Training for endurance in sport and fitness

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Contents

Introduction

Welcome to this free course where you'll be investigating endurance in sport and fitness. If you're an athlete, a coach or simply an individual who is interested in exercise, having a more in-depth understanding of what endurance is and how it can be trained will be advantageous because endurance is often a key factor in various sports and events. Endurance, in relation to exercise, may be defined as 'the ability to tolerate or withstand the strain of extended exercise' (taken from the *Oxford English Dictionary*). Hence while endurance is important for middle- to long-distance events and team sports, it may also play a role in much shorter-duration events.

This OpenLearn course is an adapted extract from the Open University course E236 *Applying sport and exercise sciences to coaching*.

Learning Outcomes

After studying this course, you should be able to:

- explain what is meant by the concept of endurance
- understand the physiological principles that underpin endurance
- apply a range of training techniques for endurance in practice
- assess which training methods are most suitable for performances in different sports.

1 What is endurance?

Endurance is often associated with sports or events that last for extended periods of time. These can include team sports, marathon running or triathlons. However, endurance is important in a multitude of sports. The following activity will get you to think about how important endurance can be in an alternative sport.

Activity 1

Allow 10 minutes for this activity

Have a look at the image below showing a rock climber ascending a climb. As you look at the image, answer the following question: why does the climber need endurance? To do this, think about how long the climb may take, how hard and long her muscles may have to contract and how much rest may be available.

Note down your answer in the box below the image.

Figure 1 Endurance during rock climbing.

Provide your answer...

Discussion

Depending on the length of the climb, a rock climber may be on the rock face from minutes to hours. A climber's cardiovascular and respiratory systems need to continually supply the working muscles with oxygen to supply fuel (via the aerobic energy system) for the length of the climb and prevent fatigue (cardiorespiratory endurance). Muscles will need to continually contract in order to provide propulsion, strength and maintain technique (muscular strength endurance). Using a combination of cardiorespiratory and muscular strength endurance, climbers can maintain a constant high speed and/or workload close to their maximum, throughout the attempt (speed/power endurance). Following a climb, a climber's body will be working hard to recover by replenishing energy stores, reducing muscle inflammation and repairing muscle damage. Recovery utilises the aerobic energy system and cardiorespiratory endurance is important to this process.

In the rest of this course you'll investigate the key factors relating to endurance and review the available training methods for optimising endurance performance.

2 Who needs endurance?

Endurance events require the body to sustain effort for a prolonged period, and to do this it needs a considerable supply of energy. Endurance exercise relies on the aerobic energy system, which uses oxygen to convert the body's extensive store of carbohydrates and fats into energy. When the aerobic system becomes the dominant energy system in exercise, it dictates that endurance becomes the major feature of the activity. Table 1 shows the aerobic and anaerobic energy systems' contribution to maximal exercise.

Table 1 Estimates of anaerobic and aerobic energy contribution during selected periods of maximal exercise

Duration of exhaustive exercise (sec)	**% of energy supplied by the anaerobic system**	**% of energy[1] supplied by the aerobic system**
0–10	94	6
0–15	88	12
0–20	82	18
0–30	73	27
0–45	63	37
0–60	55	45
0–75	49	51
0-90	44	56
0–120	37	63
0–180	27	73
0–240	21	79
a Approximately ± 10% at the 95% prediction level		

[1] Approximately ±10% at the 95% prediction level

Source: Gastin (2001)

As the duration of exercise increases, so does the contribution from the aerobic energy system. Additionally, as exercise intensity is reduced, or intermittent rest periods are included (as in team sports), the aerobic contribution to exercise will increase. So, does this mean that success in all events and sports relies on endurance? To answer this question, you will analyse the endurance needs of three athletes in the next activity.

Activity 2

Allow 20 minutes for this activity

Imagine that you are working with three athletes; a water polo player, a 200 m sprinter and a marathon runner. You are performing a needs analysis of their sport/event to determine how much endurance focus is needed in their training programme. Consider the duration and intensity of each sport/event that each athlete participates in, then answer the question: for which of the athletes is endurance relatively more important, and why?

Provide your answer...

