: 300 µg / day
- Iodine helps create essential thyroid hormones for healthy metabolism. RDA: 150 µg / day
- Vitamin K_2 is amply available in leafy greens and tempeh; still there is evidence that it is not sufficiently metabolised and supplementation is recommended. RDA: 50 - 100 µg / day

- Zinc helps the immune function. While it is amply available in vegetables, tempeh, tofu still we do not sufficiently metabolise it. RDA: 8 - 12 mg / day

Conclusion

While focusing on an overall healthy diet, the periodised ATP should include prescriptions on the total amount of calories per mesocycles and its percentage distribution of CHO, PRO, and fat.

While fat adaptation to use as a primary substrate might have benefits for slow-long runs and can be trained with fasted endurance runs, in all other cases CHO needs to be prioritised to meet energy demands of intense endurance training. In addition to support concurrent training also PRO and creatine are required to help build stronger muscles.

Macronutrients need to be supplemented based on AG athlete's need as plant-based runner and with a history of injury and REDS. The nutritional supplementation protocol is supplied in Appendix. Specific to competition and heavy workouts there is sufficient evidence to suggest the use of nitrate and caffeine.

Race considerations

Travel

In addition to travel fatigue jet lag is a key issue to be considered especially when travelling westward (Walsh et al., 2020). The duration of natural alignment is 0.5 days per time-zone crossed in a westerly direction, i.e. 2 h per day, and 1 day per time zone crossed in an easterly direction. However chronotype may also influence these responses as morning larks adapt better to eastward travel (easier to shift circadian rhythms earlier), whereas night owls adapt better to westward travel (easier to shift circadian rhythms later).

Although literature on management of travel fatigue and jet lag in athletes is limited (Janse van Rensburg et al., 2021) the consensus statement provides useful travel advise:

- Exogenous melatonin proves more beneficial when travelling east; dosages 3-5mg optimal
- Be well-rested before travel (e.g. sleep banking strategy)
- Replace long duration, high volume training which can be immunosuppressive with shorter duration, high intensity sessions
- Take naps when appropriate
- Utilise eye-masks, earplugs or noise-cancelling headphones and/or pillows
- Wear medical-grade compression and comfortable clothing
- Avoid alcohol completely
- Consume regular but smaller meals, nutritious fibre-rich snacks (fresh or dried fruit, high-fibre crackers, energy bars, trail-mix)
- Strategic caffeine intake during the local morning
- Training on arrival: at low to moderate intensity

Tapering

Tapering is the final stage of getting the athlete ready for an "A" race. According to Mujika:"Tapering does not make you faster from higher fitness but by reducing the negative impact of training, i.e. dissipate fatigue". Effects of taper are:

- Physiological changes have to be retained like running economy, VO_{2max}, muscle oxygenation, testosterone, red cell volume

- Psychosocial: reduction perception of effort, global mood disturbance, perception of fatigue, quality of sleep (Stone et al., 2023). However taper might also induce stress for athlete and coaches from the uncertainty of the outcome of the taper.

There seems high level of consensus of tapering strategy for highly trained athletes (Bosquet et al., 2007) and (Mujika & Padilla, 2003):

- Do NOT reduce intensity
- Reduce training volume 40-60% (even 60-90%)
- Taper duration is best two weeks; however individualise
- Use polarised, non-linear tapering
- Expect performance improvement of ˜3% (range 0.5 - 6.0%)

Four weeks prior to target marathons there must be a continual emphasis on CHO fuelling and fluid intake (Stellingwerf, 2012). As energy expenditure during taper is reduced be careful to decrease also nutrition consumption. However ensure that Iron levels and overall macro nutrient intake remains stable. During taper for marathon races following nutritional advise is given by Guglielmetti:

- Protein 1,2 - 2,0 g/kg BM
- CHO 7-12 g/kg BM
- Fat 0,9 - 2,0 g/kg BM
- Overall 32-40 g/kg BM

Event and pre-event nutrition

There is evidence to indicate that elevated starting muscle glycogen contents extend endurance in events lasting > 90 min (Hawley et al., 1997). This extended endurance benefit from pre-event carb loading is maintained also with CHO consumption during the event.

CHO-loading protocols were developed already in the 60s to increase (double!) glycogen stores and lasted for 6 days. The latest research has found that a well-trained muscle is able to maximise glycogen stores with as little as 24-36 hours of high CHO intake (Burke, 2023). However the recommendation is 36 - 48 hours of 10 - 12 g CHO BM per 24 hours. In addition CHO loading should be combined with a low-fibre dietary plan that reduces gastrointestinal contents over the days before competition while achieving muscle fuel goals. This practice minimises gut contents, reducing the risk of gut issues during the race, but also achieves a small reduction in BM (˜600g) to offset the mass of the additional muscle glycogen and stored water.

Research by Clark (Clark et al., 2019) emphasised the importance of CHO consumption during prolonged endurance exercise by showing that ingestion of 60 g/h CHO enabled end-test power to be maintained compared with a 9% reduction in end-test power when placebo was consumed. Jeukendrup (Jeukendrup, 2017) however has found that CHO absorption may exceed 60 g/h and suggests a new maximum of 120 g/h. Casiraghi explains that this is possible with modern CHO supplementation benefitting from two pathways SGLT1 and GLUT for fructose and glucose respectively. In fact for events over 2.5 hours Jeukendrup advocates 90 g/h of multiple transportable carbohydrates and nutritional training to help the gut adapt. This 90 g/h recommendation is echoed by Burke (Burke, 2023). Interestingly this 90 g/h seems to be the optimal dose; King (King et al., 2019) tested eleven trained cyclist for a time trial of 3 hours and provided doses of 80, 90, 100 g/h of CHO. The optimal performance was at 90 g/h dosage. However performance differences were small and so was sample size.

In addition to maximising the endurance performance with carbohydrate supplementation Coyle (Coyle, 1999) also states that such scheduled CHO supplementation needs to be practised. According to Stellingwerff (Stellingwerff, 2012) in the last 4 weeks before the athlete's target marathon CHO and fluid intake should be trained. Also Jeukendrup stresses that gut training needs to be included into the training schedule (Jeukendrup, 2017). This gut training helps to also counter flavour fatiguability from using the same CHO supplements (Berger et al., 2023).

Fluid intake for endurance events under normal weather conditions should be to thirst. In fact there is more evidence of over-drinking mostly in inexperience athletes than under-hydration. Burke (Burke, 2023) states that fluid mismatches during competitive events in elite sport mostly err on the side of a fluid deficit.

Priming

Priming helps perform immediately at the start of a race. The priming effect is scientifically defined as:"Pulmonary oxygen uptake kinetics were speeded when heavy-intensity exercise was preceded by a prior bout of a heavy-intensity warmup" (Goulding et al., 2023).

There is debate about the exact physiological mechanisms behind priming. However it seems that it works mainly on muscle O2 delivery, intercellular O2 utilisation, and motor unit recruitment.

Bailey provides promising benefits from priming (Bailey, Vanhatalo, et al., 2009):"The present data suggest that a protocol involving a 6-min bout of severe-intensity exercise followed by a 20-min recovery period, enabling baseline VO_2 to be restored and blood lactate to decline to 3 mMol, can significantly speed overall VO_2 kinetics and improve the tolerance to subsequent severe-intensity exercise by as much as 30%, an effect that appears to be linked to changes in motor unit recruitment."

This is echoed by Ingham (Ingham, 2013) who studied this on 17 800-m runners and the key finding is that for that race distance there is a benefit of 6 minutes high-intensity priming (mix of 50m sprints), followed by 15-20 minutes of recovery. However the effects of priming last for only up to 45 minutes.

Priming does not always result in better race outcomes (Goulding et al., 2023). In fact it is even reported that it might impede longer-term endurance outcomes. The authors speculate that events lasting > 30 min in duration, where critical power sets the upper limit for sustainable performance, are more likely to benefit from the performance of prior exercise.

Hence for a marathon priming might not be appropriate, instead regular warm-up seems to be more beneficial.

Conclusion

The main race consideration for Sydney is the travel across 12 time zones which will induce travel fatigue and jet lag. In addition to planning an early arrival for proper acclimatisation it is important to follow a strict routine to reduce physiological impact from travel. Tapering will start before travelling to Sydney and this will allow easier planning of the final week of race training.

Nutritional needs in final week before the marathon need to consider carb loading, race day fuelling, and in-race fuelling.

Sydney Marathon Training Plan

Introduction

The literature study builds our scientific foundations for developing an integrated annual training plan (ATP). In this chapter we will mostly rely on the work of Bompa to construct such training plan (Bompa & Buzzichelli, 2019). We will also include elements from Friel (Friel, 2015) who as a veteran coach has worked with many AG athletes and provides insights into how a non-elite AG athlete can best be trained.

This chapter will also highlight some of the key considerations for racing in Sydney by providing more insights about the competition and the athlete.

Athlete

In terms of race intensity and target setting the author is aiming for a sub-3 finish and fastest Hungarian AG finisher. Based on the previous edition on 17 Sept 2023 in the AG category 50-54 Male 688 participants finished and the top-10 time is 2:59:05. Moreover in the same AG category only one Hungarian finished at 5:06:19. The author has a PR of 2:55:42 at the London Marathon of 2023 placing him in the top 0.21% of AG runners (Nikolova, 2023). This is based on 35 million results collected in the last 20 years from more than 28,000 races.

When elaborating the ATP the athlete's desire to branch-out into 70.3 should be considered. Athlete is injury-prone hence a wider spectrum of exercises helps keep aerobic fitness up and reduce sports-specific overuse injury. As such swim and bike training should continue even in the competitive stages.

Finally it is worthwhile noting that author in addition to consuming a plant-based diet has a long history of injuries, most notably stress fractures, plantar fasciitis, REDS, and osteoporosis. This will be considered in the nutritional plan.

ATP

We are aiming for an annual training plan to peak with the "A" race in Sydney on 15 September 2024. We will use a monocycle ATP for this. This is appropriate for endurance sports with one major competition.

In general terms an ATP will have a sequence starting with strength to speed to endurance. This is reflected in the relevant phases of such cycle are:

- General Preparation - high volume of aerobic endurance to improve working capacity of physiological drive; intensity is second priority; competition is discouraged.
- Specific Preparation - sport-specific activities; towards the end of this phase the volume begins to progressively decrease, allowing for a gradual increase in the training intensity.
- Pre-competitive phase - unofficial competitions (tune-up races) in preparation for "A" Race
- Main competitive phase - maintain volume and intensity peak at 3 weeks before competition - longer rest within high-intensity exercise; stress should be undulating.
- Taper - 14 days of unloading; all extraneous activities which can contribute to fatigue should be removed and encourage recovery; 0- 2 strength sessions; include tactical elements and psychological preparation including relaxation, confidence, and motivation.
- Transition - starts immediately after main competition is completed and last 2-4 weeks with active and passive rest. Transition is not off-season; rather a bridge into next ATP.

Within the ATP we will implement following design guidelines:

- Undulating daily exercise load as expressed in ATL (train high/train low)
- Every 4 weeks an easy week with reduced weekly ATL

- CTL at 80-100 in preparation phase and to peak at 120 for Sydney
- Gradual increase in running mileage with max +10% per week
- Overall training volume: 800 hours / year
- TID: 65% LSD; 5% mid-intensity; 20 % high-intensity; 10% strength
- 600-1'000 metric ton of strength volume / year
- Consider travel fatigue and jet leg for travel to Sydney with reduced training load and mini tapering

Specificity for Sydney

In the case of Sydney the temperature in September is between 13-20C with a humidity of 50%. According to "The State of Running 2019" (Andersen, 2023) the ideal running temperature is 4-10C. Hence Sydney is quite close to ideal racing temperature which does not require heat adaptation. Moreover sweating will be at a normal rate, so there is limited need for increased hydration during the race.

Sydney is at sea level so also here there is no need for altitude adaption. Also the vertical race profile is between 5m and 45m over sea level. This is essentially one of the flattest major marathons which does therefore not require any specific hill training. There are however 10 u-turns (180 degree) in the race course (Jones, 2013) which will create significant slow down especially on fast, carbon shoes. It is worth considering what training adaptations can help with injury prevention and to reduce speed penalty of these u-turns.

However Sydney is on a time zone which is 11 hours ahead of London. With use of medical-grade melatonin the rule of thumb is to arrive at least 4 days before the race.

Finally with 30'000 participants (Jones, 2013) Sydney is a medium-sized marathon. In comparison with the Abbott Marathon Majors this is still a relatively small race. Also the streets of Sydney centre are quite wide so overcrowding should not be an issue, especially for faster runners at the front of the masses.

Objectives

Shown below are in order of priority the top-10 objectives for Sydney and the overall ATP.

Item	Factor	Objective
Performance	Race time	Sydney < 2:55
	Place	Top-10 in AG and fastest Hungarian runner
Physical preparation	Strength	Squat at 1.2 x BM (1RM) (or mStrength)
		Deadlift at 1.2 x BM (1RM) (or mStrength)
	Speed	30-sec hill sprint at 500W
	Flexibility	Complete Ashtanga Primary Series once a week
Skill	Drafting	Ability to draft at MP
	U-Turns	Ability to pickup to MP after U-Turn
Psychological preparation	Focus	Ability to focus without interruption on running form
Nutrition	Gut training	Ability to consume 1 gel / 17 minutes

ATP Objectives

Annual Training Plan

For every stage of ATP for key Areas we will define priorities to focus on. These are inserted in the Run … Other areas and can be found in the full Annual Training Plan. We will highlight the key priorities here.

Run

During general preparation focus is on aerobic threshold and capacity; this is best achieved by a combination of 4 weekly run workouts out of which 1 Fartlek, 1 LSD, 2 HIIT. The 2 HIIT will consist of 10x 30-sec of hill sprints and 1+ minute aerobic intervals. The Fartlek helps challenge the physiological systems while eliminating boredom. Although we will focus more of fat-adaption in later stages we will execute the LSD in fasted state.

