Fatigue in Sport and Exercise

التعب أثناء ممارسة الرياضة و التمارين

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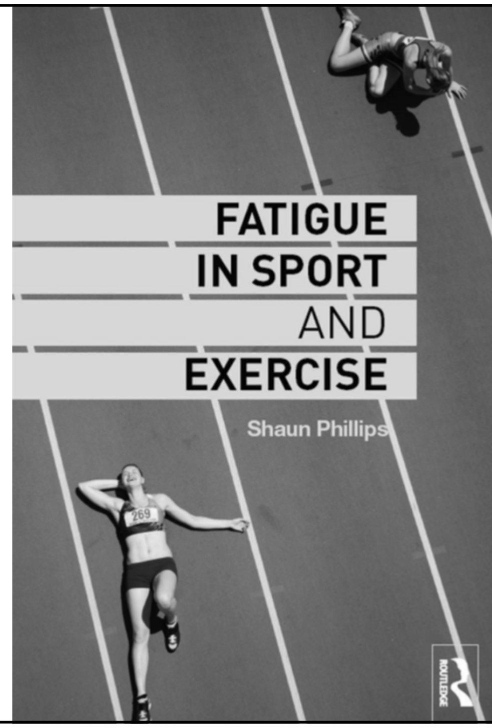

Chapter 1

Defining and measuring fatigue in sport and exercise

تعريف و قياس التعب فى الرياضة والتمارين

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Part 1 – Defining fatigue

الجزء الأول –تعريف التعب

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Introduction مقدمة

- The study of fatigue in humans has been a source of interest for over a century.
- لقد كانت دراسة التعب عند البشر مصدراً للاهتمام لأكثر من قرن من الزمان.
- The first [phenomenon characterizing fatigue] is the diminution of the muscle force.
- الظاهرة الأولى [التى تميز التعب] هى انخفاض قوة العضلات.
- The second is fatigue as a sensation.
- والثانى هو التعب كإحساس.

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Introduction مقدمة

- [The limit of exercise] has often been associated with the heart alone, but the facts as a whole indicate that the sum of the changes taking place throughout the body brings about the final cessation of effort.
  - [إن حد التمارين الرياضية] كان مرتبطًا في كثير من الأحيان بالقلب وحده، إلا أن الحقائق ككل تشير إلى أن مجموع التغيرات التي تحدث في جميع أنحاء الجسم تؤدي إلى التوقف النهائي عن بذل الجهد.
- Fatigue of brain reduces the strength of the muscles.
  - يؤدي إرهاق المخ إلى تقليل قوة العضلات.

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Introduction مقدمة

- In addition, the exercise intensity, amount of muscle mass involved, and the type and duration of exercise can all influence fatigue mechanisms.
  - بالإضافة إلى ذلك، فإن شدة التمرين، وكمية الكتلة العضلية المشاركة، ونوع ومدة التمرين، كلها عوامل يمكن أن تؤثر على آليات التعب.
- Another source of confusion is that researchers often use the terms ‘fatigue’ and ‘exhaustion’ interchangeably.
  - وهناك مصدر آخر للارتباك وهو أن الباحثين كثيراً ما يستخدمون مصطلحي "التعب" و"الإرهاق" بالتبادل.

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Introduction مقدمة

- A participant who is no longer able to maintain a given power output during a time to exhaustion test will often be classified as having reached 'exhaustion'. However, they may still be fully capable of continuing exercise at a lower intensity.
- غالبًا ما يتم تصنيف المشارک الذی لم يعد قادراً على الحفاظ على ناتج طاقة معين أثناء اختبار الوقت حتى الإرهاق على أنه وصل إلى "الإرهاق". ومع ذلک، قد يظل قادراً تماماً على مواصلة التمرين بكثافة أقل.
- Therefore, the concepts of fatigue and exhaustion are different constructs that should not be confused.
- ومن ثم فإن مفهومی التعب والإرهاق هما مفهومان مختلفان لا ينبغی الخلط بينهما.

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Introduction

Table 1.1 Different definitions of fatigue, emphasising the variation in the quantification and interpretation of fatigue

1	The moment when a participant is unable to maintain the required muscle contraction or performed workload.
2	Extreme tiredness after exertion; reduction in efficiency of a muscle, organ etc. after prolonged activity.
3	The failure to maintain the required or expected force.
4	Fatigue produced by failure to generate output from the motor cortex.
5	A loss of maximal force generating capacity.
6	A reversible state of force depression, including a lower rate of rise of force and a slower relaxation.
7	Any exercise-induced reduction in the ability of a muscle to generate force or power; it has peripheral and central causes.
8	Failure to continue working at a given exercise intensity.
9	Any exercise-induced reduction in the ability to exert muscle force or power, regardless of whether or not the task can be sustained.
10	A progressive reduction in voluntary activation of muscle during exercise.