Discussion

A water polo player is required to repeatedly sprint swim, wrestle opponents, tread water and recover between efforts indicating that all energy sources will contribute to performance. Zinner *et al*. (2015) suggested that in a match, 50–60% of a water polo player's energy is supplied by the aerobic energy system indicating that endurance will play a large role. For the sprinter, their 200 m personal best is 26.4 seconds. Therefore, according to Table 1, 27% of their energy will come from the aerobic energy system during the race. Additionally, on a race day the aerobic energy system will contribute to recovery between heats. Therefore, endurance should still play a role in training. For the marathon runner, as a beginner the marathon may take them 4–5 hours and the aerobic energy system will supply approximately 97.5% of their energy (Gastin, 2001). Therefore, endurance will be the focus of that individual's training programme.

With endurance identified as a 'need' for the athlete, you need to understand how to train it effectively; here, you first need to determine which physiological attributes are relatively more important for endurance performance. You'll tackle this in the next section.

3 Endurance exercise: physiological determinants

Figure 2 Physiological determinants of endurance exercise.

Although various physiological variables may contribute to endurance performance, the four key physiological determinants of endurance exercise are (according to Joyner and Coyle, 2008; Blumkaitis *et al*., 2016):

1. **VO_2 max**: the maximum amount of oxygen that the body can use
2. **lactate threshold**: the exercise intensity and/or speed at which the body produces more lactate than it can remove
3. **exercise economy**: the energetic cost of exercise
4. **anaerobic power and/or capacity**: the ability to sustain a high level of force.

To understand how to train for endurance effectively you need to understand the importance of these determinants for endurance exercise.

3.1 VO_2 max

VO2 max is the maximum volume of oxygen (in millilitres) that the body can use, per kilogram of body weight per minute (ml/kg/min). During endurance exercise the aerobic energy system uses oxygen to convert the body's fat and glycogen stores into the body's unit of energy (adenosine triphosphate or ATP). Having the ability to consume and use a large volume of oxygen (VO2) means that a higher level of energy, and thus performance, can be generated. The VO2 that can be utilised by the body is determined by the delivery, extraction and distribution of oxygen to the working muscles (see Table 2).

Table 2 Determinants of VO_2 max

Oxygenation of blood	Delivery of oxygen	Oxygen extraction and use by tissues
Lungs	Cardiac output	Capillary density
	(stroke volume x heart rate)	(number of capillaries per unit cross-sectional area of muscle)
Transfer to blood	Blood volume and flow	Mitochondrial density
		(number of energy cells)
	Haemoglobin content	
	(O_2-carrying capacity of blood)	

Stroke volume – the amount of blood pumped out by a single contraction of the heart – is considered the most important factor contributing to VO2 max; elite athletes tend to have higher blood volumes, higher stroke volumes and consequently lower resting and exercising heart rates (Joyner and Coyle, 2008). As well-trained athletes have already improved their oxygen delivery and extraction, large increases in VO2 max are unlikely. Therefore, to further enhance endurance performance, trained athletes may focus on other key determinants such as increasing their lactate threshold or exercise economy.

3.2 Lactate (anaerobic) threshold

First work through the interactive. Click on the icon or on 'View interactive version'.

Interactive content is not available in this format.

The lactate (anaerobic) threshold and VO_2 max determine the intensity and/or speed that can be maintained throughout an endurance event (performance VO_2) (Joyner and Coyle, 2008).

In comparison with recreationally active individuals, elite endurance athletes not only have much higher VO_2 max values, but their anaerobic threshold is at a much higher percentage of their VO_2 max, so they can generate and maintain a much higher level of power and speed during an event.

3.3 Exercise economy

Being more economical during endurance exercise should lead to a reduction in the amount of energy used for a given power output, and therefore postpone the onset of fatigue. In running, for example, if two athletes have the same VO2 max but one has a better running economy, that athlete would use less energy when running at the same speed and should therefore be able to run for longer, or faster, for the same power output. In Activity 3 you'll investigate running economy further and how you can improve it.