In specific preparation the focus shifts to lactate threshold. This will be trained with 4 weekly runs and the most important workout is the 1+ minute intervals. We will seek to add most intensity here. The other HIIT remains the hill sprints which we will increase to 12x 30-sec. The LSD remains important and we will add mileage gradually to get to 20-30 km / run. Fartlek remains for the fun component.

In both competitive stages the focus is on lactate threshold; we will further prioritise and add intensity to the long aerobic intervals, keep the hill-reps constant, add more mileage and intensity (pace) to LSD. As required the Fartlek can be replaced by another LSD mid-week. We should also aim for at least one fasted LSD run.

The workouts have differing intensity profiles and will be phased to allow microcycle rhythmicity. To add even more variation we will use various formats of workouts from the 80/20 templates. Also we will try to stay below 70 km of weekly mileage for injury prevention. If we feel very healthy and there is no counter indication from medical test we will peak at 90 km mileage.

In terms of ATP and skill development:

- In addition to aerobic capacity the hill-reps will also help build capacity for sprinting after the Sydney u-turns.
- The ability to draft behind other runners and benefit from reduced wind drag will be tested and honed during the LSD runs and also as part of the four run competitions in ATP.

Strength

In preparatory stages we will commit to 3 weekly strength sessions. However in this 18-week block we will move from more general all-body strength to focusing all three weekly sessions with at least 2 glutes/quad workouts. Also while there is an initial investment into anatomical adaption (AA) as this is mostly covered in transition we will focus mostly on maximum strength (MS).

In the competitive stage we will reduce from 3 to 2 weekly session and focus on maintaining the peak maximum strength built at the conclusion of the specific preparation.

In taper we will focus on rest and recovery so in these final two weeks we will reduce to 1 strength session in first week of taper and zero strength in last week of taper.

All strength exercises are as much as possible free-weight with 4 reps at 80% 1RM.

Cross-training

As mentioned the objective is a sub-3 time at Sydney, so the focus clearly is on running with a well-maintained injury risk. With cycling being the sport with most similarities to running we will have 3 weekly cycling sessions. These are mostly intervals to keep adding aerobic threshold and capacity.

Swimming is much less transferrable to running however with the desire to transfer in 2025 towards triathlon we will keep two weekly swim sessions and focus on HIIT and quality technique execution.

Finally time-permitting there is one weekly yoga session. This is on the rest day. Yoga does not stress the aerobic system however it helps with recovery and injury prevention by strengthening muscles and ligaments. Moreover yoga helps build capacity for attentional control (mind training). All yoga sessions will be in fasted state to keep practicing workouts while fasting.

As races are on Sundays, when there is a race this takes precedence over yoga workout.

Psychological

The ATP will also help hone existing psychological skills like goal setting, dissociation skills (counting to 100, smile at strangers, focusing on Atman, body-checkin during run), and attentional control (mainly yoga & breathing). We will also include a checking of the 4Cs are repeat and remind why this is important:

- Challenge - be fastest Hungarian, top-10 AG runners to finish Sydney sub-3
- Commitment - follow the ATP and put in the required love and intensity into each workout
- Control - while life-work balance and family life is important make time for sport
- Confidence - I have done this before, I can do this again and better with EPEP skills

In the main competitive phase we will learn the Sydney run map: what are the key sights & landmarks, what are the names and characteristics of the main streets, where are the hills, where are the u-turns, and how does the start and finish area look like in detail. Moreover we will visualise the smells, sounds, crowd of the race. Finally we will add in some dedicated training to accelerate out of u-turns while counting to 10 before falling back into MP.

Taper can bring stress due to the lack of training and the associated fear of losing preparation, we will recognise this and ensure we stay strong and on course.

During the race and in all other preparation competitions we will also test other psychological tools for mind endurance: association (i.e. focus on gait, stride frequency, technique, pace), positive self-talk in second person (i.e. you've got this), and flow in the form of prayers.

Nutrition

In the preparatory phase we need to ensure sufficient CHO for the intense workouts (run, cross-train, and strength). As intensity differs between days we will also adjust CHO intake accordingly. Protein is well-integrated into the diet and spread over the day focusing also on evenings to help recovery.

In addition to cycling CHO based on training load a full list of supplements is provided. For those morning runs that are carried out in fasted state the pre-run nutrition consists of: shot of concentrated beetroot, calcium supplement, espresso, medjool date.

In the competitive stages we focus on maintaining maximum strength while reducing to <10% BF. This is achieved by increasing PRO for lean mass maintenance. This will be supported by even more fasted runs.

In the main competitive phase we will continue to keep body composition stable and fine-tune, however the focus is on gut training by using same quality, quality of gels as during Sydney race.

Gut training continues into taper, but especially in the last days before the race we will focus on topping-up responsibly glycogen stores (while focusing on BM) and limiting fibre intake to avoid gut distress during race. Clearly all this is also tested during the tune-up marathon race in Munich.

Testing and Medical Measurements

Summarised in the table below are the key parameters we want to test at regular intervals to see if/how we are progressing towards being able to realistically meet our objectives. Testing against these measurements should occur in the last week of each mesocycle. In addition there will be a formal lab test in CW 16 at Pavia University and if possible at the end of the ATP.

Test	Measure	Measure	Base	CW 11	CW 16	CW 23	CW 30	CW 41	Goal
Running Power	CP	W	292	318					307
	30-sec Power	W	409	477					500
Physiology	VO_{2max}	mL/kg/min	48.9						60.0
	LT	% VO_{2max}	75%						85%
	RE	mL/kg/min	NA						43.0
Strength	Glute	mStrength	88	78					95
	Quadriceps	mStrength	67	62					95
Body composition	BM	Kg	75	74					68
	Body fat	%BF	8.7						<10
Pulmonary power	Powerbreathe	cmH_2O	182	173					200

Testing Battery

In addition to these formal five test dates we will also track progress on training, recovery, body composition within WKO5. Most data is collected using Garmin sport watch supplemented with manual input for rest and recovery markers which are captured every morning into TP. As shown in appendix there is a dashboard for weekly tracking:

- Training load & stress - ATL as indicator for training stress versus RHR & HRV as indicator for physiological adaptation and to avoid overtraining
- Recovery from sleep and overall feeling as indicators for passive recovery
- Weekly mileage vs Injury as indicator for injury risk
- Body composition as indicated by training caloric expenditure, RMR, BM and skinfold
- TID as percentage of runs in Moderate, Heavy, and Severe domains augmented with time spent on strength training and yoga
- Evolution of Pulmonary strength
- As a reference we are also displaying all past races in reverse order focusing on the World Marathon Majors, followed by all other run races
- Finally we also show the CTL

Physiology

As per Jones (Jones, 2023) and Joyner (Joyner & Coyle, 2008) we will measure the big three physiological measures. However as this can reliably only be tested in a sports lab with calibrated equipment we will only be able to test at the beginning and completion of the ATP. However we will use Calibre-based VT assessments with same 3-min incremental protocol on treadmill (1% incline).

We have a baseline from 28 April 2023 however and despite lab-testing there is reasons to believe the generated dataset is unrepresentative. Moreover RE was not assessed. Yet as these are the only data points available we have still listed these in table.

The goal values are based on a combination of data points from (Jones, 2023) and (Barnes & Kilding, 2015a) which were considered realistic for an AG athlete without a lab-validated base point.

Running Power

Critical Power is our most important aggregate measure for marathon running; Stryd predicts that for a 2:55:00 marathon at 75kg 307W is required. This is achievable as current CP is 292W, while for Tokyo marathon (2023) average was 283W; London marathon (2023) average was 277W. Moreover decreasing BM in competitive phase will lower CP requirements for sub-3 marathon.

We have also included a 30-sec power target of 500W. While we fully appreciate that sprinting power is not a priority in steady-state marathon running the Sydney race course with it's 10 U-turns warrants us to build and maintain a strong sprinting base to accelerate out of these turns.

As seen there is a strong correlation between LT2, CV and CP. If we assume that Stryd is the most accurate power-measurement tool for running then CP should be used as best proxy for running power. Moreover in combination with Caliber this will be our best approximation of the three physiological measures.

Stryd uses two different protocols for determining CP. Initial testing requires three runs over 2 weeks with 3 all-out intervals of 8, 15, and 2 minutes respectively. Ongoing testing can happen in the same test week with 2 all-out intervals of 3 and 20 minutes respectively.

Strength

The two most important muscles for running are glutes and quadriceps. FitBod allows us to assess their strength in a continuous fashion from a range of different strength exercises which work these muscle groups.

However the measure is a compound measure which cannot be independently verified. Moreover when progressing through the stages in the training cycle we will increase specificity and focus more on explosive power (maximum force development). This too is not yet clear how it will be determined inside the mStrength measure. If this measure cannot be used we will fall-back to 1RM calculated for squat and deadlift as assessed from a 4-rep maxed exercise.

The mStrength measure is on a range of 1-100 with 100 being the top-1 percentage of all athletes using FitBod. We have no method to determine what is a good parameter for running performance and what is the comparison athlete population, so this parameter is admittedly selected without reference points.

FitBod has been contacted for clarification on using mStrength for these purposes.

Body Composition

We are aware that there is no scientifically demonstrated correlation between body composition and running performance. However with a reduction of BM while retaining the key physiological adaptations will result in better VO_{2max} and RE. As such in competition phase we will focus on a gradual reduction of BM and BF%.

The assessment of BM will be done via averaging 5-day BM measurements using Garmin S2 scales always in the morning after a run. While this electronic scale provides a calculated BF% approximation we will rely on 7-site skinfold measurement with Harpenden Callipers using the Jackson & Pollock method (Norton, 2018).

Pulmonary Power

PowerBreathe IMT provides a testing function which assesses based on one strong exhalation the pulmonary capacity expressed in cmH_2O. We will take three measurements on three days after morning exercise and take the mathematical average. If there are outliers we will retest on the same day.

The target number of 200 cmH2O has not been validated to be a strong indicator for running success. According to PowerBreathe the current 182 is already an excellent result and the 200 is very high and may not be achievable for AG athlete. They also questioned if that increase will have marginal impact on RE.

Medical

With high-injury risk and past medical events we will execute one blood test every 3 months and one chiropractor full check-up 2 weeks before major events. We have been using the same chiropractor for 7 years who is fully aware of the focus areas and past injuries.

The blood tests are carried out with the same laboratory so results are comparable and we will mostly focus on the evolution of key blood markers which in the past caused medical concern, mainly thyroid function, cholesterol, and creatinine.

In addition at the end of the transition phase we will do another blood checkup. This only leaves 4 weeks after Sydney marathon. It is known that blood markers due to the immunosuppressive outcome of marathon running for a number of weeks might be compromised. Hence we will seek advise on best duration for blood testing.

Races

We need to select tune-up races in preparation of Sydney. While we recognise that London 10K and Lisbon HM are in the general preparation phase - where usually we want to avoid racing - these are "C" and "B" races more for fun and overall fitness. It’s important to reduce injury risk and jeopardise the rest of the ATP.

Similarly Venice 70.3 and Pisa TT are fitness-centric "C" races. Moreover they not run-specific meaning they would incur a lower injury risk.

The only full marathon in the northern hemisphere which is useful timing-wise is a small semi-road race close to Munich. The limitations are: field size and depth, level of crowd-support, uncertainty of terrain, and lack of testing u-turns. With 8 weeks before Sydney however timing wise it is correct.

After Sydney marathon and the ATP transition phase we will look for foot races in October - December to benefit for the peak developed for Sydney.

Date	CW	Race [City - Name (Distance)]	Priority	Gap (Wk)
25 February	8	London - Winter Run (10 km)	C	
17 March	11	Lisbon - Superhalf (HM)	B	3
5 May	18	Venice Jesolo - 70.3	C	7
9 June	23	Calci - TT - Trittico del Serra	C	5
20 July	29	Füssen - Königsschlösser Marathon	B	6
15 September	37	Sydney - Marathon	A	8

Prioritised race plan 2024

Final considerations

Travelling to Sydney is long and requires a stop-over. We will use this stop-over in Singapore to help acclimatise to temperature, time zone, and use as a relaxing during taper. Flying will be supported by compression garment to keep muscles and ligaments rested. Travel back will be the day after the race to allow for a big, protein rich meal and a well deserved celebration.