الجدول 1.1 تعريفات مختلفة للتعب، مع التركيز على الاختلاف في القياس الكمي وتفسير التعب

| اللحظة التي يكون فيها المشارك غير قادر على الحفاظ على تقلص العضلات المطلوب أو أداء عبء العمل.
2 التعب الشديد بعد المجهود. انخفاض في كفاءة العضلات والأعضاء وما إلى ذلك. بعد نشاط طويل.

3 ـ عدم الحفاظ على القوة المطلوبة أو المتوقعة.
4 التعب الناتج عن الفشل في توليد المخرجات من القشرة الحركية.
5 فقدان القدرة القصوى على توليد القوة.
6 حالة عكسية من انخفاض القوة، بما في ذلك انخفاض معدل ارتفاع القوة واسترخاء أبطأ.

7 أي انخفاض ناجم عن ممارسة الرياضة في قدرة العضلات على توليد القوة أو الطاقة؛ وله أسباب طرفية ومركزية.
8 عدم الاستمرار في العمل بكثافة تمرين معينة.
9 أي انخفاض ناجم عن ممارسة الرياضة في القدرة على ممارسة قوة العضلات أو قوتها، بغض النظر عما إذا كانت المهمة يمكن أن تستمر أم لا.
10 انخفاض تدريجي في التنشيط الإرادي للعضلات أثناء التمرين.

Prevalent fatigue theories: peripheral and central fatigue

نظريات التعب السائدة :التعب المحيطى و التعب المركزى

- Fatigue can be broadly categorized into two types: peripheral fatigue and central fatigue.
- **يمكن تصنيف التعب بشكل عام إلى نوعين: التعب المحيطى و التعب المركزى.**

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Peripheral fatigue التعب المحيطى

A Exercise-related changes in the internal environment

1 Accumulation of lactate and H^+. H^+ is partly buffered, increasing carbon dioxide production from bicarbonate.

2 Accumulation of heat, leading to increased sweat secretion. The loss of water may lead to dehydration.

التغيرات المرتبطة بالتمرين في البيئة الداخلية

1 تراكم اللاكتات و H^+. يتم تخزين H+ جزئيًا، مما يزيد من إنتاج ثاني أكسيد الكربون من البيكربونات.

2 تراكم الحرارة مما يؤدي إلى زيادة إفراز العرق. قد يؤدي فقدان الماء إلى الجفاف.

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Peripheral fatigue التعب المحيطى

B Exercise-related changes within muscle fibres

1 Accumulation of P_i in the sarcoplasm, decreasing contractile force due to cross-bridge inhibition.

2 Accumulation of H^+ in the sarcoplasm, decreasing contractile force due to cross-bridge inhibition. Accumulation of H^+ may also depress Ca^{2+} re-uptake in the sarcoplasmic reticulum.

3 Accumulation of sarcoplasmic Mg^{2+}. Mg^{2+} counteracts Ca^{2+} release from the sarcoplasmic reticulum.

ب- التغيرات المرتبطة بالتمرين داخل الألياف العضلية

| تراكم P_1 في الساركوبلازم، مما يقلل من قوة الانقباض بسبب تثبيط الجسر المتقاطع.

2 تراكم H+ في الساركوبلازم، مما يقلل من قوة الانقباض بسبب تثبيط الجسر المتقاطع. قد يؤدي تراكم Ht أيضًا إلى تثبيط إعادة امتصاص Ca2+ في الشبكة الساركوبلازمية.

3 تراكم الهيولى البلازمية Mg2+. Mg2+ يقاوم إطلاق Ca2+ من الشبكة الهيولية العضلية.

التعب المحيطى

4 Inhibition of Ca^{2+} release from the sarcoplasmic reticulum by accumulation of P_i (see point 1). Ca^{2+} release is inhibited by precipitation of calcium phosphate in the sarcoplasmic reticulum and phosphorylation of Ca^{2+} release channels.
5 Decline of glycogen stores and (in extreme cases) decline of blood glucose levels.
6 Decreased conduction velocity of action potentials along the sarcolemma, probably as a result of biochemical changes in and around the muscle fibres. This has no known immediate effect on muscle force production.
7 Increased efflux of K^+ from muscle. Increased K^+ in the lumen of the t-tubuli may block the tubular action potential and lessen force due to a depression of excitation-contraction coupling.

4 تثبيط إطلاق Ca2+ من الشبكة الساركوبلازمية عن طريق تراكم P (انظر النقطة 1). يتم تثبيط إطلاق Ca2+ عن طريق ترسيب فوسفات الكالسيوم في الشبكة الساركوبلازمية والفسفرة في قنوات إطلاق Ca2+.
5 انخفاض مخازن الجليكوجين و (في الحالات القصوى) انخفاض مستويات الجلوكوز في الدم.
6 انخفاض سرعة توصيل جهود الفعل على طول غمد العضلة، ربما نتيجة للتغيرات البيوكيميائية في ألياف العضلات وحولها. هذا ليس له تأثير فوري معروف على إنتاج القوة العضلية.
7 زيادة تدفق K+ من العضلات. قد تؤدي زيادة K+ في تجويف الأنابيب t إلى منع جهد الفعل الأنبوبي وتقليل القوة بسبب انخفاض اقتران الإثارة والانكماش.

