

## Assessment Guide

### Seminar 1: Running Economy (10 points)

- 1) Define running economy and explain how it can be measured.
- 2) Describe some of the key spatiotemporal variables that can be measured during running.
- 3) Which mechanisms may explain associations between spatiotemporal variables and running economy?

#### *Assessment guide*

- 1) *The oxygen demand per distance for a given velocity of submaximal running. During steady-state treadmill running,  $\text{VO}_2$  is measured at different constant speeds. These values are then interpolated in order to compare across a group at a given velocity, relative to body mass per minute or per kilometre.*
- 2) *GCT is the time per stride that a foot is in contact with the ground; stride rate is the number of strides per minute; stride length is the length of the total stride [here you could also refer to other variables such as step frequency and step length].*
- 3) *A higher stride frequency is associated with better running economy. This could be due to an associated shorter stride length which can reduce the horizontal forces. Propulsive horizontal forces cost a lot in terms of oxygen. Spatiotemporal characteristics may be to some extent self-optimised, reflecting that the runners are used to/familiar with these characteristics.*

### Seminar 3: Biomechanics of overuse injuries (10 points)

1. Describe the different types of loading that the lower limb bones, for example the tibia, may experience during running. How can the loading influence bone remodelling?
2. What are important factors to consider when designing a research study to assess biomechanical risk factors for running overuse injury?

#### *Assessment guide*

- 1) *Lower limb bones experience axial loading and bending, which can result in both compression and tension. There is internal loading experienced, largely due to*

*muscular forces. Bone loading stimulates remodelling where existing material is removed and new material deposited, which results in a stronger bone over time if there is sufficient recovery.*

- 2) An RCT would be the strongest study design, and retrospective/cross-sectional would be weakest. Ideally injury outcomes would be measured prospectively, using clear definitions and specific for different injury sites. A lengthy follow-up period would be required with a large sample of participants (>1000) with clear inclusion criteria for the participants. If possible, it would be ideal to control running exposure and footwear, for example.*

#### **Seminar 4: Performance analysis in Team sport (10 points)**

1. Explain how match analysis can be used to support coaching and performance improvement (4 points)
2. A team shows reduced high-speed running in one match compared with previous matches. Identify factors that could explain this result without indicating reduced performance (6 points)

#### *Assessment guide*

- 1. The primary goal of match analysis in team sports is to systematically analyse the performance of teams and players to inform tactical decisions, training focuses, and player development. This data-driven approach allows coaches to tailor their strategies and training programs based on objective insights, ultimately enhancing team performance and competitive advantage.*
- 2. A reduction in high-speed running during a match does not necessarily indicate reduced performance, as this outcome can be influenced by several contextual and tactical factors. These may include a deliberate tactical approach (e.g. maintaining possession or adopting a low defensive block), match status (such as protecting a lead), or the quality and style of the opposition, which may reduce the need for high-intensity running. Environmental conditions, fixture congestion, and player role changes can also affect physical outputs. Therefore, high-speed running data must be interpreted within the broader match context to avoid misleading conclusions about team or player performance.*

## Seminar 6: Integrated performance analysis (10 points)

1. During a 15-km individual-start cross-country skiing competition, oxygen demand and oxygen uptake interact dynamically as athletes navigate varying terrain (uphill, flat, and downhill sections).
  - a. How do changes in terrain influence the relationship between oxygen demand and oxygen uptake? Describe what happens during uphill sections and immediately after, in a downhill section.
  - b. Explain how skiers use this interplay between oxygen demand and uptake to optimize pacing, tactics, and overall performance.

### Assessment guide

- a. On level terrain, oxygen demand ( $\text{VO}_2\text{dem}$ ) and oxygen uptake ( $\text{VO}_2$ ) are closely matched. During uphill skiing,  $\text{VO}_2\text{dem}$  becomes significantly higher than  $\text{VO}_2$ , resulting in an oxygen deficit. In contrast, during downhill sections,  $\text{VO}_2\text{dem}$  is lower than  $\text{VO}_2$ , allowing athletes to partially recover the oxygen deficit accumulated on the uphills.*
  - b. A sustained oxygen deficit will eventually lead to exhaustion if it persists too long, as there is an individual maximal accumulated oxygen deficit (MAOD). However, because athletes can recover part of the oxygen deficit accumulated during climbs on downhill sections, they can repeatedly utilize portions of their MAOD throughout the race. To optimize performance, athletes should adjust their uphill pacing so that the oxygen deficit remains within a range that can be recovered during the descent. If uphill intensity is too low relative to the recovery capacity on downhills, pacing becomes suboptimal. Conversely, if uphill intensity is too high, recovery will be incomplete, which may lead to premature exhaustion unless adjustments are made later in the race. This, too, represents suboptimal pacing.*
2. Pacing is a critical determinant of performance in middle- and long-distance running events held on level ground, such as track races (800 m to 5000 m) and road races (half-marathon and marathon).
    - a. Describe pacing patterns that are considered optimal for performance in the 800 m, 5000 m, and marathon.
    - b. Explain the tactical challenges related to pacing faced by a runner with comparatively lower physical capacity in a competitive field.