Learnings and Recommended Further Research

Developing this paper and going through the most recent and relevant research on endurance sport has provided many insights especially when applied to AG runners. The key learnings are:

- How to build an Annual Training Plan
- Workouts need to be administered in polarised fashion
- Different type of run workout target different parts of Joyner model with HIIT most relevant
- Critical Power is a good athlete proxy for the Big Three physiological parameters
- Phased strength training is part of ATP with low reps and high intensity
- Train high and low (weekly microcycles)
- Recovery needs to be part of the training plan, with personalised monitoring
- Cross-training supports run training while reducing overall injury risk

There are a number of areas where additional scientific or practitioner research was not identified and might help future athletes on a similar journey:

- After athlete has carried out VT1, VT2, VO_{2max}, RE testing we would benefit from AG-specific ranges and recommendations on what training interventions for best outcomes
- How strong is the correlation between CS vs. CP and how well aligned is the Stryd-measured CP compared to laboratory based physiological markers
- What are the best strength training exercises, what would be target weights (x% of BM), and how to test (e.g. split squat and lunges)
- Can, how, and to what degree VO_{2max} be increased by IMT
- What other mobile apps are there which might be a better fit with the science-oriented approach; recently we have seen following:
  - BET - Rewire, Neuronation, Eargym
  - Mindfulness: Champion's Mind, Headspace
  - Recovery: Recover, Dynamic Triathlon
  - Strength training: Fitness AI, Freeletics
- While the need for BET is recognised there are little concrete and practical interventions which have also been independently tested for effectiveness with endurance athletes
- How can CWI be inserted into ATP; while there is evidence to support recovery benefits it's also attenuating muscle adaptation. When and how to plan for endurance athletes
- Modafinil is a schedule-4 drug which in the UK can be sold over the counter. While it's effect seem supportive of countering mental fatigue there is no research on endurance athletes
- Beetroot juice is supportive of increased aerobic performance, but can it be used on a continuous based, for what duration is it safely consumed and is a washout period required
- Creatine monohydrate supports muscle hypertrophy and strength; should it's administration be training stage-specific and include washout
- Polyphenols are recommended to help oxygenise muscles, yet they seems to counter effect of iron supplementation. So should this supplement be integrated and how.
- Intensive endurance training and racing are immunosuppressive and alter blood markers; when is the best period for blood testing
- Yoga needs to be better studied for its support with recovery, managing mental fatigue, injury prevention from restoring muscle flexibility and length, and its overall effect on endurance sports

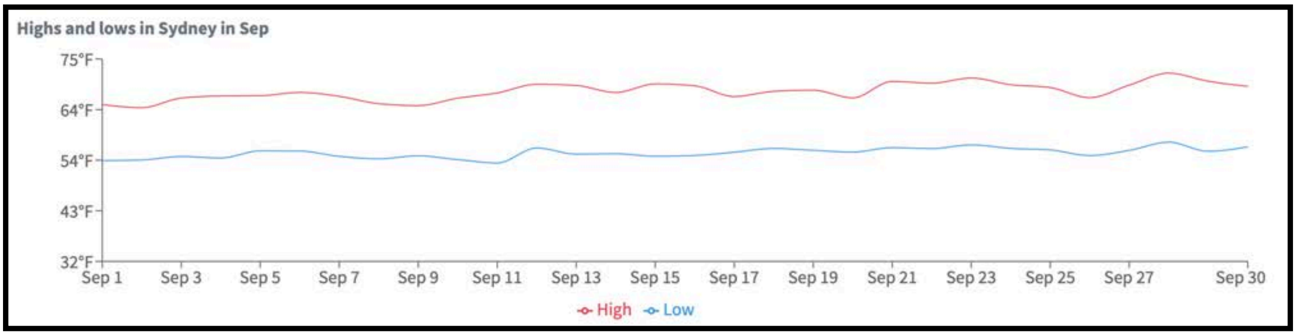
I. Abbreviations

Acronym	Full text	Explanation
1RM	One (1) Rep Maximum	Maximum amount of weight that a person can possibly lift for one repetition
70.3	Half IronMan distance triathlon	Triathlon with 1.9km swim, 90 km bike, 21.1 km run
AG	Age Group	Gender-specific cohort of amateur athletes in same age range; typically expressed as 50-55 yo.
ASRM	Athlete Self-Report Measure	Monitoring tool for recovery assessment
ATL	Acute Training Load	Single number expressing the intensity x duration of day with multiple exercises
ATP	Annual Training Plan	Integrated training plan for an individual athlete for one discipline which covers usually one calendar year / sports season
ATP	Adenosine Triphospate	Nucleotide that provides energy to drive and support many processes in living cells, such as muscle contraction
BCAA	Branch-chain amino acids	Three of the 9 Essential Amino Acids (EAA): Leucine, Isoleucine, and Valine
BET	Brain Endurance Training	Gadget or mobile app which induces central fatigue; usually training is concurrent to physical exercise to increase mental fatigue resistance
BF%	Body Fat %	Total mass of fat divided by total body mass, multiplied by 100
BM	Body Mass	Naked athlete weight expressed in kg
BMD	Bone Mineral Density	The amount of bone mineral in bone tissue. Low BMD is osteoporosis or osteopenia. Low BMD can lead to stress-fractures, esp in impact sports like running.
BMR	Basal Metabolic Rate	Rate of energy expenditure per unit time by endothermic animals at rest. It is reported in energy units per unit time ranging from watt to ml O_2/min
BP	Block periodisation	Sequential and specialised training blocks
BR	Beetroot	Purple vegetable rich in nitrates
CGM	Continuous Glucose Monitoring	Monitoring blood glucose on a continual basis instead of periodically by drawing a drop of blood from a finger
CHO	Carbohydrate	One of three macronutrients (with PRO and fat) responsible for supporting fast-energy (ATP cycle)
Cr	Cost of Running	Oxygen consumption (mL/kg/min or mL/kg/km) -OR- Energy use (kcal.kg/min or J/kg)
CPET	CardioPulmonary Exercise Testing	Laboratory test to assess mainly VO_{2max}
CS	Critical Speed	Speed at which an athlete is at VT2 / LT2 hence can maintain for 30 minutes

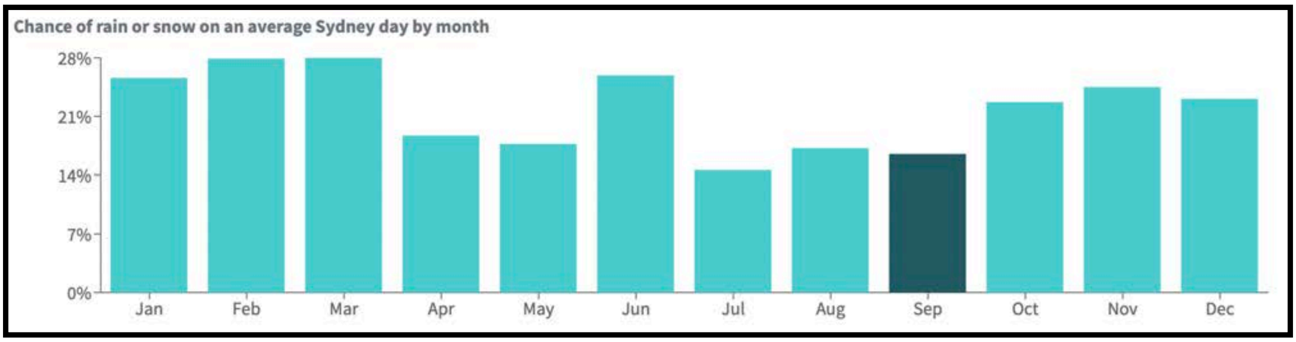
Acronym	Full text	Explanation
CTL	Chronic Training Load	Weighted sum of 42-days of ATL expressing the accumulated training load from last 6 weeks of exercise
CW	Calendar Week	Week (starting with Monday) in a calendar year (1-53)
CWI	Cold-water immersion	Recovery protocol of 10-15 mins immersion in 10-15C water
EAA	Essential Amino Acids	Amino acid that cannot be synthesised from scratch by the organism fast enough to supply its demand, and must therefore come from the diet. There are 9 EAAs
EPEP	Exercise Physiology and Endurance Performance	One-year Masters' degree course at Pavia University
HIIT	High-Intensity Interval Training	Training protocol alternating short periods of intense or explosive anaerobic exercise with brief recovery periods until the point of exhaustion
HRV	Heart Rate Variability	Difference in HR during the day; variable is highly individual and provides an indication of good recovery (increasing HRV) or limited recovery (decreasing HRV)
IM	Iron Man	Triathlon with 3.8 km swim, 180 km bike, 42.2 km run
IMT	Inspiratory muscle training	Training of lung volume and power by inspiration into a tool which can modulate air throughput
IU	International Units	Unit of measurement for the effect or biological activity of a substance, for the purpose of easier comparison across similar forms of substances (e.g. vitamins)
LCHF	Low-carb High-fat	A form of diet which promotes fat utilisation in steady-state long term endurance events at lower intensity levels
LIEE	Low-Intensity Endurance Exercise	Exercises aimed at increasing aerobic fitness
LSD	Long-slow duration	Running at conversational pace - high volume / low intensity
LT	Lactate Threshold	The exercise intensity at which the blood concentration of lactate and/or lactic acid begins to increase rapidly
MP	Marathon Pace	Speed at which an athlete trains and executes a marathon-distance race. For a sub-3 marathon MP is 4:12 min / km
PB	Personal Best	the fastest time you've clocked for a certain race, distance, or run
PCr	Phosophocreatine	Phosphorylated form of creatine that serves as a rapidly mobilisable reserve of high-energy phosphates to recycle adenosine triphosphate, the energy currency of the cell.
PI_{max}	maximal peak inspiratory mouth pressure	Highest level of pressure applied to the lungs during inhalation
PR	Personal Record	It refers to your fastest time for a specific distance or timed running event
PRO	Protein	One of three macronutrients (with CHO and fat) responsible for muscle recovery. BCAA/EAA are forms of protein

Acronym	Full text	Explanation
RDA	Recommended Dietary Allowance	Daily dietary intake level of a nutrient considered sufficient by the Food and Nutrition Board of the Institute of Medicine to meet the requirements of 97.5% of healthy individuals in each life stage and sex group
RE	Running Economy	Sum of metabolic, cardiorespiratory, biomechanical and neuromuscular efficiency during running expressed in mL/kg/min at a given test speed (e.g. 14 km/h)
REDS	Relative Energy Deficiency Syndrome	Is a syndrome in which disordered eating (or low energy availability), amenorrhoea/oligomenorrhoea (in women), and decreased bone mineral density (osteoporosis and osteopenia) are present
RHR	Resting Heart Rate	Heart rate immediately after waking up; RHR is an indicator of recovery
ROM	Range of Motion	Angular distance and direction a joint can move between the flexed position and the extended position
RPE / sRPE	Relative Perceived Effort (Session)	Athlete provided effort on scale 1-10 (low-high) for any given workout
S&C	Strength & Conditioning	Practitioner's lingo for strength training specific to one sport
SDT	Self-Determination Theory	Macro theory of human motivation and personality that concerns people's innate growth tendencies and innate psychological needs.
SF	Stride Frequency	Number of times one leg touches the ground per minute
SL	Stride Length	Distance traveled (m) during one stride
TID	Training Intensity Distribution	Split of overall training volume by exercise intensity
TSB	Total Stress Balance	Chronic training load minus acute training load - as an indicator for race readiness
TSS	Training Stress Score	The acute stress from one specific workout
TST	Total Sleep Time	Total time in sleep excluding waking time
VO_{2max}	VO2 max	is the maximum rate of oxygen consumption attainable during physical exertion
VT	Ventilatory Threshold	Point during exercise at which ventilation starts to increase at a faster rate than VO2

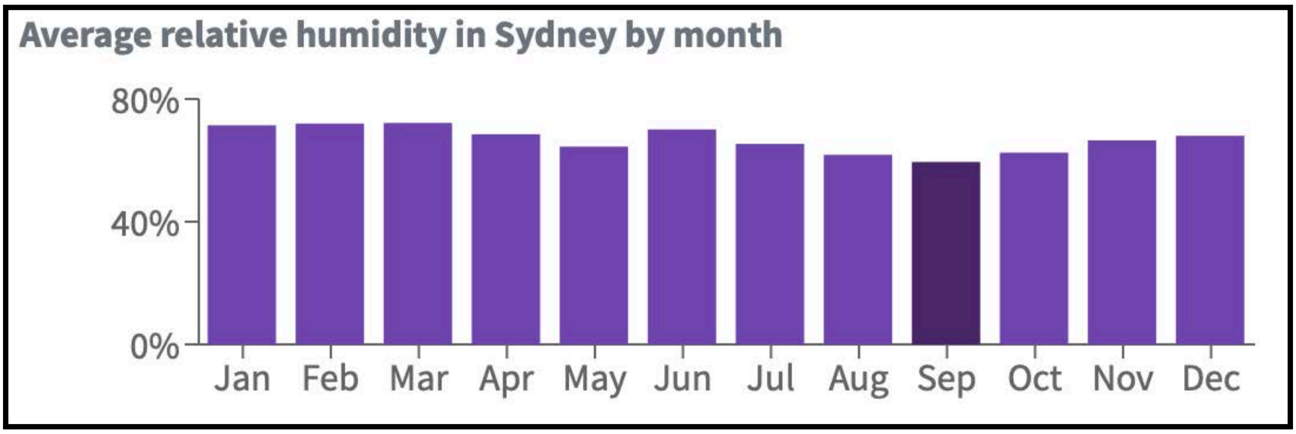
II. Sydney Weather Conditions



Average daily temperature (source: Wanderlog)