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Central fatigue

التعب المركزى

II Central fatigue

1 The conduction of axonal action potentials may become blocked at axonal branching sites, leading to a loss of muscle fibre activation.
2 Motor neuronal drive may be influenced by reflex effects from muscle afferents.
3 Stimulation of type III and IV nerves decreasing motor neuron firing rate and inhibiting motor cortex output.
4 The excitability of cells within the cerebral motor cortex may change during the course of maintained motor tasks, as suggested by measurements using transcranial magnetic stimulation.

ثانيا التعب المركزي

1 قد يتم حظر توصيل إمكانات العمل المحوري في مواقع التفرع المحوري، مما يؤدي إلى فقدان تنشيط الألياف العضلية.
2 قد يتأثر محرك الخلايا العصبية الحركية بالتأثيرات المنعكسة من العضلات الواردة.
3 تحفيز الأعصاب من النوع الثالث والرابع مما يقلل من معدل إطلاق الخلايا العصبية الحركية ويمنع إنتاج القشرة الحركية.
4 قد تتغير استثارة الخلايا داخل القشرة الحركية الدماغية أثناء المهام الحركية المستمرة، كما تقترح القياسات باستخدام التحفيز المغناطيسي عبر الجمجمة.

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Central fatigue

التعب المركزى

5 Synaptic effects of serotoninergic neurons may become enhanced, causing increased tiredness and fatigue. This may occur from increased brain influx of the serotonin precursor tryptophan, via exercise-induced decreases in the blood concentration of BCAAs.

6 Exercise-induced release of cytokines; IL-6 induces sensations of fatigue and IL-1 induces sickness behaviour.

5 قد تتعزز التأثيرات المتشابكة للخلايا العصبية السيروتونينية، مما يسبب زيادة التعب والإرهاق. قد يحدث هذا من زيادة تدفق الدماغ من سلائف السيروتونين التربتوفان، عن طريق النقصان الناجم عن ممارسة الرياضة في تركيز BCAAs في الدم.

6 إطلاق السيتوكينات الناتج عن ممارسة الرياضة؛ يحفز IL-6 الإحساس بالتعب ويحفز IL-I السلوك المرضي.

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Peripheral fatigue

التعب المحيطى

- Peripheral fatigue states that the sites of fatigue sit outside of the central nervous system (CNS).
  - تشير عبارة التعب المحيطى إلى أن مواقع التعب تقع خارج الجهاز العصبى المركزى (CNS).
- More specifically, peripheral fatigue is associated with an attenuation of muscle force production caused by a process or processes distal to the neuromuscular junction.
  - وبشكل أكثر تحديداً، يرتبط التعب المحيطى بتخفيف إنتاج القوة العضلية الناجم عن عملية أو عمليات بعيدة عن الوصلة العصبية العضلية.
- This develops an anaerobiosis within the working muscles, causing lactic acid accumulation.
  - ويؤدى هذا إلى تطور حالة من اللاهوائى داخل العضلات العاملة، مما يسبب تراكم حمض اللاكتيک.

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Peripheral fatigue — التعب المحيطى

- Because of this change in the intramuscular environment, continued contraction becomes impossible and the muscle reaches a state of failure.
  - و بسبب هذا التغيير فى البيئة العضلية، يصبح الاستمرار فى الانقباض مستحيلا وتصل العضلة إلى حالة من الفشل.
- Hill and colleagues concluded that the primary limiting factor in exercise tolerance was the heart's capacity to pump blood to the active muscles.
- واستنتج هيل وزملاؤه أن العامل المحدد الأساسى لتحمل التمارين الرياضية هو قدرة القلب على ضخ الدم إلى العضلات النشطة.

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Peripheral fatigue — التعب المحيطى

- This theory, termed the cardiovascular/anaerobic/catastrophic model of human exercise performance ('catastrophic' due to the predicted failure of homeostatic cardiac function), became the dominant theory within exercise science teaching and research.
  - أصبحت هذه النظرية، التى أطلق عليها اسم النموذج القلبى الوعائى/اللاهوائى/الكارثى لأداء التمارين الرياضية البشرية (كارثى بسبب الفشل المتوقع لوظيفة القلب المتوازنة)، النظرية السائدة فى تدريس وأبحاث علوم التمارين الرياضية.

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Central fatigue

التعب المركزى

- Whereas peripheral fatigue occurs via processes outside of the CNS, unsurprisingly central fatigue proposes that the origin of fatigue is located within the CNS, with a loss of muscle force occurring through processes proximal to the neuromuscular junction.
  - فى حين يحدث التعب المحيطى من خلال عمليات خارج الجهاز العصبى المركزى، فمن غير المستغرب أن يقترح التعب المركزى أن أصل التعب يقع داخل الجهاز العصبى المركزى، مع حدوث فقدان القوة العضلية من خلال العمليات القريبة من الوصلة العصبية العضلية.
- Specifically, this refers to locations within the brain, spinal nerves and motor neurons.
  - ويشير هذا على وجه التحديد إلى المواقع داخل الدماغ والأعصاب الشوكية والخلايا العصبية الحركية.