## Assessment guide

- a. *It is evident that the duration of the 5000m and marathon running (approximately 30 minutes and more than 2 hours, respectively) and the level ground for these activities necessitate a relatively constant aerobic energy production. The absence of up-and-down hills in these activities does not offer opportunities to recover from oxygen deficits, as is the case in cross-country skiing. Consequently, accumulated oxygen deficits would lead to a reduction in performance, with the exception of the final stretch into the finish line. Here, the accumulated oxygen deficit is cleared after the competition, allowing for a higher pace at the end of the competition. In the 800 m race, competitors initiate and conclude the event at a higher velocity than during the middle portion of the race. The delayed aerobic response to physical exertion during the initial minutes of exercise is utilised to initiate the race at a higher velocity than during the middle portion of the race. The final segment of the race is completed at a higher velocity, as the accumulated oxygen deficit is eliminated after the conclusion of the event.*
- b. *Athletes experience psychological benefits and improved air resistance when running in groups. While the most physically capable athletes typically establish an even pacing strategy, this pace is likely to be too high for those with a lower physical endurance capacity. Consequently, athletes with a lower capacity must consider the trade-offs involved in running in groups, following the pacing dictated by their more capable counterparts, as opposed to the increased possibility of running alone and losing ground to those who can maintain the pace without accumulating oxygen deficits.*

## Seminar 7: Ergogenic aids (10 points)

A male cross-country skier comes to you with a question whether he would benefit from using caffeine for performance in the Birkebeiner race (53 km).

1. Give an overview of the proposed ergogenic mechanisms, quality of scientific evidence and relevance for use of caffeine supplementation in context of this race.
2. Provide concrete advice for him with respect to supplementation protocol (type, amount and timing) and discuss on how factors that can determine whether he responds to the supplement.

## Assessment guide

### 1. Explaining the main ergogenic mechanisms and level of evidence:

- Strong evidence
  - increased endorphin release
  - improved neuromuscular function
  - improved vigilance and alertness
  - reduce perception of exertion during exercise
- Low levels of evidence/speculative
  - Effect on fat oxidation and calcium regulation in muscle?
  - Effect on strength and power?

Explaining the relevance of “strong evidence” mechanisms on prolonged endurance performance:

- Reduced perception of exertion towards end of the race likely result in positive performance effect, as seen in several exhausting tests and TT tests of various duration.
- More willing to take risk, increased speed in pacing – can be positive, but also potentially negative in such a long race (if the body is not able to keep the pace to the end).

Up to 2 points for correct description of mechanisms, up to 2 points for discussion on their scientific evidence. Up to 2 points for discussing how these are relevant for the 53 km race. 1 point for good reflection and overall discussion.

TOTAL max 7 points.

### 2. 1 point for good description of proposed protocol: Acute supplementation 3-6 mg/kg 1 hour prior to race. Use of caffeine supplement not coffee, as amount of caffeine in coffee varies substantially.

Up to 2 points for discussion on response: individual response determined by genes, age, gender, training status, diet, belief. Up to 33% non-responders in single test protocols.

TOTAL max 3 points.

## Seminar 8: Sex differences in oxygen transport and utilization during exercise (10 p)

1. Describe what arterial oxygen saturation ( $SO_2$ ) is and how  $SO_2$  impacts maximum oxygen uptake ( $VO_{2max}$ ).
2. What is the difference in  $SO_2$  between the following individuals and situations, and why? (precise numbers are not essential, but the directional change and a description of mechanisms are paramount)
  - a. Compare  $SO_2$  between individuals that are untrained ( $VO_{2max}$ : under 45 ml/min/kg) and well-trained ( $VO_{2max}$ : over 75 ml/min/kg) during maximum exercise (> 95% of maximum heart rate)
  - b. Compare  $SO_2$  at sea level and at 2500 meters above sea level during maximum exercise
  - c. Compare  $SO_2$  when an untrained individual inhale a higher oxygen gas fraction than normal air (for instance, 26% oxygen) vs normal air during maximum exercise
  - d. Compare  $SO_2$  when a well-trained individual inhale a higher oxygen gas fraction than normal air (for instance, 26% oxygen) vs normal air during maximum exercise

### Assessment guide

1. *Arterial oxygen saturation ( $SO_2$ ) is how many percent of haemoglobin that is loaded with oxygen. A given percent-point reduction in  $SO_2$  will lower the arterial oxygen content proportionally. Therefore,  $SO_2$  impact systemic oxygen delivery together with haemoglobin concentration and cardiac output.*
2.
  - a. *In untrained to moderately trained individuals, the lungs (ventilation and gas exchanges) constitute more or less no limitations to the maximum oxygen uptake. The arterial  $SO_2$  is kept close to 100% during maximum exercise, meaning that the blood, even with higher lung capacity, could not take up more oxygen. However, in well-trained individuals, arterial  $SO_2$  can fall close to or below 90% during maximal exercise, which would limit their maximum oxygen uptake proportionally. This is called exercise-induced arterial hypoxaemia (term not needed to get full score, but bonus). One theory for reduced arterial  $SO_2$  in well-trained individuals is that the cardiac output and muscle's ability to consume oxygen both improves because of training, while the pulmonary systems do not adapt to the same extent. As such, the increased "demand" caused by the up-scaled cardiovascular and metabolic systems are higher than the pulmonary systems capacity for gas exchanges. One mechanism included in this is that the red blood cells' transit time through the pulmonary capillaries is too quick to fully load and saturate*