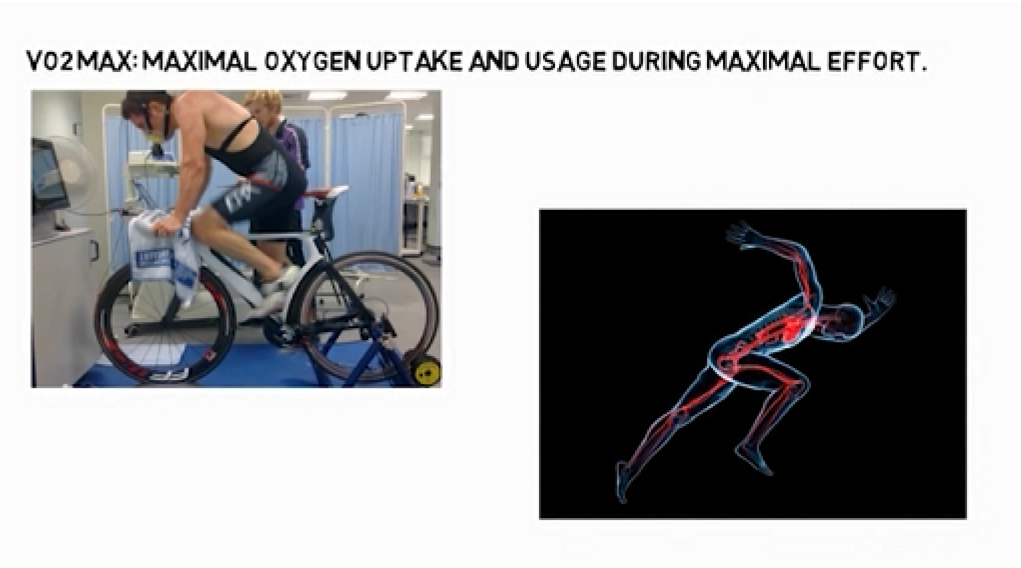
Activity 3

Allow 15 minutes for this activity

Watch Video 1, which explains the factors that determine running economy and how these may be improved. While you watch Video 1, note down the factors that you as an athlete or coach may be able to influence – for example, if working with a marathon runner, how could you improve their running economy?

Video content is not available in this format.

Video 1 Improve your running economy



Provide your answer...

Discussion

Running economy is determined by multiple predetermined factors. However, there are some factors that can be trained for. A marathon runner may improve their running economy by reducing body fat (if they need to), wearing lighter shoes with good cushioning, and improve their biomechanics (in terms of freely chosen stride length, minimal movement at the arms, more acute knee angle, and low bouncing when running). Additionally, by including resistance and plyometric training in their training programme they can enhance their running economy by improving the function of her neuromuscular system.

For longer-duration events where fatigue plays a relatively larger role, lactate threshold and running economy become relatively more important. However, in shorter-duration endurance events (such as a 5 km run), where fatigue plays a smaller role, the VO2 max and anaerobic capacity of athletes should correlate more accurately with performance.

3.4 Anaerobic power/capacity

Figure 3 The Vertical Jump Test.

The first three determinants (VO_2 max, lactate threshold and exercise economy) have been synonymous with endurance research for years. However, more recent research has added anaerobic power and/or capacity as a fourth key determinant of endurance exercise. Research suggests that power tests (that is, vertical jump and 50 m sprint test) correlated relatively better with 5–10 km performance than VO_2 max (Baumann *et al*., 2012; Blumkaitis *et al*., 2016).

Middle-distance races (1500 m to 5 km) are commonly run at 90–100% of VO_2 max and therefore a considerable contribution is required from the anaerobic energy system during the race because the races are at an intensity beyond their anaerobic threshold. The anaerobic energy system may be used not only to maintain a high speed (power output) during the race, but also to gain a fast start, quickly pass a competitor, chase down a breakaway or engage in a sprint finish.

Now that you've gained more understanding of the key physiological determinants of endurance exercise, the next stage is to determine the most effective training methods for developing these determinants.

4 Training endurance

Figure 4 Water Polo endurance.

Endurance training usually falls into two categories: extensive training or intensive training. Extensive training aims to extend the duration of exercise during which you can maintain heart rate, good technique, equilibrium of pace and effort. Intensive training conditions the body to endure the demands of high-intensity exercise for as long as possible. The different types of training available to enhance aerobic endurance are explained in Table 3.

Table 3 Types of aerobic endurance training

Long Slow Distance	Low density (~70% of VO2 max), long duration (≥30–120 minutes) training enhances running economy, fuel utilisation and cardiovascular endurance.
Fartlek	Speed play training combines high and low intensity training to enhance VO2 max, lactate threshold, running economy and fuel utilisation.
Pace/tempo	A 20–30 minute session at lactate threshold/race pace intensity enhances energy production from both aerobic and anaerobic metabolism.
Aerobic intervals	3–5 minute intervals at an intensity close to VO2 max with a work:rest ratio of 1:1 will enhance VO2 max and anaerobic metabolism.
High Intensity Intervals	Short (30–90 seconds), high intensity (> VO2 max) intervals with a work:rest ratio of 1:5 will enhance anaerobic capacity, VO2 max and potentially running economy.