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Several definitions of central fatigue

- A negative central influence that exists despite the subject's full motivation.
  - تأثير مركزى سلبى موجود على الرغم من وجود الدافع الكامل للموضوع.
- A force generated by voluntary muscular effort that is less than that produced by electrical stimulation.
  - القوة التى تولدها المجهود العضلى الطوعى والتى تكون أقل من القوة التى ينتجها التحفيز الكهربائى.
- The loss of contractile force or power caused by processes proximal to the neuromuscular junction.
  - فقدان القوة الانقباضية أو القدرة الناجمة عن العمليات القريبة من الوصلة العصبية العضلية.

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Measuring fatigue قياس التعب

- **Direct methods of fatigue assessment**
- **الطرق المباشرة لتقييم التعب**
- *Maximal voluntary force generation/electrical stimulation.*
- الحد الأقصى لتوليد القوة الطوعية/التحفيز الكهربائى
- Accurate measurement of the force generating capacity of muscle is crucial for the reliable assessment of muscle fatigue.
  - يعد القياس الدقيق لقدرة العضلات على توليد القوة أمراً بالغ الأهمية لتقييم إجهاد العضلات بشكل موثوق.
- The maximal isometric force production (MVC for maximal voluntary contraction) is often used for this purpose.
  - غالبًا ما يتم استخدام إنتاج القوة المتساوية القياس القصوى (MVCللانقباض الطوعى الأقصى) لهذا الغرض.
- does not enable dynamic contraction of the muscle.
- لا يسمح بالانكماش الديناميكى للعضلة.
- Strong verbal encouragement is provided by the investigator in an effort to assist the participant in reaching a true maximal contraction.
- يقوم الباحث بتقديم تشجيع لفظى قوى فى محاولة لمساعدة المشارك فى الوصول إلى أقصى انكماش حقيقى.

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Measuring fatigue قياس التعب

- Concerns with the use of MVC for assessing fatigue
- المخاوف بشأن استخدام MVCلتقييم التعب
- Force production can be limited by the voluntary effort/motivation of the participant.
- يمكن الحد من إنتاج القوة من خلال الجهد/الدافع الطوعى للمشارك.
- Not even strong encouragement and feedback may be sufficient to enable someone to achieve a true maximal contraction.
- حتى التشجيع القوى وردود الفعل قد لا تكون كافية لتمكين شخص ما من تحقيق أقصى انكماش حقيقى.
- Therefore, it is not possible to clearly determine potential mechanisms for reduced MVC.
- لذلك، فإنه من غير الممكن تحديد الآليات المحتملة لانخفاض MVCبشكل واضح.

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Measuring fatigue

قياس التعب

Figure 1.2 A person preparing to undertake a maximal voluntary contraction of the quadriceps muscles.

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Low-frequency fatigue **التعب منخفض التردد**

- Low-frequency fatigue (LFF) is characterized by a proportionately greater loss of force during low-frequency compared with high-frequency muscle stimulation.
  - يتميز التعب منخفض التردد ((LFFبفقدان أكبر نسبيًا للقوة أثناء تحفيز العضلات بتردد منخفض مقارنة بتحفيز العضلات بتردد عالٍ.
- This form of fatigue can take hours or even days to dissipate, and may play a key role in the decline in muscle force production.
  - قد يستغرق هذا النوع من التعب ساعات أو حتى أيامًا حتى يتلاشى، وقد يلعب دوراً رئيسيًا فى انخفاض إنتاج قوة العضلات.

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Low-frequency fatigue التعب منخفض التردد

- Low-frequency fatigue may increase the requirement for greater CNS activation to elicit a given muscle force.
  - قد يؤدى التعب منخفض التردد إلى زيادة الحاجة إلى تنشيط أكبر للجهاز العصبى المركزى لإثارة قوة عضلية معينة.
- Consequently, this could cause an increase in effort perception for a given force production, potentially contributing to the development of central fatigue.
  - وبالتالى، فإن هذا قد يؤدى إلى زيادة فى إدراك الجهد المبذول لإنتاج قوة معينة، مما قد يساهم فى تطور التعب المركزى.

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Indirect methods of fatigue assessment

الأساليب غير المباشرة لتقييم التعب

- ***Endurance time ('time to exhaustion')***
  - ***وقت التحمل (الوقت حتى الإرهاق)***
- Many research studies have utilized an endurance test, commonly known as a time to exhaustion test, to assess and/or quantify fatigue, particularly the influence of an intervention on the development of fatigue.
  - استخدمت العديد من الدراسات البحثية اختبار التحمل، المعروف باسم اختبار الوقت حتى الإرهاق، لتقييم و/أو تحديد كمية التعب، وخاصة تأثير التدخل على تطور التعب.
- Use of these tests is partly based on the assumption that there is a relationship between the force generating capacity of muscles and the time to exhaustion.
  - ويعتمد استخدام هذه الاختبارات جزئيًا على افتراض وجود علاقة بين قدرة العضلات على توليد القوة والوقت المستغرق حتى الإرهاق.