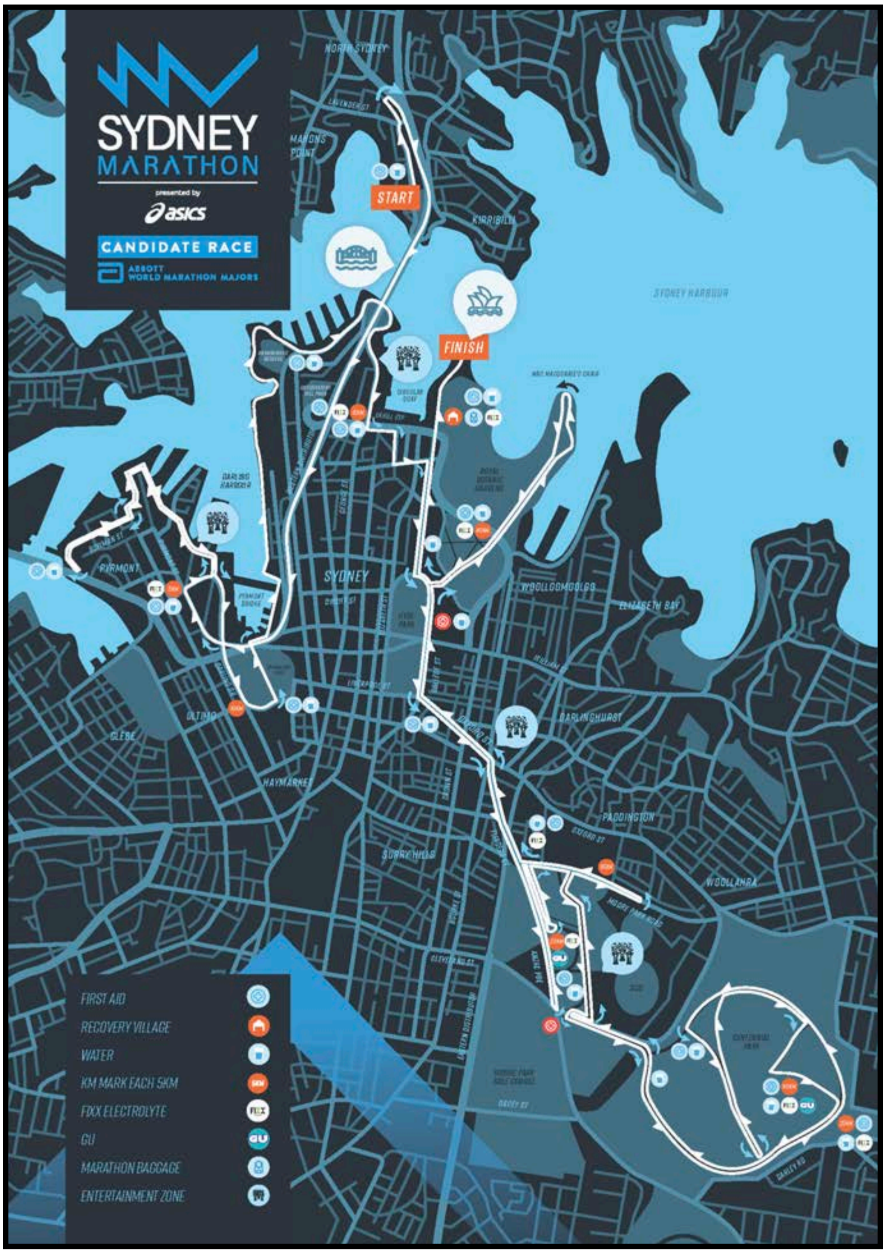


Chance of Rain (source: Wanderlog)

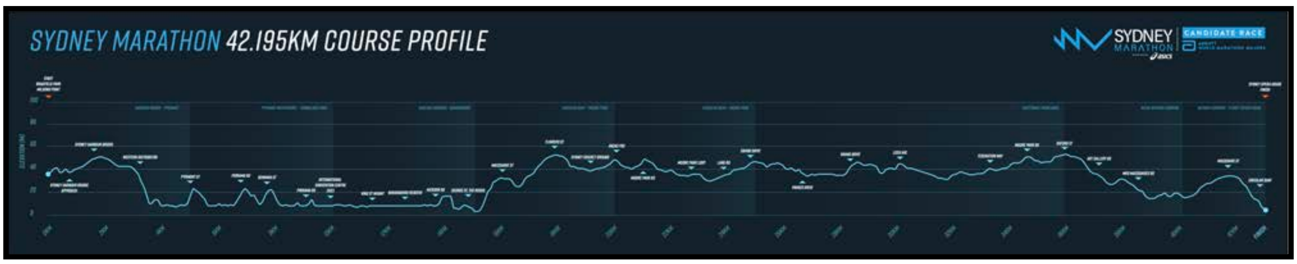


Average relative humidity (source: Wanderlog)

III. Sydney Race Profile



Marathon race map (source: official Sydney Marathon site)



Marathon course profile (source: Sydney marathon official website)

IV. Sydney 2023 Results

Below are the AG and by nation results of the Sydney 2023 marathon race. It's worthwhile noting that in 2023 Sydney was not yet nominated as an Abbott candidate race for inclusion into the World Major Marathons, hence it's appeal to AG athletes was less compared to this year's competition.

Sydney Marathon: M50-54							
Pos	Name	Gun Time	Net Time	Representing	Overall Pos	Gender (Pos)	
1	Luke Grattan (#4501)	02:40:39	02:40:38	AUS |	53	Male (42)	
2	Antony Rickards (#1853)	02:43:50	02:43:46	AUS |	71	Male (60)	
3	Daniel Hopkins (#1928)	02:48:55	02:48:50	AUS |	100	Male (85)	
4	大介 植田 (#7532)	02:51:36	02:51:33	JPN |	125	Male (108)	
5	Andrew Cross (#3865)	02:52:46	02:52:41	AUS |	135	Male (118)	
6	Baden Reynolds (#6371)	02:53:39	02:52:17	AUS |	138	Male (121)	
7	Jamie Irving (#4873)	02:56:30	02:56:15	AUS |	182	Male (162)	
8	Chris Hartwig (#135)	02:56:58	02:56:54	AUS |	190	Male (169)	
9	John Price (#6261)	02:57:50	02:57:40	AUS |	207	Male (185)	
10	Justin Smith (#138)	02:59:08	02:59:05	AUS |	239	Male (215)	

Sydney 2023 AG results – top-10 finishers

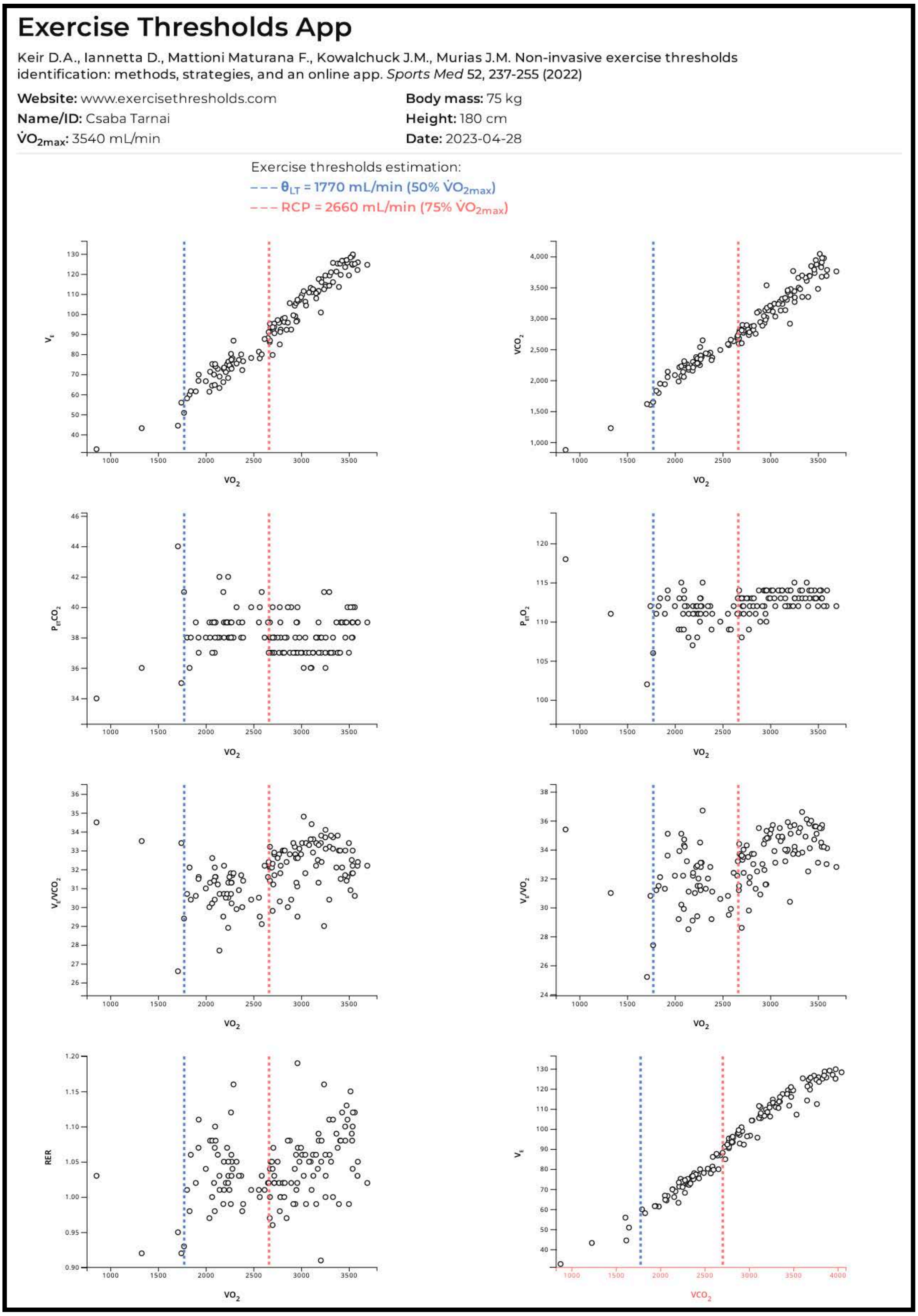
Sydney Marathon: Hungary							
Pos	Name	Gun Time	Net Time	Representing	Category (Pos)	Gender (Pos)	
1	Zoltan Torok (#17828)	05:14:19	05:06:11	HUN |	45-49 (627)	Male (6865)	

Sydney 2023 Hungarian finishers

V. Cardiorespiratory Parameters

VT1 1720 mL/min @ 11km/hr | VT2 3220 mL/min @ 14km/hr

VO_{2peak} 3665 mL/min @ 15km/hr | VO_{2max} 48,9 mL/min/Kg



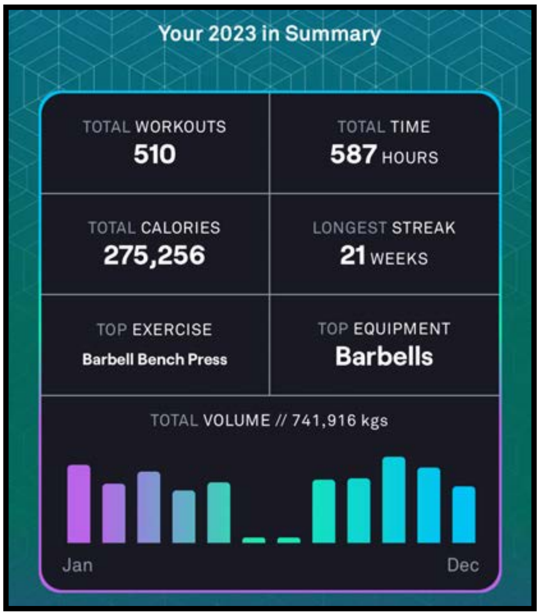
Csaba Tarnai cardiorespiratory report (28 April 2023)

VI. Physiological Considerations

The Harpenden caliber is used for skinfold measurements (Norton, 2018). These measurements are tracked at the end of mesocycles using below table. In addition skinfold is also uploaded into the TrainingPeaks metrics.

Method / Tool		16 Dec 2023	22 January 2023		
Harpenden Skinfold measurement (mm)	Triceps	7.0 mm	7.0 mm		
	Chest	2.9 mm	4.9 mm		
	Subscapular	8.0 mm	8.0 mm		
	Midaxillary	5.1 mm	5.1 mm		
	Abdominal	6.0 mm	6.3 mm		
	Supariliac	4.2 mm	6.0 mm		
	Thigh	7.1 mm	7.8 mm		
Garmin S2	Weight (kg)	74.4 kg	76 kg		
	Muscle Mass (kg)	30.6 kg	30.9 kg		
	Water (%)	60.9%	57.5%		
	BF (%)	16.5%	21.2%		
	BMI	23.0	23.5		
Calculation	**Weight (lbs)**	**164.0 lbs**	**167.6 lbs**	**0.0 lbs**	**0.0 lbs**
	Total skinfold (mm)	**40.3 mm**	**45.1 mm**	**0.0 mm**	**0.0 mm**
	BF (%)	**7.9%**	**8.7%**	**0.0%**	**0.0%**

7-Site Skinfold (Jackson & Pollock) Protocol



Tracking of Volume per Year in FitBod

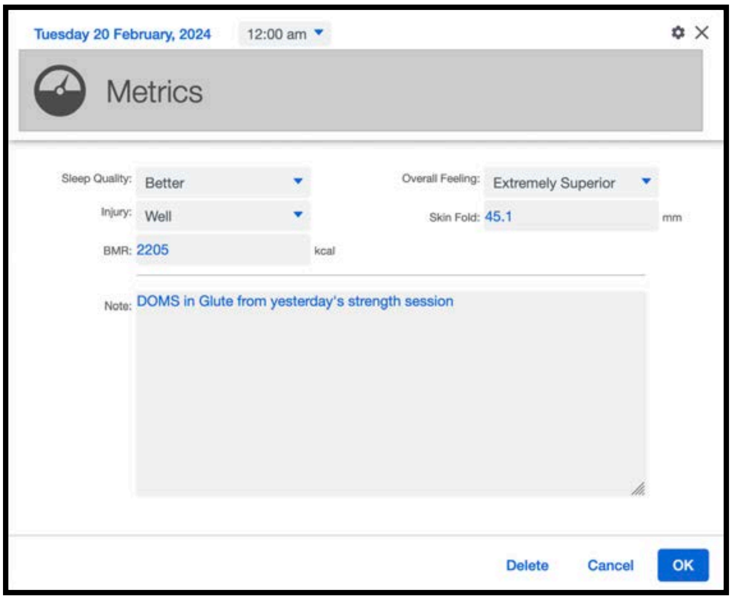
VII. Supplementation Protocol

Timing	Supplement / Nutrition	Daily quantity
1st breakfast	Calcium	1'348 mg
Pre aerobic workouts	Nitrate	400 mg
	Citrulline mallet	3 g
2nd breakfast	D_3	30 µg (1'200 IU)
	K_2	120 µg
	B_{12}	20 µg
	Iron	9 µg
	Zinc	7 µg
	Iodine	120 µg
	Omega-3	**352 mg**
	DHA	*207 mg*
	EPA	*123 mg*
	DPA	*22 mg*
	Whey isolate	25 g
Snack Cacao Nibs (15 g)	Potassium	73.5 mg
	Magnesium	57.3 mg
	Iron	0.5 mg
	Copper	0.4 mg
Post strength workout	Creatine monohydrate	5 g
	EAA	25 g
Pre-sleep	Kiwi fruit	2 pieces
	Parmesan Cheese	50g
	Benecol yoghurt drink	
BMD Medication	Alendronic Acid	70 mg / week

Daily dietary supplementation

VIII. Tracking Physiological Parameters

Key physiological parameters are tracked in TrainingPeaks and visualised in WKO5.