Source: Reuter and Dawes (2016)

Using the description of each training method in Table 3, which type of training do you think would be best suited for developing endurance in a team-sports player? The next activity will help you answer these questions.

Activity 4

Allow 20 minutes for this activity

Endurance is important within many team sports. For example, in water polo endurance is required to maintain a high performance throughout the match. So what type of endurance training would benefit a water polo player?

First, examine the intensities, durations and aims of each type of training in Table 3. Then answer the following question: which training method is best suited for a water polo player and why?

Provide your answer...

Discussion

In water polo, a player is required to repeatedly sprint-swim (high intensity), wrestle opponents (high intensity), tread water (moderate intensity) and recover between efforts (low intensity), indicating that all energy sources are contributing to performance. Therefore, you probably indicated that all types of training would be beneficial. However, from a purely endurance perspective, Long Slow Distance Training (LSDT), aerobic intervals and fartlek training may offer the best results. Typically, for most team sports LSDT is used in the off-season to build up a base of aerobic fitness; then in pre-season, aerobic interval training and High Intensity Interval Training (HIIT) are used to replicate the intermittent high-intensity efforts and provide specificity of training while still achieving some endurance adaptations. Fartlek training is often used in both the base and pre-season phases because training at varying intensities enhances VO2 max, lactate threshold and exercise economy.

The types of aerobic programming you investigated in Activity 4 offer excellent opportunities to develop endurance. In addition to these training modalities, strength training may enhance endurance performance; in the next section you'll look at how.

5 Resistance training for endurance

Whether someone is climbing, running, swimming or playing sport for an extended period, muscular strength endurance (MSE) is required for muscles to continually contract so as to provide propulsion and power, and maintain technique. Therefore, resistance training to develop muscular strength endurance may enhance the performance of endurance athletes. To develop muscular endurance, resistance training should be performed using low intensities, high repetitions (volume) and limited rest to create the repetitive strain on the muscles (see Table 4). For an athlete who is new to resistance exercise, one set of exercises per muscle group should create beneficial muscular adaptations. However, 2–3 sets of repetitions per exercise is recommended for more experienced athletes.

Table 4 Training principle recommendations for training goals

Training goal		Load (% of 1RM)	Repetitions	Sets	Rest
Maximal strength	core exercises	≥85	≤6	2–6	2–5 min
	assistance exercises	80			
Power	single-effort event	80–90	1–2	3–5	
	multiple-effort event	75–85	3–5		
Hypertrophy		67–85	6–12	3–6	30–90 s
Muscular endurance		≤67	≥12	2–3	≤30 s

Source: Sheppard and Triplett (2016)

For more advanced endurance athletes, the volume of endurance training completed through running, cycling or swimming should create sufficient positive endurance adaptations in the muscle. Therefore, instead of using endurance volumes and intensities, resistance training can focus on developing muscular strength, which allows muscles to function more effectively, to expend less energy in performing the same action and to become more resilient to injury (Blagrove, 2015). Incorporating strength training into an endurance athlete's programme should enhance the athlete's exercise economy and anaerobic power, and reduce their risk of injury (Blagrove, 2015; Denadai *et al*., 2017). However, when combining endurance and strength training in a programme, more care is needed to control programming variables (frequency, intensity, time and rest) to minimise the risk of overtraining and to maximise the success of the programme.