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Indirect methods of fatigue assessment

الأساليب غير المباشرة لتقييم التعب

- ***Endurance time ('time to exhaustion')***
- ***وقت التحمل (الوقت حتى الإرهاق)***
- Also, gross time to exhaustion tests (e.g. a cycle to exhaustion at 80% VO2max) exhibit large coefficients of variation (up to ~35%), suggesting that time to exhaustion tests should not be the only measure used to determine the influence of a treatment on performance/fatigue.
  - كما أن اختبارات الوقت الإجمالي حتى الإرهاق (على سبيل المثال دورة حتى الإرهاق عند ٨٠٪ من VO2max) تظهر معاملات تباين كبيرة (تصل إلى ~٣٥٪)، مما يشير إلى أن اختبارات الوقت حتى الإرهاق لا ينبغي أن تكون المقياس الوحيد المستخدم لتحديد تأثير العلاج على الأداء/الإرهاق.
- Most other research into the reliability of time to exhaustion tests has used longer duration exercise, which may be less reliable than shorter exercise due to the multitude of factors that can influence a person's decision of whether or not to continue, such as motivation and boredom.
  - استخدمت معظم الأبحاث الأخرى حول موثوقية اختبارات الوقت حتى الإرهاق تماريناً مدتها أطول، والتي قد تكون أقل موثوقية من التمارين القصيرة بسبب تعدد العوامل التي يمكن أن تؤثر على قرار الشخص بشأن الاستمرار أم لا، مثل الدافع والملل.

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Indirect methods of fatigue assessment

الأساليب غير المباشرة لتقييم التعب

- ***Electromyography*** **تخطيط كهربية العضلات**
- Electromyography (EMG) is the analysis of the electrical activity of muscle tissue.
  - تخطيط كهربية العضلات (EMG) هو تحليل النشاط الكهربائي لأنسجة العضلات.
- The two common forms of EMG are surface EMG (non-invasive) and needle EMG (invasive). For ethical reasons, surface EMG is most prevalent in the sports science literature.
  - الشكلان الشائعان لتخطيط كهربية العضلات هما تخطيط كهربية العضلات السطحى (غير جراحى) وتخطيط كهربية العضلات بالإبرة (جراحى). ولأسباب أخلاقية، فإن تخطيط كهربية العضلات السطحى هو الأكثر انتشاراً فى أدبيات العلوم الرياضية.

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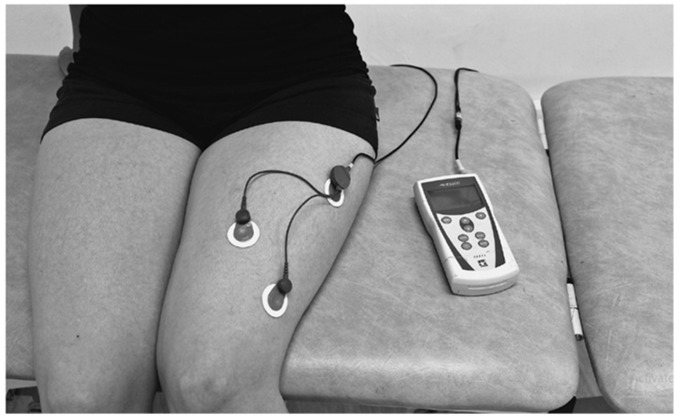
Indirect methods of fatigue assessment

الأساليب غير المباشرة لتقييم التعب

- ***Electromyography***

تخطيط كهربية العضلات



Indirect methods of fatigue assessment

الأساليب غير المباشرة لتقييم التعب

- ***Electromyography*** **تخطيط كهربية العضلات**
- Finally, EMG can only be used with any form of validity during isometric contractions, as changes in muscle length alter the relation -ship between EMG and neuromuscular activation.
- أخيراً، لا يمكن استخدام تخطيط كهربية العضلات إلا مع أى شكل من أشكال الصلاحية أثناء الانقباضات المتساوية القياس، حيث تؤدى التغييرات فى طول العضلات إلى تغيير العلاقة بين تخطيط كهربية العضلات والتنشيط العصبى العضلى.
- This indicates that EMG may not be a particularly useful or appropriate index of fatigue during many sport-specific muscle actions.
- يشير هذا إلى أن تخطيط كهربية العضلات قد لا يكون مؤشراً مفيداً أو مناسبًا بشكل خاص للتعب أثناء العديد من الأنشطة العضلية الخاصة بالرياضة.