ASMR in TrainingPeaks

Performance monitoring in WKO5

IX. Powerbreathe Training Protocol

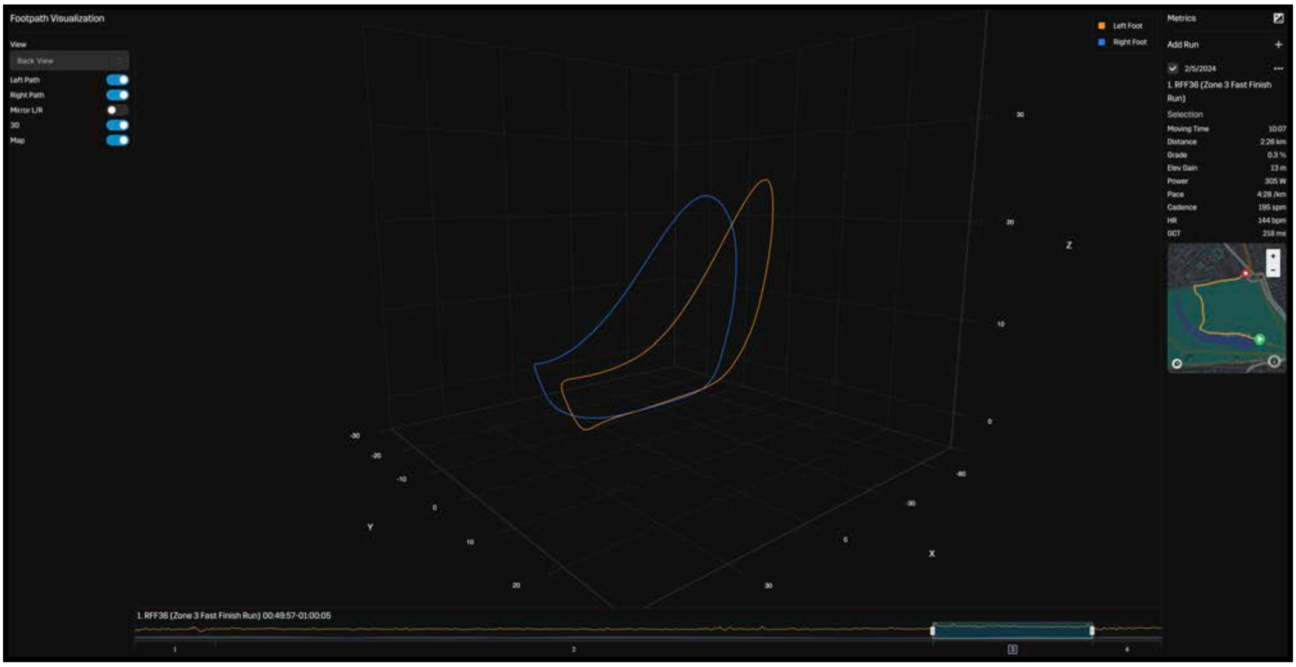
There is no formal Powerbreathe training protocol however one of their key employees with a scientific and running background suggested following protocol

- I do the training standing as you are training for a running event not rowing.
- Your maximum training load will eventually hit a ceiling just as you would lifting weight in a gym, you can't increase forever. Mine was 85 cmH2O load but I could still do the volume I usually did which was 5.2 litres, only 4.2L when I started. These figures obviously vary from person to person.
- Maintaining a consistent volume key. Train at the highest load whilst maintaining your normal volume. Eventually you will plateau and can then just use 3 times a week to maintain your fitness.
- I would also recommend doing one of the 2 sessions at half your normal load e.g. 40 cmH2O but try to only use your diaphragm, no accessory muscles, neck or upper ribcage. This will help train your slower running breathing and even try running only breathing through the nose when jogging.

X. Stryd Footpath Visualisation

Shown here is a 10-minute fast segment (z3) section of a road run. Interesting to notice are that the Power is 305W (which is slightly over the 295 CP). Cadence is 195 spm (which is in line with running cadence at 4:28/km pace).

From the graph below it can be seen that the left and right feet are almost following the same symmetrical flight path. Moreover it is shown that the runner is a mid foot striker. No irregularities are seen / no intervention is needed.



Footpath visualisation with Stryd

XI. Run Training Types

Below are the key workouts from 80/20 Endurance. They have been enhanced with the key physiological benefits.

Name	Description
Endurance Run	As their name suggests, Endurance Runs serve to develop the basic physiological and psychological ingredients of endurance, including fat-burning capacity and mental focus. Whether you use pace, heart rate, or power as your primary intensity metric, you should always regulate your Endurance Runs by perceived effort as well, in such a way that you COULD speed up slightly at the end of the run if you chose to. Note that heart rate tends to rise over the course of an Endurance Run and may exceed Zone 2 toward the end even if you maintain a steady pace. This phenomenon, known as cardiac drift, is caused by fatigue-related efficiency loss and dehydration. When it happens, you do NOT need to slow down to lower your heart rate unless your pace or power is also above the Zone 2 range.
Lactate Intervals Run	Lactate Intervals Runs are designed to boost aerobic capacity (aka VO2max), which is the most important physiological underpinning of running performance. This particular format was developed by exercise scientists at Inland Norway University as a way to increase the amount of time an athlete is able to spend near VO2max intensity within a single session without becoming exhausted. Lactate Intervals target Zone 4, which is fairly broad. You'll get the most benefit if you aim for a pace you could sustain for 15 minutes in race conditions, which will put you close to the middle of the zone. Because both the intervals and the recoveries are so short in this workout, pacing can be tricky. Don't worry--you'll get the hang of it as you go.
Over/Under Intervals Run	Over/Under Intervals Runs feature intervals in which the intensity fluctuates between slightly above and slightly below the lactate threshold (LT). The harder segments target Zone Y, which occupies the small space between Zone 3 and Zone 4, while the easier segments target Zone 3, whose upper limit aligns with LT. Like Tempo Runs and other runs that directly target LT, Over/Under Intervals develop the ability to run relaxed and efficiently at moderate speeds, but their variable-pace format offers the additional benefit of teaching the body to recover from a harder effort while still running somewhat aggressively. In doing this or any Over/Under Intervals Run, focus on oscillating gently around the high end of Zone 3, going from just below it in the Zone 3 segments to just above it in the Zone Y segments.
5K Pace Intervals Run	5K Pace Intervals offer essential practice at race pace during 5K training but are also a useful fitness builder in training for shorter and longer events. Although the 5K pace (5KP) intervals in this workout target Zone 4, your 5KP may fall outside this zone, so do your best to complete the intervals at a pace you could sustain for 5K in race conditions regardless of zone. Unlike most 80/20 workouts, this one is distance-based rather than time-based because its job is to give runners of all ability levels equal preparation for the 5K race distance. Any time associated with this session is a broad estimate. Note that the 0.1 km Zone 1 segment following each 5KP segment is actually intended as passive rest, so just walk for 100 meters.

Name	Description
10K Pace Intervals Run	10K Pace Intervals offer essential practice at race pace during 10K training but are also a useful fitness builder in training for shorter and longer events. Although the 10K pace (10KP) intervals in this workout target Zone 4, your 10KP may fall outside this zone, so do your best to complete the intervals at a pace you could sustain for 10K in race conditions regardless of zone. Unlike most 80/20 workouts, this one is distance-based rather than time-based because its job is to give runners of all ability levels equal preparation for the 10K race distance. Any time associated with this session is a broad estimate. Note that the 0.1 km Zone 1 segment following each 10KP segment is actually intended as passive rest, so just walk for 100 meters.
Accelerations Run	Developed by influential French exercise physiologist Veronique Billat, Accelerations Runs combine the unique physical challenge of running at every pace between a jog and a full sprint with a unique and valuable pacing challenge. Correct execution of the two accelerations in this workout entails accelerating continuously and gradually from Zone 2 to the top of Zone 5. The most common mistake is speeding up too quickly and thus running out of "gears" before the end, so guard against this. Because each acceleration culminates in an all-out effort, you'll need to walk a but before you resume running.
Critical Velocity Run	Critical Velocity Runs feature longer intervals at an intensity that rides the line between moderate and high. They are designed to enable runners to maintain a stable metabolic state at faster paces. Critical Velocity (CV) is the fastest pace a runner can sustain for 30 minutes, which for most falls at the low end of Zone 4. CV is also slower than 5K race pace and faster than 10K race pace for most runners. Try to maintain a steady pace from the start of the first CV interval to the end of the last interval in this and other Critical Velocity Runs. Also pay attention to your pace in the Zone 1 recovery segments. If you find yourself slowing down in these as the workout progresses, you may be running the CV segments too fast.
Depletion Run	A Depletion Run is essentially an Endurance Run that is performed in a calorie-restricted state. Do this run on an empty stomach and consume only water and electrolytes during it--no calories. Depriving your muscles of calories before and during a longer run, as Depletion Runs like this one require, offers two proven benefits. The best-known benefit is improvement in the ability of the muscles to burn fat during running. But Depletion Runs have also been shown to increase aerobic capacity (aka VO2max) more than regular long runs. Because Depletion Runs are meant to be done on an empty stomach, it's generally most convenient to do them first thing in the morning before breakfast.
Descending Intervals Run	Developed by scientists at the University of Udine in Italy, Descending Intervals are proven to increase the amount of time an athlete is able to spend above 90% of VO2max intensity within a single session. This makes the workout a potent way to boost aerobic capacity (aka VO2max). The heart of the workout is a set of five efforts of decreasing length that target Maximal Aerobic Speed (MAS), which is the fastest pace a runner can sustain for about 6 minutes and falls at the high end of Zone 4. Each MAS effort is followed by a Zone 1 active recovery that's two-thirds the duration of the preceding effort. Runners have a natural tendency to adjust their effort to the duration of a segment, automatically running shorter segments faster than longer ones. In Descending Intervals Runs like this one, though, you should run each Zone 4 segment at the same speed even though they get shorter.

Name	Description
Fartlek Run	Fartlek Runs are essentially casual interval runs. Designed to deliver modest doses of faster running, they fit well in base training, recovery weeks, and pre-race taper periods. "Fartlek" means "Speed Play" in Swedish. Bring a playful mindset to this run by relying more on perceived effort than on pace, heart rate, or power to regulate your effort level during the faster segments. Note that the recovery segments in this Fartlek Run target Zone 2 rather than Zone 1, as in most interval sessions. In other words, the "easy" parts aren't quite as easy, which contributes to the fitness-boosting effect of the run.
Half-Marathon Pace Run	Half-Marathon Pace Runs offer essential practice at race pace during half-marathon training, but are also a useful fitness builder in training for shorter and longer events. Although the half-marathon pace (HMP) segments in this run target Zone 3, your HMP may fall outside this range, so do your best to complete the segments at a pace you could sustain for a half marathon in race conditions regardless of zone. Unlike most 80/20 workouts, this one is distance-based rather than time-based because its job is to give runners of all ability levels equal preparation for the half-marathon race distance. Any time associated with this session is a broad estimate. Note that the 0.1 km Zone 1 segment following each HMP segment is actually intended as passive rest, so just walk for 100 meters.
Long Run	Long Runs are intended to develop the endurance required to "go the distance" on race day. For this reason they are always distance-based. Any time associated with this session is a broad estimate. Whether you use pace, heart rate, or power as your primary intensity metric, you should always regulate your Long Runs by rate of perceived effort as well, distributing your energy in such a way that you COULD speed up slightly at the end of the run if you chose to. Note that heart rate tends to rise over the course of a Long Run and may exceed Zone 2 toward the end even if your pace is steady. This phenomenon, known as cardiac drift, is caused by fatigue-related efficiency loss and dehydration. When it happens, you do NOT need to slow down in order to lower your heart rate unless your pace or power is also above the Zone 2 range.
Speed Intervals Run	Speed Intervals Runs will not make you a faster sprinter, but they will improve your running economy and your ability to resist fatigue at faster speeds. Studies have shown that even ultrarunners benefit from including some speed intervals in their training. Speed Intervals are necessarily quite short. For this reason, you'll need to rely mainly in perceived effort to regulate your effort. Specifically, aim for a 9-out-of effort for the workout as a whole. It's a good idea to include some form drills in your warm-up before doing Speed Intervals. These will help you perform better and reduce the risk of muscle/tendon strains. Here are links to some suggested drills: A Skips https://www.youtube.com/watch?v=3V6FikqxUrw B Skips https://www.youtube.com/watch?v=rF93P6EOpUo High Knees https://www.youtube.com/watch?v=RG1_6AYBbow Butt Kicks https://www.youtube.com/watch?v=n_AiN4nzSl8