6 Programming endurance training

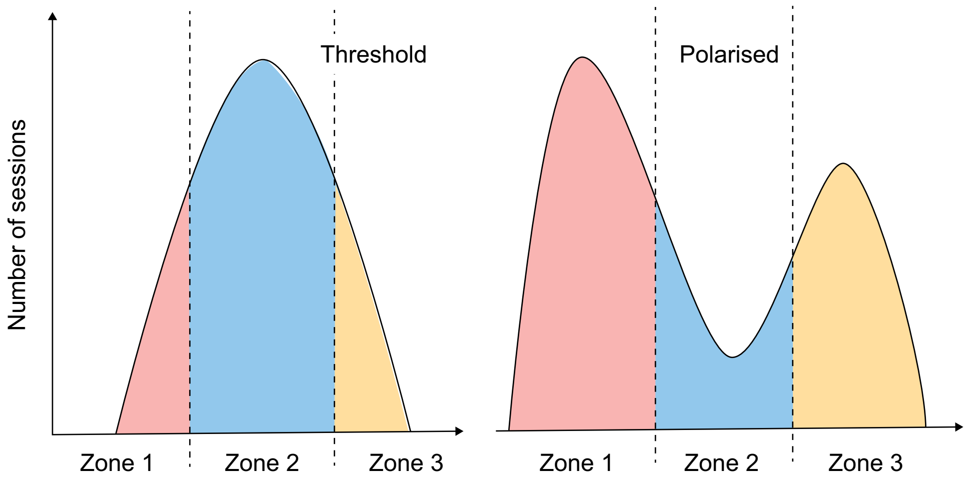


Figure 5 Training intensity/volume distribution for threshold and polarised training.

Now that you've learned about the different methods available to train for endurance, the next question is: how do these training modalities fit together in a programme? Should an endurance athlete focus on LSDT or should he or she prioritise higher intensities? The distribution of intensities across a training programme (**training intensity distribution**, or **TID**) is commonly debated by researchers aiming to identify the optimal TID to maximise performance while minimising the risk of overtraining. Two popular models of TID are **polarised training** and **threshold training**, illustrated in Figure 5.

You will look at each model of training and then complete an activity in which you apply this knowledge and choose the optimal model for Petra, an athlete who is looking to complete their first marathon (see Box 1).

Box 1 Case study: Petra

Petra is a 30-year-old recreational runner who regularly completes 2–3 runs a week ranging from 5–10 km. She has just accepted a place to run for a charity in a marathon which is taking place in 6 months' time. However, usually when trying to increase her distance, she often gets small injuries which prevent her from training and so she now avoids running further than 10 km. Petra only enjoys running and therefore has not included any form of cross training or resistance training in her previous programmes.

6.1 Polarised training (or 80/20 training)

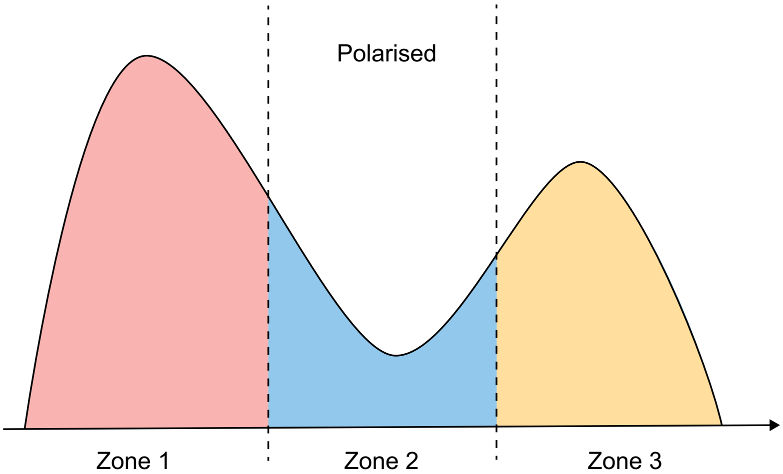


Figure 6 Training intensity/volume distribution polarised training.

The 'polarised' model of TID suggests that 80% of an endurance athlete's training time should be performed below the aerobic threshold in zone 1 (low to moderate intensity), and 15–20% should be spent in zone 3 (high intensity), above the anaerobic threshold (see Figure 6) (Fiskerstrand and Seiler, 2004). Many elite endurance athletes from multiple sports (rowing, running, cycling, swimming and skiing) have followed this periodised model of training (Seiler and Tønnessen, 2009) and have been highly successful. The low-intensity training enhances exercise economy, fuel utilisation and lactate threshold and the high-intensity training stimulates VO_2 max and anaerobic capacity adaptations while reducing the risk of injury due to limited time at high intensity (Stöggl and Sperlich, 2014).

In contrast to the polarised model of training, the threshold model suggests that more beneficial endurance adaptations may be gained from training at moderate to high intensity in zone 2.