Indirect methods of fatigue assessment

الأساليب غير المباشرة لتقييم التعب

- ***Muscle biopsies*** ***خزعات العضلات***
- In a muscle biopsy, a small piece of muscle tissue is removed from an intact human muscle for examination.
  - فى خزعة العضلات، يتم إزالة قطعة صغيرة من أنسجة العضلات البشرية السليمة للفحص.
- In sport and exercise science research, the needle biopsy is most common.
  - فى أبحاث العلوم الرياضية والتمارين، تعتبر خزعة الإبرة هى الأكثر شيوعًا.
- Here, local anesthetic is applied to the area after which a needle is inserted into the muscle (commonly the vastus lateralis of the quadriceps).
  - هنا، يتم تطبيق مخدر موضعى على المنطقة و بعد ذلك يتم إدخال إبرة فى العضلة (عادةً العضلة الواسعة الجانبية للعضلة الرباعية الرؤوس).

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Indirect methods of fatigue assessment

الأساليب غير المباشرة لتقييم التعب

- ***Muscle biopsies*** ***خزعات العضلات***
- Muscle biopsies can be used for quantifying muscle fiber composition, muscle energy content, and the concentration and activity of a multitude of enzymes involved in energy production.
- يمكن استخدام خزعات العضلات لتحديد كمية تركيب ألياف العضلات، ومحتوى الطاقة العضلية، وتركيز ونشاط العديد من الإنزيمات المشاركة فى إنتاج الطاقة.
- A potential limitation is that a biopsy sample may not be representative of the entire muscle from which it is drawn.
- إن أحد القيود المحتملة هو أن عينة الخزعة قد لا تكون ممثلة للعضلة بأكملها التى تم أخذها منها.

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Indirect methods of fatigue assessment

الأساليب غير المباشرة لتقييم التعب

- ***Muscle biopsies*** ***خزعات العضلات***
- In addition, if repeated biopsy samples are required, variations in the sampling site may affect the validity and/or reliability of the data.

- بالإضافة إلى ذلك، إذا كانت هناك حاجة إلى أخذ عينات خزعة متكررة، فإن الاختلافات في موقع أخذ العينات قد تؤثر على صحة و/أو موثوقية البيانات.

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Indirect methods of fatigue assessment

الأساليب غير المباشرة لتقييم التعب

- ***Blood sampling*** **أخذ عينات الدم**
- Methods of sampling vary, from simple fingertip or earlobe capillary sampling (Figure 1.5) to arterial and venous sampling and cannulation.
- تتنوع طرق أخذ العينات، من أخذ عينات بسيطة من أطراف الأصابع أو الشعيرات الدموية فى شحمة الأذن (الشكل ١.٥) إلى أخذ عينات من الشرايين والأوردة والقسطرة.
- A classic example is the testing of blood lactate.
- ومن الأمثلة الكلاسيكية على ذلك اختبار اللاكتات فى الدم.

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Indirect methods of fatigue assessment

الأساليب غير المباشرة لتقييم التعب

- ***Blood sampling***

Figure 1.5 Antecubital venous blood sampling (left) and capillary earlobe sampling (right).

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Indirect methods of fatigue assessment

الأساليب غير المباشرة لتقييم التعب

- ***Ratings of perceived exertion*** ***تقييمات الجهد المبذول***
- The most commonly used perceptual scale is the Borg rating of perceived exertion (RPE) scale (also referred to as the Borg 6–20 scale).
- المقياس الإدراكي الأكثر استخدامًا هو مقياس بورغ لتقييم الجهد المتصور () (RPEيشار إليه أيضًا باسم مقياس بورغ ٦-٢٠).
- 1970 by Gunnar Borg.
- ١٩٧٠ بواسطة جونار بورج.
- The seemingly arbitrary 6–20 range of the original Borg scale was developed due to the observed correlation between heart rate and RPE ratings, such that the given score on the scale can be multiplied by 10 and provide a close approximation of the exercising person's heart rate (e.g. an RPE of 12 approximates a heart rate of 120 bpm).
- تم تطوير النطاق التعسفي ظاهريًا من ٦ إلى ٢٠ لمقياس بورج الأصلي بسبب الارتباط الملحوظ بين معدل ضربات القلب وتقييمات RPE، بحيث يمكن ضرب النتيجة المعطاة على المقياس في ١٠ وتوفير تقريب وثيق لمعدل ضربات قلب الشخص الذي يمارس الرياضة (على سبيل المثال، RPE 12 يقارب معدل ضربات القلب ١٢٠ نبضة في الدقيقة).

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Part II

What causes (and what does not cause) fatigue in sport and exercise?