Name	Description
Marathon Pace Run	Marathon Pace Runs are intended to help runners become more efficient and comfortable at marathon pace (MP). They can also be used outside of marathon training to provide an endurance stimulus that's more challenging than a standard long run. Complete the Marathon Pace segments of this run at a speed you could sustain for a full marathon in race conditions. If you're not sure what this is, just do your best and focus on using the run to get a clearer sense of your current marathon pace. Note that Marathon Pace Runs are always distance-based. Any time associated with this session is a broad estimate.
Progression Run	Similar to Fast Finish Runs, Progression Runs teach the body to run faster on tired legs. This particular run features a three-step progression that hits three moderate to high intensities: Lactate Threshold Pace, Critical Velocity, and Maximal Aerobic Speed. Be careful to avoid speeding up too early in anticipation of the progression part of this Progression Run. Stay in Zone 2 until your device cues you to accelerate. The three moderate to high intensities targeted at the end of this Progression Run are not far apart from each other pace-wise. For this reason, you may find it challenging initially to hit each one individually without overshooting. That's okay; you'll get better with repetition.
Progression Intervals Run	This workout format was developed by scientists at the University of Copenhagen in the 2010's and found to improve race performance in trained recreational runners. It features 1-minute intervals in which the first 30 seconds are completed in Zone 3, the next 20 seconds in Zone 4, and the last 10 second in Zone 5. You then go straight back to the top and complete the same sequence four times more for a total of five repetitions before easing down to Zone 1 for recovery. Because they hit a variety of intensities without focusing on any single intensity, Progression Intervals work well as a general fitness developer during base building and as a fitness maintainer during recovery weeks and taper periods. Progression Intervals can be challenging to pace correctly because they require you to "shift gears" frequently. But it's a fun challenge if you embrace it, and you will get better with practice.
Steady State Run	Steady State Runs target Zone X, a zone that is generally avoided in the 80/20 system but is good to spend SOME time in, as doing so builds a bridge between extensive endurance (the ability to run far) and intensive endurance (the ability to run fast without fatiguing). The Zone X segment in this run should be completed at a pace you feel you could sustain for 2 hours, a number that falls between half-marathon and marathon pace for most runners.
Relaxed Time Trial	A Relaxed Time Trial is a time trial that is run at 95% of race effort. These workouts serve to enhance goal-specific fitness and build confidence. To execute this workout, simply add 5% to your 5K race goal time, calculate the corresponding pace, and complete the Relaxed Time Trial segment of the workout at that pace. For example, if your goal time is 20:00 (4:00/km), run the Relaxed Time Trial segment at 4:12/km.
Variable-Intensity Intervals Run	Variable-Intensity Interval Runs feature an unusual two-step interval format that is proven to enable athletes to spend more time at or near VO2max intensity than they do in traditional, single-pace intervals. The result is bigger gains in aerobic capacity/VO2max. The first 30 seconds of each Variable-Intensity Interval are run at Maximal Aerobic Speed (MAS), which is the fastest pace you could sustain for about 6 minutes, and the next 45 seconds are run at Lactate Threshold Pace, which aligns with the top end of Zone 3. These two steps are repeated four times before you dial back to Zone 1 to recover. Variable-Intensity Intervals are almost as challenging mentally as they are physically. Effective execution does not require that you run each and every segment at just the right intensity, but it does require that you make your best effort to do so, and this effort demands steady focus.

XII. Facebook Sub-3 Runner's Group Questions

Train

- **How to optimise cross-training for performance benefits in long-distance running (what sports, duration and intensity, timing) 18%**
- **What is best duration and training regime for tapering in preparation of A race 12%**
- **What is best way to determine marathon fitness (e.g. CP, CV, LTHR, VO_{2max}) 16%**
- **What are best S&C exercises and rep and intensity range (x% of 1RM) for injury prevention and running economy 15%**
- How to train and prepare to reduce mental fatigue during training and racing 1%
- What other training tools provide a measurable training benefit (e.g. lung power, gait analysis) 0%
- How to adapt training interventions / adaptation based on runner's age 9%

Fuel

- How to optimise supplementation by training cycle based on blood and other physiological tests 0%
- How to balance achieving racing weight vs REDS by training cycle 3%
- Optimal race nutrition timing, quality and quantity (pre-race, during race) (gels, caffeine, beetroot) 4%
- Best timing and quantity for creatine monohydrate, BCAA, and protein supplementation 0%

Recover

- What are the key KPIs to monitor to guarantee recovery (e.g. RHR, HRV, sleep duration, time in deep sleep) 5%
- What is role, intensity, and frequency of yoga for injury prevention in AG runners 0%
- Are there scientifically researched mindfulness and meditation techniques for long-distance runners? 0%

Other

- Key considerations in preparing an annual training plan (e.g. number of A races, tune-up races, recovery blocks, duration of meso-cycles) 4%
- Race-specific training considerations (e.g. heat and humidity adaption, time zones, vertical) 2%
- What is the latest scientific explanation of cramps during long-distance foot events and how to best prepare and avoid 2%

XIII.EPEP Speakers & Interventions

Below is an overview of the key international experts who presented at EPEP lectures. Some of the speakers provided anecdotal / practitioners' expertise which may not be linked to a biographic reference. Link to recording

Speaker	Topic	Date
Adam Sharples	Chronic Resistance Training	8 Sep 2023
Andrew Jones	Physiological Resilience as a determinant of Endurance Performance	19 May 2023
Cinzia Ferraris	Sports Nutrition	29 Sep 2023
Cosme Buzzachera	Skills classification & assessment	30 Sep 2023
	Sports Nutrition - general principles	9 Sep 2023
Daniel Boullosa	Strength Training for Endurance Athletes	24 Nov 2023
	Training & Periodisation	30 Sep 2023
Daniele Cardinale	Optimising performance in elite endurance athletes	15 Jul 2023
Elena Casiraghi	Sports Nutrition	15 Dec 2023
Gianluca Vernillo	Neuromuscular fatigue	23 Jun 2023
Iñigo Mujika	Tapering and Peaking for optimal performance	23 Jun 2023
	Planning and periodisation in endurance sport	24 Jun 2023
Leonardo Tartaruga	Biomechanics of endurance sports	15 Jul 2023
	Biomechanical assessment	30 Sep 2023
Luca Correale	Critical Speed & Peak Velocity	19 May 2023
Marcello Bigliassi	Exercise Tolerance / Neuroscience	16 Dec 2023
Monica Guglielmetti	Nutritional integration	28 Sep 2023
Nicola Maffiuletti	Force Development	27 Oct 2023
Samuele Marcora	Psychobiology of Endurance Performance - Theory and Practical Applications	24 Nov 2023
Simone Villanova	Concurrent Training	25 Mar 2023
	Priming exercise - physiology and performance	19 May 2023
Stefano Dell'Anna	Training & Planning	28 Oct 2023
	Weight training for endurance	29 Sep 2023

XIV.Questions To EPEP Presenters

Expert	Question	Short Answer
Buzzachera	Is CTL important for marathon running? Not well researched / use ACWR instead?	
Jones	How to apply the four variables for structuring a BP training plan? How to best test the four variables and increment them?	Do it yourself :-)
Tartaruga	How would you integrate into a block periodised training plan exercises to help prepare / cope with such u-turns	
	I have a Stryd power meter which now also shows the gait analysis - attached. Are you aware of any advise based on such analysis? For now Stryd only displays the flight path without any commentary. By looking at the images and confronting with other runners I seem to be very symmetrical (L/R), without any anomalies. The flight path seems to indicate that I am a front / mid foot striker (which is true).	
Boullosa	How to integrate run exercises (HIIT, Fartlek, fast-finish, …). So what are good examples of a weekly training plan in the various macro-cycles?	Provided one article with case study of 50 year-old runner and training plan and how to assess exertion using HRV and sRPE
	Running Efficiency and stated that there is no difference in RE in front-foot, mid-foot, rear-foot strike - or if there is it is probably negated by the retraining effect	
	Best and periodised methods for improving RE in an annual training plan	
Guglielmetti	Nurofen/ibuprofen 2x one hour before race. Maybe check if to take with half banana. Also check why urine is red for 28 hours.	
	EAA over BCAA over whey protein?	
	When citrulline mallate, what timing compared to nitrate?	
	Safety of nitrate / beetroot concentrate on annual plan	
	Green tea (Sencha/Matcha)	
	Apple Cider vinegar	
Marcora	How to integrate brain training into a block periodised marathon training plan?	
	Are there any BET tools / protocols you would recommend?	
	You also mentioned Brain stimulation (TMS/tDCS) - again are there tools / can this be done by an athlete or only by a medical professional? (https://nurosym.com/)	
	Modafinil - any updates?	
	Coffee / caffeine - what maximum dosage would you recommend for a marathon race?	
Mujika	Strength training inside marathon plan?	Yes, 2-3x week
	Which measures for recovery tracking?	RHR and HRV

XV. Mindfulness Prayers

Pater Noster

Qui es in caelis,
Sanctificetur nomen tuum.
Adveniat regnum tuum.
Fiat voluntas tua,
Sicut in caelo et in terra.
Panem nostrum quitidianum da nobis hodie,
Et dimitte nobis debita nostra,
Sicut et nos dimittimrus debitoribus nostris
Et ne nos inducas in tentationem:
Sed libera nos a malo

Ave Maria gratia plena,
Dominus tecum;
Benedicta tu in mulieribus,
Et benedictus fructus ventris tui, Jesus.
Santa Maria, Mater Dei,
Ora pro nobis peccatoribus,
Nunc et in hora mortis nostrae.
Amen

EASY

- Embrace
- Accept
- Surrender
- Yield

XVI.Bibliography

Altini, M., & Plews, D. (2021). What Is behind Changes in Resting Heart Rate and Heart Rate Variability? A Large-Scale Analysis of Longitudinal Measurements Acquired in Free-Living. Sensors (Basel), 21(23). https://doi.org/10.3390/s21237932

Andersen, J. J. (2023, 3 November 2023). The State of Running 2019. https://runrepeat.com/state-of-running

Andersen, J. L., & Aagaard, P. (2010). Effects of strength training on muscle fiber types and size; consequences for athletes training for high-intensity sport. Scand J Med Sci Sports, 20 Suppl 2, 32-38. https://doi.org/10.1111/j.1600-0838.2010.01196.x

Antonio, J., Candow, D. G., Forbes, S. C., Gualano, B., Jagim, A. R., Kreider, R. B., Rawson, E. S., Smith-Ryan, A. E., VanDusseldorp, T. A., Willoughby, D. S., & Ziegenfuss, T. N. (2021). Common questions and misconceptions about creatine supplementation: what does the scientific evidence really show? J Int Soc Sports Nutr, 18(1), 13. https://doi.org/10.1186/s12970-021-00412-w

Anupama, N. V., & Kumar, P. S. (2021). Yogasanas. Adhyaksha.

Bache-Mathiesen, L. K., Andersen, T. E., Dalen-Lorentsen, T., Tabben, M., Chamari, K., Clarsen, B., & Fagerland, M. W. (2024). A new statistical approach to training load and injury risk: separating the acute from the chronic load. Biol Sport, 41(1), 119-134. https://doi.org/10.5114/biolsport.2024.127388

Bailey, S. J., Vanhatalo, A., Wilkerson, D. P., Dimenna, F. J., & Jones, A. M. (2009). Optimizing the "priming" effect: influence of prior exercise intensity and recovery duration on O2 uptake kinetics and severe-intensity exercise tolerance. J Appl Physiol (1985), 107(6), 1743-1756. https://doi.org/10.1152/japplphysiol.00810.2009

Bailey, S. J., Winyard, P., Vanhatalo, A., Blackwell, J. R., Dimenna, F. J., Wilkerson, D. P., Tarr, J., Benjamin, N., & Jones, A. M. (2009). Dietary nitrate supplementation reduces the O2 cost of low-intensity exercise and enhances tolerance to high-intensity exercise in humans. J Appl Physiol (1985), 107(4), 1144-1155. https://doi.org/10.1152/japplphysiol.00722.2009

Barnes, K. R., & Kilding, A. E. (2015a). Running economy: measurement, norms, and determining factors. Sports Med Open, 1(1), 8. https://doi.org/10.1186/s40798-015-0007-y

Barnes, K. R., & Kilding, A. E. (2015b). Strategies to improve running economy. Sports Med, 45(1), 37-56. https://doi.org/10.1007/s40279-014-0246-y

Bassett, D. R., Jr., & Howley, E. T. (2000). Limiting factors for maximum oxygen uptake and determinants of endurance performance. Med Sci Sports Exerc, 32(1), 70-84. https://doi.org/10.1097/00005768-200001000-00012

Beattie, K., Kenny, I. C., Lyons, M., & Carson, B. P. (2014). The effect of strength training on performance in endurance athletes. Sports Med, 44(6), 845-865. https://doi.org/10.1007/s40279-014-0157-y

Berger, N. J. A., Best, R., Best, A. W., Lane, A. M., Millet, G. Y., Barwood, M., Marcora, S., Wilson, P., & Bearden, S. (2023). Limits of Ultra: Towards an Interdisciplinary Understanding of Ultra-Endurance Running Performance. Sports Med. https://doi.org/10.1007/s40279-023-01936-8

Black, M. I., Kranen, S. H., Kadach, S., Vanhatalo, A., Winn, B., Farina, E. M., Kirby, B. S., & Jones, A. M. (2022). Highly Cushioned Shoes Improve Running Performance in Both the Absence and Presence of Muscle Damage. Med Sci Sports Exerc, 54(4), 633-645. https://doi.org/10.1249/MSS.0000000000002832

Blanchfield, A. W., Hardy, J., De Morree, H. M., Staiano, W., & Marcora, S. M. (2014). Talking yourself out of exhaustion: the effects of self-talk on endurance performance. Med Sci Sports Exerc, 46(5), 998-1007. https://doi.org/10.1249/MSS.0000000000000184

Bompa, T. O., & Buzzichelli, C. (2019). Periodization : theory and methodology of training (Sixth edition. ed.). Human Kinetics,.