6.2 Threshold training

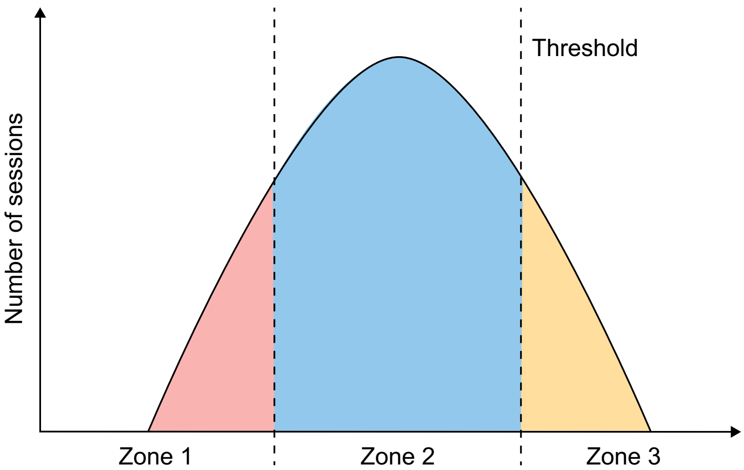


Figure 7 Training intensity/volume distribution for threshold training.

The ‘threshold’ model of TID suggests that the bulk of training should be completed in zone 2 of the three-zone model of intensity (see Figure 7). Threshold training works close to or at your anaerobic threshold and has been shown to be more effective than low-intensity training at generating beneficial endurance adaptations: increased plasma volume, mitochondrial volume, lactate threshold, muscle glycogen storage, muscle capillarisation, stroke volume, cardiac output, VO_2 max, slow-twitch muscle fibre hypertrophy and muscle fibre type conversion (type IIb to type IIa; Billat *et al.*, 2003; Coggan, 2016; Fiskerstrand and Seiler, 2004).

Research confirms that elite endurance athletes have adopted a threshold training model, with positive results (Billat *et al.*, 2003; Fiskerstrand and Seiler, 2004). However, training regularly at an increased intensity may lead to an accumulation of stress to the autonomic nervous system (Neal *et al.*, 2012) and increase the risk of injury if insufficient rest is provided (Owen *et al.*, 2015). Now complete Activity 5.

Activity 5

Allow 45 minutes for this activity

You have considered two TID models as approaches to enhancing endurance performance. If you were Petra’s trainer, which of these models would you advise her to use, and why?

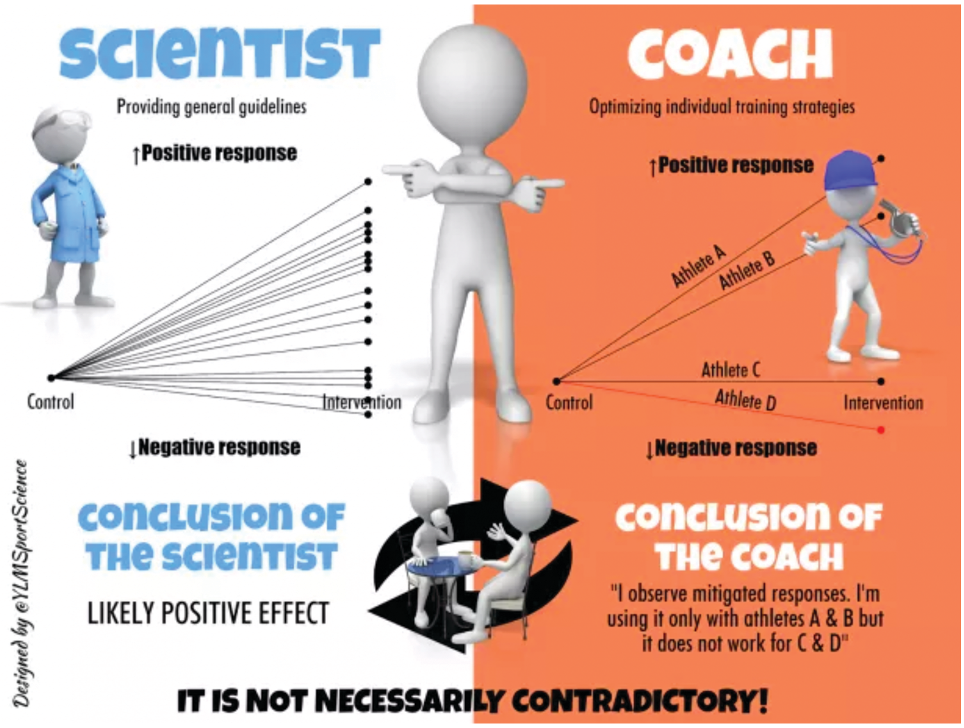


Figure 8 Scientist v coach.