ما هى الأسباب)وما لا يسبب (التعب أثناء ممارسة الرياضة؟

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Energy depletion

استنزاف الطاقة

- **Energy metabolism during exercise**
- **استقلاب الطاقة أثناء ممارسة الرياضة**
- Adenosine triphosphate has three components:
- يحتوى أدينوسين ثلاثى الفوسفات على ثلاثة مكونات:
- Adenine, ribose, and three phosphates.
- الأدينين والريبوز وثلاثة فوسفات.
- The energy in these bonds is released when ATP is broken down in a hydrolysis reaction, and this energy is used by the cell for various functions such as muscle contraction.
- يتم إطلاق الطاقة الموجودة في هذه الروابط عندما يتم تحلل ATPفي تفاعل التحلل المائي، وتستخدم الخلية هذه الطاقة للعديد من الوظائف مثل تقلص العضلات.

$$ATP + H_2O \underset{\longleftarrow}{\overset{ATPase}{\longrightarrow}} ADP + P_i + H^+ + energy$$

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Energy depletion

استنزاف الطاقة

- **Energy metabolism during exercise**
- **استقلاب الطاقة أثناء ممارسة الرياضة**
- Only a small amount of ATP is stored in the body at any time (enough to fuel approximately 2 seconds of maximal intensity muscle contraction).
- يتم تخزين كمية صغيرة فقط من ATP فى الجسم فى أى وقت (ما يكفى لتغذية حوالى ثانيتين من انقباض العضلات بأقصى شدة).
- three primary metabolic pathways:
- ثلاثة مسارات أيضية أساسية:
- the phosphocreatine (PCr) pathway,
- مسار فوسفوكرياتين (PCr)،
- the anaerobic pathway,
- المسار اللاهوائى،
- and the aerobic pathway.
- والمسار الهوائى.

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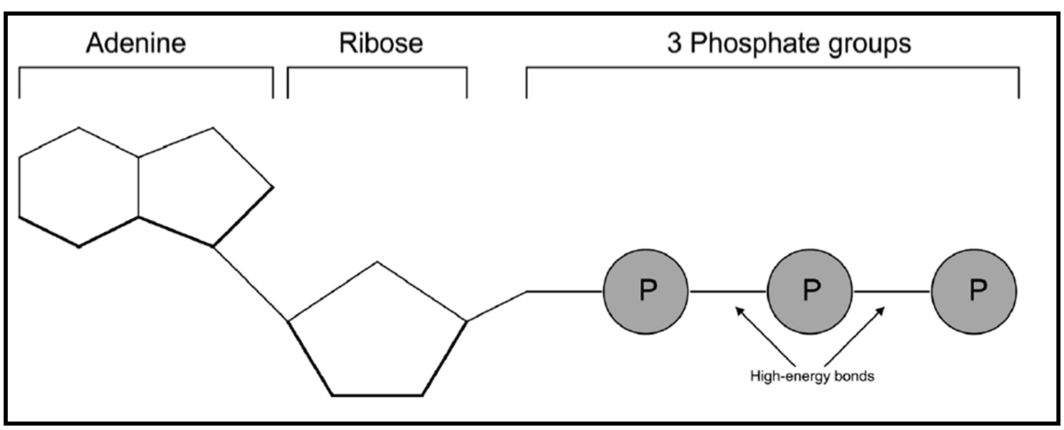
Energy depletion

استنزاف الطاقة

- **Energy metabolism during exercise**

استقلاب الطاقة أثناء ممارسة الرياضة



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Energy depletion استنزاف الطاقة

- **Energy metabolism and fatigue during exercise**
- **استقلاب الطاقة أثناء ممارسة الرياضة**
- **ATP depletion** **استنفادATP**
- In exercising humans, intramuscular ATP concentrations do not fall below about 60% of resting levels, regardless of the intensity or duration of exercise. However, the ATP concentration of single fibres can drop to very low levels.
- فى البشر الذين يمارسون التمارين الرياضية، لا تنخفض تركيزات ATPداخل العضلات عن حوالى ٦٠٪ من مستويات الراحة، بغض النظر عن شدة أو مدة التمرين. ومع ذلك، يمكن أن ينخفض تركيز ATP للألياف الفردية إلى مستويات منخفضة للغاية.
- The occurrence of ATP depletion and its role in exercise-induced fatigue is open to debate, and more research is required.
- إن حدوث استنفاد ATPودوره فى التعب الناجم عن التمارين الرياضية أمر مفتوح للنقاش، وهناك حاجة إلى المزيد من البحث.

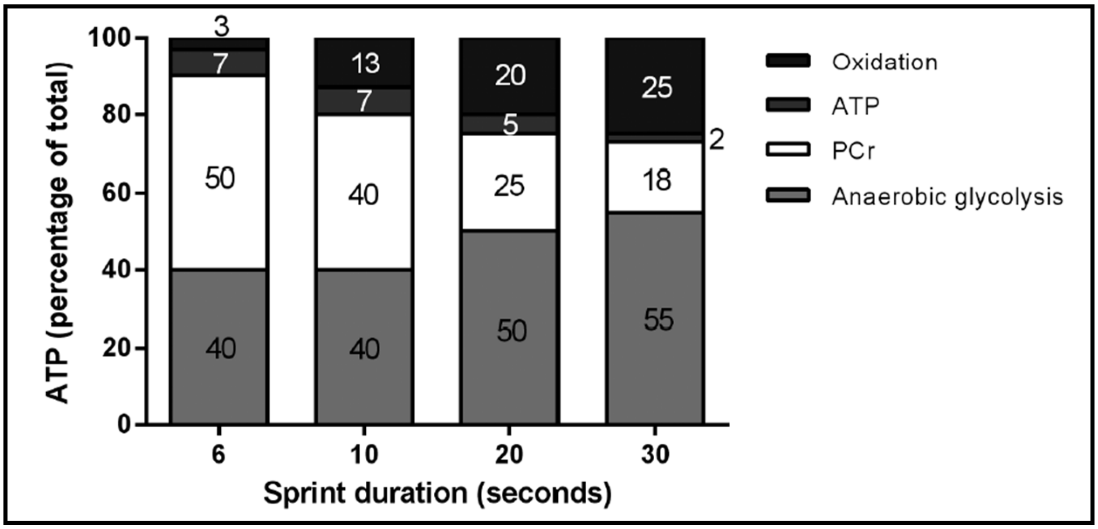
Phosphocreatine depletion نقص الفوسفوكرياتين