*haemoglobin by oxygen.*

- b. At higher altitudes, arterial  $SO_2$  falls, irrespective of training status, and the decline in  $VO_{2max}$  is linear with the fall in  $SO_2$ . Hence, the lungs gradually become a greater limitation to  $VO_{2max}$  with increasing altitude.  $SO_2$  and  $VO_{2max}$  reduces by approximately 6% per 1000 meters increase in altitude (e.g., 15% at 2500 vs 0 meters).*
- c. Since the untrained individual has almost 100%  $SO_2$  during maximum exercise breathing normal air, breathing a gas mixture containing 26% oxygen would not affect arterial  $SO_2$  and  $VO_{2max}$ .*
- d. However, when a well-trained person does the same, who is characterized by having an arterial  $SO_2$  of close to 90% when breathing normal air, this person's  $SO_2$  and  $VO_{2max}$  would increase when breathing 26% oxygen.*

### **Seminar 9: Strength training (10 points)**

1. Describe how mechanical tension during resistance exercise can be sensed by muscle fibres and translated into intracellular signalling cascades stimulating muscle protein synthesis!
2. Explain how this knowledge can be used to design effective resistance training interventions, considering load and volume variables!

### *Assessment guide*

- 1) Mechanical tension during resistance exercise is detected by muscle fibers through several complementary mechanisms:
  - **Costameres / Integrins**  
Mechanical forces deform the muscle membrane and the cytoskeleton. Integrins (e.g.,  $\alpha_7\beta_1$ ) act as mechanosensors and transmit force into the cell, activating focal adhesion kinase (FAK) and downstream signaling.
  - **Titin**  
Titin behaves like a molecular spring. Increased tension changes titin stiffness and triggers signaling through pathways such as titin kinase, which influences mTOR activation.
  - **Z-disc and cytoskeleton structures**  
Deformation of Z-discs stimulates signaling proteins (e.g.,  $\alpha$ -actinin-associated complexes) that regulate hypertrophy.
  - **Cell swelling and sensors that sense changes in stiffness of the ECM**

Once sensed, tension activates a cascade of anabolic signals:

#### **A. mTORC1 activation**

Mechanical tension is *the* primary activator of mTORC1 — the central regulator of muscle protein synthesis.

Pathways include:

- **Phosphatidic acid (PA)** production (via mechanical activation of phospholipase D).
- **FAK → PI3K → Akt → mTOR** signaling.
- **Tension-induced localization of mTORC1 to the lysosome**, where it becomes activated.

#### **B. MAPK / ERK pathways**

Mechanical deformation activates MAPK signaling (ERK1/2, p38), which further promotes muscle growth and satellite cell activity.

#### **C. Calcium- and ROS-mediated signaling**

Although less dominant than mTORC1, tension-induced calcium fluctuations and reactive oxygen species also stimulate hypertrophic pathways.

Activated mTORC1 stimulates:

- **Increased initiation of mRNA translation**
- Upregulated ribosomal biogenesis
- Increased synthesis of myofibrillar proteins (myosin, actin, titin)

The result is an increase in net muscle protein balance and, over time, *muscle fiber hypertrophy*.

2. Understanding mechanotransduction may help optimizing training variables such as **load, volume, effort, and time under tension**.

#### **A. Load (Intensity)**

Mechanical tension increases with **high force production**, not necessarily high load alone.

**Practical implications:**

- Hypertrophy can be achieved across a wide load spectrum (~30–90% 1RM) *if* sets are performed close to failure (high fiber recruitment).
- Heavier loads (>70% 1RM) naturally produce high tension early in the set and especially target high-threshold motor units.

## B. Volume

Volume determines the **total amount of mechanically effective tension** applied.

- More sets → more mTOR activation cycles → more hypertrophy (up to an individual's recoverable threshold).
- Effective volume depends on:
  - number of hard sets
  - effort level

A typical evidence-based hypertrophy range:

**10–20 hard sets per muscle per week** (adjusted individually).

## C. Effort (proximity to failure)

Mechanical tension at the muscle fiber level is *maximal* when motor units are fully recruited — which occurs as you approach failure.

## D. Time under tension and repetition tempo

Mechanical tension is sensed during:

- peak force,
- stretch under load,
- and prolonged contraction time.

Strategies:

- Controlled eccentrics (2–4 seconds) increase fiber-level tension.
- Lengthened-position training (e.g., RDL, incline curls) may amplify mechanotransduction.

By manipulating load, volume, and effort to maximize mechanical tension and muscle fiber recruitment, we can design highly effective resistance training programs that stimulate hypertrophy efficiently and safely.