Bosquet, L., Montpetit, J., Arvisais, D., & Mujika, I. (2007). Effects of tapering on performance: a meta-analysis. Med Sci Sports Exerc, 39(8), 1358-1365. https://doi.org/10.1249/mss.0b013e31806010e0

Boullosa, D., Del Rosso, S., Behm, D. G., & Foster, C. (2018). Post-activation potentiation (PAP) in endurance sports: A review. Eur J Sport Sci, 18(5), 595-610. https://doi.org/10.1080/17461391.2018.1438519

Boullosa, D., Esteve-Lanao, J., Casado, A., Peyre-Tartaruga, L. A., Gomes da Rosa, R., & Del Coso, J. (2020). Factors Affecting Training and Physical Performance in Recreational Endurance Runners. Sports (Basel), 8(3). https://doi.org/10.3390/sports8030035

Boullosa, D., Medeiros, A. R., Flatt, A. A., Esco, M. R., Nakamura, F. Y., & Foster, C. (2021). Relationships between Workload, Heart Rate Variability, and Performance in a Recreational Endurance Runner. J Funct Morphol Kinesiol, 6(1). https://doi.org/10.3390/jfmk6010030

Boullosa, D. A., Abreu, L., Varela-Sanz, A., & Mujika, I. (2013). Do olympic athletes train as in the Paleolithic era? Sports Med, 43(10), 909-917. https://doi.org/10.1007/s40279-013-0086-1

Burke, L. M. (2023). Nutrition for Endurance Training and Competition. In I. Mujika (Ed.), Endurance Training - Science and Practice (Second Edition ed., pp. 298-315). Inigo Mujika S.L.U.

Cavanagh, P. R., & Kram, R. (1989). Stride length in distance running: velocity, body dimensions, and added mass effects. Med Sci Sports Exerc, 21(4), 467-479. https://www.ncbi.nlm.nih.gov/pubmed/2674599

Chang, Y. C., Chang, H. Y., Ho, C. C., Lee, P. F., Chou, Y. C., Tsai, M. W., & Chou, L. W. (2021). Effects of 4-Week Inspiratory Muscle Training on Sport Performance in College 800-Meter Track Runners. Medicina (Kaunas), 57(1). https://doi.org/10.3390/medicina57010072

Clark, I. E., Vanhatalo, A., Thompson, C., Joseph, C., Black, M. I., Blackwell, J. R., Wylie, L. J., Tan, R., Bailey, S. J., Wilkins, B. W., Kirby, B. S., & Jones, A. M. (2019). Dynamics of the power-duration relationship during prolonged endurance exercise and influence of carbohydrate ingestion. J Appl Physiol (1985), 127(3), 726-736. https://doi.org/10.1152/japplphysiol.00207.2019

Coyle, E. F. (1999). Physiological determinants of endurance exercise performance. J Sci Med Sport, 2(3), 181-189. https://doi.org/10.1016/s1440-2440(99)80172-8

Doherty, R., Madigan, S., Nevill, A., Warrington, G., & Ellis, J. G. (2023). The Impact of Kiwifruit Consumption on the Sleep and Recovery of Elite Athletes. Nutrients, 15(10). https://doi.org/10.3390/nu15102274

Fernandez-Lazaro, D., Corchete, L. A., Garcia, J. F., Jerves Donoso, D., Lantaron-Caeiro, E., Cobreros Mielgo, R., Mielgo-Ayuso, J., Gallego-Gallego, D., & Seco-Calvo, J. (2022). Effects on Respiratory Pressures, Spirometry Biomarkers, and Sports Performance after Inspiratory Muscle Training in a Physically Active Population by Powerbreath((R)): A Systematic Review and Meta-Analysis. Biology (Basel), 12(1). https://doi.org/10.3390/biology12010056

Ferrada-Contreras, E., Bonomini-Gnutzmann, R., Jorquera-Aguilera, C., Macmillan Kuthe, N., Pena-Jorquera, H., & Rodriguez-Rodriguez, F. (2023). Does Co-Supplementation with Beetroot Juice and Other Nutritional Supplements Positively Impact Sports Performance?: A Systematic Review. Nutrients, 15(22). https://doi.org/10.3390/nu15224838

Ferrando, A. A., Wolfe, R. R., Hirsch, K. R., Church, D. D., Kviatkovsky, S. A., Roberts, M. D., Stout, J. R., Gonzalez, D. E., Sowinski, R. J., Kreider, R. B., Kerksick, C. M., Burd, N. A., Pasiakos, S. M., Ormsbee, M. J., Arent, S. M., Arciero, P. J., Campbell, B. I., VanDusseldorp, T. A., Jager, R., . . . Antonio, J. (2023). International Society of Sports Nutrition Position Stand: Effects of essential amino acid supplementation on exercise and performance. J Int Soc Sports Nutr, 20(1), 2263409. https://doi.org/10.1080/15502783.2023.2263409

Fitzgerald, M. (2014). 80/20 running : run stronger and race faster by training slower. NAL, New American Library.

Fitzgerald, M. (2015). How bad do you want it? : mastering the psychology of mind over muscle. VeloPress.

Fitzgerald, M. (2023). Racing Weight: how to get lean for peak performance (Velopress, Ed.) https://books.apple.com/book/id1617073370

Frazier, M., Cheeke, R., & Holtzman, R. (2021). The plant-based athlete : the game-changing approach to peak performance (First edition. ed.). HarperOne.

Friel, J. (2015). Fast after 50 : how to race strong for the rest of your life. VeloPress.

Furrer, R., Hawley, J. A., & Handschin, C. (2023). The molecular athlete: exercise physiology from mechanisms to medals (20230105 ed., Vol. 103) https://doi.org/10.1152/physrev.00017.2022

Giandolini, M., Arnal, P. J., Millet, G. Y., Peyrot, N., Samozino, P., Dubois, B., & Morin, J. B. (2013). Impact reduction during running: efficiency of simple acute interventions in recreational runners. Eur J Appl Physiol, 113(3), 599-609. https://doi.org/10.1007/s00421-012-2465-y

Goulding, R. P., Burnley, M., & Wust, R. C. I. (2023). How Priming Exercise Affects Oxygen Uptake Kinetics: From Underpinning Mechanisms to Endurance Performance. Sports Med, 53(5), 959-976. https://doi.org/10.1007/s40279-023-01832-1

Guest, N. S., VanDusseldorp, T. A., Nelson, M. T., Grgic, J., Schoenfeld, B. J., Jenkins, N. D. M., Arent, S. M., Antonio, J., Stout, J. R., Trexler, E. T., Smith-Ryan, A. E., Goldstein, E. R., Kalman, D. S., & Campbell, B. I. (2021). International society of sports nutrition position stand: caffeine and exercise performance. J Int Soc Sports Nutr, 18(1), 1. https://doi.org/10.1186/s12970-020-00383-4

Halson, S. L., Argus, C. K., O'Riordan, S. F., & Stephens, J. M. (2023). Recovery for Endurance Training. In I. Mujika (Ed.), Endurance Training - Science and Practice (Second Edition ed., pp. 81-96). Inigo Mujika S.L.U.

Harries, S. K., Lubans, D. R., & Callister, R. (2015). Systematic review and meta-analysis of linear and undulating periodized resistance training programs on muscular strength. J Strength Cond Res, 29(4), 1113-1125. https://doi.org/10.1519/JSC.0000000000000712

Haugen, T., & Tonnessen, E. (2023). Periodisation of Endurance Training. In I. Mujika (Ed.), Endurance Training - Science and Practice (Second Edition ed., pp. 14-25). Inigo Mujika S.L.U.

Hawley, J. A., Schabort, E. J., Noakes, T. D., & Dennis, S. C. (1997). Carbohydrate-loading and exercise performance. An update. Sports Med, 24(2), 73-81. https://doi.org/10.2165/00007256-199724020-00001

Hobrough, P. (2016). Running free of injuries - from pain to personal best. Bloomsbury Sport.

Hunter, I., Lee, K., Ward, J., & Tracy, J. (2017). Self-optimization of Stride Length Among Experienced and Inexperienced Runners. Int J Exerc Sci, 10(3), 446-453. https://www.ncbi.nlm.nih.gov/pubmed/28515840

Hutchinson, A. (2018). Endure : mind, body, and the curiously elastic limits of human performance (First edition. ed.).

Impellizzeri, F. M., Marcora, S. M., & Coutts, A. J. (2019). Internal and External Training Load: 15 Years On. Int J Sports Physiol Perform, 14(2), 270-273. https://doi.org/10.1123/ijspp.2018-0935

Ingham, S. A. F., B. W.; Pringle, J. S.; Jones, A. M. (2013). Improvement of 800-m Running Performance with Prior High-Intensity Exercise. International Journal of Sports Physiology and Performance(8), 77-83.

Inglis, E. C., Iannetta, D., Rasica, L., Mackie, M. Z., Keir, D. A., MacInnis, M. J., & Murias, J. M. (2024). Heavy-, Severe-, and Extreme-, but not Moderate-Intensity Exercise Increase V̇o2max and Thresholds after 6 Weeks of Training. Med Sci Sports Exerc. https://doi.org/10.1249/MSS.0000000000003406

Issurin, V. B. (2010). New horizons for the methodology and physiology of training periodization. Sports Med, 40(3), 189-206. https://doi.org/10.2165/11319770-000000000-00000

Issurin, V. B. (2019). Biological Background of Block Periodized Endurance Training: A Review. Sports Med, 49(1), 31-39. https://doi.org/10.1007/s40279-018-1019-9

Jamnick, N. A., Pettitt, R. W., Granata, C., Pyne, D. B., & Bishop, D. J. (2020). An Examination and Critique of Current Methods to Determine Exercise Intensity. Sports Med, 50(10), 1729-1756. https://doi.org/10.1007/s40279-020-01322-8

Janse van Rensburg, D. C., Jansen van Rensburg, A., Fowler, P. M., Bender, A. M., Stevens, D., Sullivan, K. O., Fullagar, H. H. K., Alonso, J. M., Biggins, M., Claassen-Smithers, A., Collins, R., Dohi, M., Driller, M. W., Dunican, I. C., Gupta, L., Halson, S. L., Lastella, M., Miles, K. H., Nedelec, M., . . . Botha, T. (2021). Managing Travel Fatigue and Jet Lag in Athletes: A Review and Consensus Statement. Sports Med, 51(10), 2029-2050. https://doi.org/10.1007/s40279-021-01502-0

Jeukendrup, A. E. (2017). Training the Gut for Athletes. Sports Med, 47(Suppl 1), 101-110. https://doi.org/10.1007/s40279-017-0690-6

Jones, A. M. (2023). The fourth dimension: physiological resilience as an independent determinant of endurance exercise performance. J Physiol. https://doi.org/10.1113/JP284205

Jones, A. M., Burnley, M., Black, M. I., Poole, D. C., & Vanhatalo, A. (2019a). The maximal metabolic steady state: redefining the 'gold standard'. Physiol Rep, 7(10), e14098. https://doi.org/10.14814/phy2.14098

Jones, A. M., Burnley, M., Black, M. I., Poole, D. C., & Vanhatalo, A. (2019b). Response to considerations regarding Maximal Lactate Steady State determination before redefining the gold-standard. Physiol Rep, 7(22), e14292. https://doi.org/10.14814/phy2.14292

Jones, A. M., Kirby, B. S., Clark, I. E., Rice, H. M., Fulkerson, E., Wylie, L. J., Wilkerson, D. P., Vanhatalo, A., & Wilkins, B. W. (2021). Physiological demands of running at 2-hour marathon race pace. J Appl Physiol (1985), 130(2), 369-379. https://doi.org/10.1152/japplphysiol.00647.2020

Jones, A. M., & Vanhatalo, A. (2017). The 'Critical Power' Concept: Applications to Sports Performance with a Focus on Intermittent High-Intensity Exercise. Sports Med, 47(Suppl 1), 65-78. https://doi.org/10.1007/s40279-017-0688-0

Jones, H. (2013). Marathons of the world. Barron's.

Joyner, M. J. (1991). Modeling: optimal marathon performance on the basis of physiological factors. J Appl Physiol (1985), 70(2), 683-687. https://doi.org/10.1152/jappl.1991.70.2.683

Joyner, M. J., & Coyle, E. F. (2008). Endurance exercise performance: the physiology of champions. J Physiol, 586(1), 35-44. https://doi.org/10.1113/jphysiol.2007.143834

Kataoka, R., Vasenina, E., Loenneke, J., & Buckner, S. L. (2021). Periodization: Variation in the Definition and Discrepancies in Study Design. Sports Med, 51(4), 625-651. https://doi.org/10.1007/s40279-020-01414-5

Kellmann, M., Bertollo, M., Bosquet, L., Brink, M., Coutts, A. J., Duffield, R., Erlacher, D., Halson, S. L., Hecksteden, A., Heidari, J., Kallus, K. W., Meeusen, R., Mujika, I., Robazza, C., Skorski, S., Venter, R., & Beckmann, J. (2018). Recovery and Performance in Sport: Consensus Statement. Int J Sports Physiol Perform, 13(2), 240-245. https://doi.org/10.1123/ijspp.2017-0759

King, A. J., O'Hara, J. P., Arjomandkhah, N. C., Rowe, J., Morrison, D. J., Preston, T., & King, R. (2019). Liver and muscle glycogen oxidation and performance with dose variation of glucose-fructose ingestion during prolonged (3 h) exercise. Eur J Appl Physiol, 119(5), 1157-1169. https://doi.org/10.1007/s00421-019-04106-9

Lambert, M. I. (2023). Quantification of Endurance Training and Competition Loads. In I. Mujika (Ed.), Endurance Training - Science and Practice (Second Edition ed., pp. 29-38). Inigo Mujika S.L.U.

Laursen, P. B., & Buchheit, M. (2023). Developing Aerobic Power with High-Intensity Interval Training. In I. Mujika (Ed.), Endurance Training - Science and Practice (Second Edition ed., pp. 56-66). Inigo Mujika S.L.U.