Provide your answer...

Discussion

A personal trainer or coach should critique the available research in order to be able to select the optimal training strategy for Petra. She is a recreational athlete, and research would suggest that all methods of training would be effective in enhancing her endurance performance in preparation for the marathon. If you investigated further by looking online or in journal articles that compare the models (for example, using Google Scholar) you'll have discovered that research comparing the effects of polarised and threshold training on endurance performance (for example, time-trial performance, VO2 max, time to exhaustion and RE) suggests that polarised training is the more effective (Neal *et al*., 2012; Munoz *et al*., 2014; Rosenblat *et al*., 2019). However, athletes undertaking polarised training need a lot of time to complete a high volume of training at low intensity, and currently Petra is only completing 2–3 runs a week. Therefore, if Petra has limited time a threshold approach could be adopted but a good pre-habilitative strength programme would be needed to minimise risk of injury.

A personal trainer or coach should use their experience and understanding of the science while factoring in various characteristics of the athlete (that is, experience, environment and relationships) to make an informed decision. The science doesn't always work for everyone and it's the job of the trainer/coach to decide.

7 End-of-course quiz

You can take part in a quiz which is an opportunity to check your learning of some of the main points addressed in this course.

End-of-course quiz

What are the key determinants of endurance performance?

- ☐ a) VO2 max, Lactate threshold, Exercise economy, Anaerobic power
- ☐ b) VO2 max, Lactate turnpoint, Exercise economy, Aerobic power
- ☐ c) VO2 max, Lactate threshold, Exercise economy, Anaerobic power
- ☐ d) VO2 peak, Lactate turnpoint, Exercise economy, Aerobic power

How can running economy be improved?

- ☐ a) Reduce body fat
- ☐ b) Improve biomechanics
- ☐ c) Wear lighter shoes with good cushioning
- ☐ d) all of the above

Which of the following is not a form of endurance training?

- ☐ a) Long Slow Distance Training
- ☐ b) High Intensity Interval Training
- ☐ c) Plyometrics
- ☐ d) Fartlek training

Why should strength training be included within an endurance athletes training programme?

- ☐ a) To reduce the risk of injury
- ☐ b) To enhance exercise economy
- ☐ c) To enhance anaerobic power
- ☐ d) All of the above

Which of the following models of training intensity distribution is more beneficial for endurance performance?

- ☐ a) Pyramid training
- ☐ b) Polarised training
- ☐ c) Threshold training
- ☐ d) Fartlek training

Conclusion

This free course has provided you with an explanation of what endurance is, how to train it effectively and the optimal method of distributing training intensity across a programme. The course has also helped you to identify dominant themes in research. The main points covered were:

- VO_2 max, lactate threshold, exercise economy and anaerobic power are all key determinants of endurance performance.
- Pace/tempo training, interval training, high-intensity interval training and Fartlek training will create beneficial adaptations for all determinants of endurance performance depending on the intensity and duration of exercise.
- Resistance training for endurance athletes should focus on developing strength and power rather than endurance.
- Polarised training is more effective than threshold training at enhancing endurance performance.
- It is the trainer's responsibility to understand the underpinning science of each technique/model to determine the most appropriate one for your individual athlete.

This OpenLearn course is an adapted extract from the Open University course E236 *Applying sport and exercise sciences to coaching*.

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Acknowledgements

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Figure 5: Adapted from-Stöggl, T.L., 2018. What is the best way to train to become a star endurance athlete. Front. Young Minds, 6(17), pp.10–3389. https://kids.frontiersin.org/article/10.3389/frym.2018.00017

Figure 6: Adapted from-Stöggl, T.L., 2018. What is the best way to train to become a star endurance athlete. Front. Young Minds, 6(17), pp.10–3389. https://kids.frontiersin.org/article/10.3389/frym.2018.00017

Figure 7: Adapted from-Stöggl, T.L., 2018. What is the best way to train to become a star endurance athlete. Front. Young Minds, 6(17), pp.10–3389. https://kids.frontiersin.org/article/10.3389/frym.2018.00017

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