Lopes, T. R., Fortes, L. S., Smith, M. R., Roelands, B., & Marcora, S. M. (2023). Editorial: Mental fatigue and sport: from the lab to the field. Front Sports Act Living, 5, 1213019. https://doi.org/10.3389/fspor.2023.1213019

Marcora, S. (2016). Can Doping be a Good Thing? Using Psychoactive Drugs to Facilitate Physical Activity Behaviour. Sports Med, 46(1), 1-5. https://doi.org/10.1007/s40279-015-0412-x

Marcora, S. M., Staiano, W., & Manning, V. (2009). Mental fatigue impairs physical performance in humans. J Appl Physiol (1985), 106(3), 857-864. https://doi.org/10.1152/japplphysiol.91324.2008

McConnell, A. K. (2012). CrossTalk opposing view: respiratory muscle training does improve exercise tolerance. J Physiol, 590(15), 3397-3398; discussion 3399-3400. https://doi.org/10.1113/jphysiol.2012.235572

Millet, G. P., Candau, R. B., Barbier, B., Busso, T., Rouillon, J. D., & Chatard, J. C. (2002). Modelling the transfers of training effects on performance in elite triathletes. Int J Sports Med, 23(1), 55-63. https://doi.org/10.1055/s-2002-19276

Mujika, I., & Padilla, S. (2003). Scientific bases for precompetition tapering strategies. Med Sci Sports Exerc, 35(7), 1182-1187. https://doi.org/10.1249/01.MSS.0000074448.73931.11

Mujika, I., Stellingwerff, T., & Tipton, K. (2014). Nutrition and training adaptations in aquatic sports. Int J Sport Nutr Exerc Metab, 24(4), 414-424. https://doi.org/10.1123/ijsnem.2014-0033

Nikolova, V. (2023, 3 November 2023). Compare Running Finish Times [Calculator] - 5K, 10K, Half Marathon, Marathon. https://runrepeat.com/how-do-you-masure-up-the-runners-percentile-calculator

Norton, K. I. (2018). Standards for Anthropometry Assessment. In Kinanthropometry and Exercise Physiology (pp. 68-137). https://doi.org/10.4324/9781315385662-4

Ogueta-Alday, A., Rodriguez-Marroyo, J. A., & Garcia-Lopez, J. (2014). Rearfoot striking runners are more economical than midfoot strikers. Med Sci Sports Exerc, 46(3), 580-585. https://doi.org/10.1249/MSS.0000000000000139

Perry, J. L. (2015). Sport psychology : a complete introduction. Hodder & Stoughton.

Porcari, J. P., Bryant, C. X., & Comana, F. (2015). Exercise Physiology. Quincy McDonald.

Prabhavananda, S., & Isherwood, C. (2022). Patanjali Yoga Sutras. Adhyaksha.

Ribeiro, F., Longobardi, I., Perim, P., Duarte, B., Ferreira, P., Gualano, B., Roschel, H., & Saunders, B. (2021). Timing of Creatine Supplementation around Exercise: A Real Concern? Nutrients, 13(8). https://doi.org/10.3390/nu13082844

Roberts, L. A., Raastad, T., Markworth, J. F., Figueiredo, V. C., Egner, I. M., Shield, A., Cameron-Smith, D., Coombes, J. S., & Peake, J. M. (2015). Post-exercise cold water immersion attenuates acute anabolic signalling and long-term adaptations in muscle to strength training. J Physiol, 593(18), 4285-4301. https://doi.org/10.1113/JP270570

Salazar-Martinez, E. (2024). Breathing Pattern Response after 6 Weeks of Inspiratory Muscle Training during Exercise. Adv Respir Med, 92(1), 58-65. https://doi.org/10.3390/arm92010008

Sandbakk, Ø. (2023). Physiological Determinants of Endurance Performance. In I. Mujika (Ed.), Endurance Training - Science and Practice (Second Edition ed., pp. 3-11). Inigo Mujika S.L.U.

Sandbakk, O., Pyne, D. B., McGawley, K., Foster, C., Talsnes, R. K., Solli, G. S., Millet, G. P., Seiler, S., Laursen, P. B., Haugen, T., Tonnessen, E., Wilber, R., van Erp, T., Stellingwerff, T., Holmberg, H. C., & Bucher Sandbakk, S. (2023). The Evolution of World-Class Endurance Training: The Scientist's View on Current and Future Trends. Int J Sports Physiol Perform, 18(8), 885-889. https://doi.org/10.1123/ijspp.2023-0131

Saw, A. E., Kellmann, M., Main, L. C., & Gastin, P. B. (2017). Athlete Self-Report Measures in Research and Practice: Considerations for the Discerning Reader and Fastidious Practitioner. Int J Sports Physiol Perform, 12(Suppl 2), S2127-S2135. https://doi.org/10.1123/ijspp.2016-0395

Sedano, S., Marin, P. J., Cuadrado, G., & Redondo, J. C. (2013). Concurrent training in elite male runners: the influence of strength versus muscular endurance training on performance outcomes. J Strength Cond Res, 27(9), 2433-2443. https://doi.org/10.1519/JSC.0b013e318280cc26

Seiler, K. S., & Kjerland, G. O. (2006). Quantifying training intensity distribution in elite endurance athletes: is there evidence for an "optimal" distribution? Scand J Med Sci Sports, 16(1), 49-56. https://doi.org/10.1111/j.1600-0838.2004.00418.x

Seiler, S. (2023). Training Intensity Distribution: the Why behind the What. In I. Mujika (Ed.), Endurance Training - Science and Practice (Second Edition ed., pp. 42-53). Inigo Mujika S.L.U.

Sekiguchi, Y., Curtis, R. M., Huggins, R. A., Benjamin, C. L., Walker, A. J., Arent, S. M., Adams, W. M., Anderson, T., & Casa, D. J. (2021). The Relationships Between Perceived Wellness, Sleep, and Acute: Chronic Training Load in National Collegiate Athletics Association Division I Male Soccer Players. J Strength Cond Res, 35(5), 1326-1330. https://doi.org/10.1519/JSC.0000000000004003

Shorkey, S. (2020). The Vegan Bodybuilder's Cookbook. Rockridge Press.

Simons, J. (2023). Psychological Factors in Endurance Sport. In I. Mujika (Ed.), Endurance Training - Science and Practice (Second Edition ed., pp. 278-294). Inigo Mujika S.L.U.

Solli. (2020). The development process of the Most Successful Winter Olympian in History

Staiano, W., Bosio, A., de Morree, H. M., Rampinini, E., & Marcora, S. (2018). The cardinal exercise stopper: Muscle fatigue, muscle pain or perception of effort? Prog Brain Res, 240, 175-200. https://doi.org/10.1016/bs.pbr.2018.09.012

Staiano, W., Marcora, S., Romagnoli, M., Kirk, U., & Ring, C. (2023). Brain Endurance Training improves endurance and cognitive performance in road cyclists. J Sci Med Sport, 26(7), 375-385. https://doi.org/10.1016/j.jsams.2023.05.008

Stellingwerf, T. (2012). Case study: Nutrition and training periodization in three elite marathon runners. Int J Sport Nutr Exerc Metab, 22(5), 392-400. https://doi.org/10.1123/ijsnem.22.5.392

Stellingwerff, T. (2012). Case study: Nutrition and training periodization in three elite marathon runners. Int J Sport Nutr Exerc Metab, 22(5), 392-400. https://doi.org/10.1123/ijsnem.22.5.392

Stellingwerff, T. (2018). Case Study: Body Composition Periodization in an Olympic-Level Female Middle-Distance Runner Over a 9-Year Career. Int J Sport Nutr Exerc Metab, 28(4), 428-433. https://doi.org/10.1123/ijsnem.2017-0312

Stellingwerff, T., Boit, M. K., Res, P. T., & International Association of Athletics, F. (2007). Nutritional strategies to optimize training and racing in middle-distance athletes. J Sports Sci, 25 Suppl 1, S17-28. https://doi.org/10.1080/02640410701607213

Stoggl, T., & Sperlich, B. (2014). Polarized training has greater impact on key endurance variables than threshold, high intensity, or high volume training. Front Physiol, 5, 33. https://doi.org/10.3389/fphys.2014.00033

Stone, M. J., Knight, C. J., Hall, R., Shearer, C., Nicholas, R., & Shearer, D. A. (2023). The Psychology of Athletic Tapering in Sport: A Scoping Review. Sports Med, 53(4), 777-801. https://doi.org/10.1007/s40279-022-01798-6

Swenson, D. (2021). Ashtanga Yoga - The Practice Manual. Ashtanga Yoga Productions.

Tan, R., Black, M., Home, J., Blackwell, J., Clark, I., Wylie, L., Vanhatalo, A., & Jones, A. M. (2022). Physiological and performance effects of dietary nitrate and N-acetylcysteine supplementation during prolonged heavy-intensity cycling. J Sports Sci, 40(23), 2585-2594. https://doi.org/10.1080/02640414.2023.2176052

Tenforde, A., Hoenig, T., Saxena, A., & Hollander, K. (2023). Bone Stress Injuries in Runners Using Carbon Fiber Plate Footwear. Sports Med, 53(8), 1499-1505. https://doi.org/10.1007/s40279-023-01818-z

Van Hooren, B., Souren, T., & Bongers, B. C. (2023). Accuracy of respiratory gas variables, substrate, and energy use from 15 CPET systems during simulated and human exercise. Scand J Med Sci Sports. https://doi.org/10.1111/sms.14490

Walsh, N. P., Halson, S. L., Sargent, C., Roach, G. D., Nedelec, M., Gupta, L., Leeder, J., Fullagar, H. H., Coutts, A. J., Edwards, B. J., Pullinger, S. A., Robertson, C. M., Burniston, J. G., Lastella, M., Le Meur, Y., Hausswirth, C., Bender, A. M., Grandner, M. A., & Samuels, C. H. (2020). Sleep and the athlete: narrative review and 2021 expert consensus recommendations. Br J Sports Med. https://doi.org/10.1136/bjsports-2020-102025

White, P. (2023). How Coaches Can Use Blood Testing For Better Endurance Training. https://www.trainingpeaks.com/coach-blog/coaches-blood-testing-endurance-training/

Wu, H., Brooke-Wavell, K., Fong, D. T. P., Paquette, M. R., & Blagrove, R. C. (2024). Do Exercise-Based Prevention Programs Reduce Injury in Endurance Runners? A Systematic Review and Meta-Analysis. Sports Med. https://doi.org/10.1007/s40279-024-01993-7

Zamani, H., de Joode, M., Hossein, I. J., Henckens, N. F. T., Guggeis, M. A., Berends, J. E., de Kok, T., & van Breda, S. G. J. (2021). The benefits and risks of beetroot juice consumption: a systematic review. Crit Rev Food Sci Nutr, 61(5), 788-804. https://doi.org/10.1080/10408398.2020.1746629

XVII.Annual Training Plan

Dates: Phase	CW	Competition: Priority	Location	Race type
February	8	C	London	10K
March	11	B	Lisbon	HM
April	18	C	Venice	70.3
June	23	C	Pisa	TT
July	29	B	Munich	M
September	37	A	Sydney	M

Periodisation	CW 1–4	CW 5–11	CW 12–23	CW 24–29	CW 30–35	CW 36–37	CW 38–40
Training Phase	Transition	Preparatory	Preparatory	Competitive	Competitive	Competitive	Transition
Sub-phase	Transition	General preparation	Specific preparation	Precompetitive phase	Main competitive phase	Taper	Transition
Peaking index	4 (CW 1–8); 3 (CW 9–10)		3	2	2	1	4
Run		Aerobic Threshold and Capacity Low intensity 3-6 runs max	Lactate Threshold, Aerobic capacity	Lactate Threshold	Lactate Threshold	Reduced Volume Keep intensity	
Strength		Max Strength AA/MS 3x week 4 reps @ 80% 1RM	Max Strength MS 3x week 4 reps @ 80% 1RM	Maintain Max Strength SM 2x week	Maintain Max Strength SM 2x week	0 - 2 x week	
Cross-train		13 workouts / week 3x cycling (HIIT) 2x swimming (HIIT) 1x Yoga	13 workouts / week 3x cycling (HIIT) 2x swimming (HIIT) 1x Yoga	13 workouts / week 3x cycling (HIIT) 2x swimming (HIIT) 1x Yoga	13 workouts / week 3x cycling (HIIT) 2x swimming (HIIT) 1x Yoga	No cross-train	
Skill				Drafting; U-Turns	Drafting; U-Turns		
Psychological		Goal Setting Dissociation (counting to 100, smile, Atman)	4C: challenge, commitment, control, confidence	Attentional control (YOGA)	Visualisation Count to 10 for hills / u-turns	Dealing with taper-induced stress, Association Positive Self-talk Flow (Pray)	
Nutrition		3-12 g CHO / day / BM (based on workload on day) 1.5 - 1.7g PRO kg / BM	3-12 g CHO / day / BM (based on workload on day) 1.5 - 1.7g PRO kg / BM	1+ fasted run / week < 10% BF 2.2 - 2.4g PRO (lean mass maintenance) 3-12 g CHO / day / BM (based on workload on day)	1+ fasted run / week Gut training 3-12 g CHO / day / BM (based on workload on day)	Melatonin Gut training Reduced food during taper: Protein 1,2 - 2,0 g/kg; CHO 7-12 g/kg; Fat 0,9 - 2,0 g/kg; Overall 32-40 g/kg <10%BF Pre-event 36-48 hours of 12-12g BM CHO (per 24 hours!) Low-fibre diet	
Other		No competition Unloading microcycle after macrocycle Microcycle rythmicity	No competition Unloading microcycle after macrocycle Microcycle rythmicity	Tune-up races Unloading microcycle after macrocycle Microcycle rythmicity	Undulating stress, longer rest	Tactical elements Confidence, Motivation	
Testing Dates							
Medical Dates							