- **Energy metabolism and fatigue during exercise**
- **استقلاب الطاقة أثناء ممارسة الرياضة**
- Phosphocreatine is a phosphorylated creatine molecule that is particularly important in resynthesizing ATP during explosive, high-intensity exercise.
- فوسفوكرياتين هو جزىء الكرياتين المفسفر الذى له أهمية خاصة فى إعادة تخليق ATPأثناء التمرينات المتفجرة عالية الكثافة.

$$PCr + ADP + H^+ \underset{}{\overset{\textit{creatine kinase}}{\rightleftharpoons}} ATP + Cr$$

- In theory, this is sufficient for approximately 10-seconds of maximal work before PCr stores become depleted.
- من الناحية النظرية، هذا يكفى لمدة ١٠ ثوانٍ تقريبًا من العمل الأقصى قبل استنفاد مخازن PCr.

Phosphocreatine depletion نقص الفوسفوكرياتين



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Phosphocreatine depletion نقص الفوسفوكرياتين

- **Energy metabolism and fatigue during exercise**
  - **استقلاب الطاقة أثناء ممارسة الرياضة**
- The reduction in power output may be partially due to PCr depletion, which would reduce the rate of ATP resynthesize and necessitate a reduction in power output to prevent critical reductions in ATP concentration.
  - قد يكون الانخفاض في إنتاج الطاقة ناتجًا جزئيًا عن استنفاد PCr، مما يقلل من معدل إعادة تخليق ATPويستلزم تقليل إنتاج الطاقة لمنع الانخفاضات الحرجة في تركيز ATP.
- Phosphocreatine levels are not fully depleted during single sprints lasting 5–30 seconds. Therefore, it does not appear that PCr depletion is the sole cause of fatigue during short duration maximal exercise.
  - لا يتم استنفاد مستويات فوسفوكرياتين بشكل كامل أثناء الركض السريع لمدة ٥-٣٠ ثانية. لذلك، لا يبدو أن استنفاد فوسفوكرياتين هو السبب الوحيد للإرهاق أثناء التمرينات القصيرة التي تتطلب أقصى قدر من الطاقة.

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Glycogen depletion استنزاف الجليكوجين

- **Energy metabolism and fatigue during exercise**
- **استقلاب الطاقة والتعب أثناء ممارسة الرياضة**
- Carbohydrate, in the form of muscle and liver glycogen and blood glucose, is the primary fuel during exercise.
- الكربوهيدرات، فى شكل جليكوجين العضلات والكبد وجلوكوز الدم، هى الوقود الأساسى أثناء ممارسة التمارين الرياضية.
- Carbohydrate is metabolized in glycolysis (anaerobic) and the Krebs cycle (aerobic).
- يتم استقلاب الكربوهيدرات فى عملية تحلل الجلوكوز (اللاهوائى) ودورة كريبس (الهوائية).
- Therefore, it is a fuel that can be metabolized to generate ATP across a wide range of exercise demands.
- لذلك، فهو وقود يمكن استقلابه لتوليد ATP عبر مجموعة واسعة من متطلبات التمرين.
- glycogen depletion causes fatigue, and more recent perceptions of the role of carbohydrate in exercise fatigue.
- يؤدى نقص الجليكوجين إلى الشعور بالتعب، وهناك تصورات حديثة لدور الكربوهيدرات فى الشعور بالتعب أثناء ممارسة التمارين الرياضية.

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Glycogen depletion استنزاف الجليكوجين

- **Potential carbohydrate-related causes of fatigue during exercise**
- **الأسباب المحتملة للإرهاق المرتبط بالكربوهيدرات أثناء ممارسة الرياضة**
- glycogen is an important fuel source during exercise – we only have a limited amount of it stored in our body – when it runs out we can no longer exercise at the same intensity – the end result: fatigue. Problem solved?
- الجليكوجين هو مصدر مهم للوقود أثناء ممارسة التمارين الرياضية – لدينا كمية محدودة منه مخزنة فى أجسامنا – عندما ينفد الجليكوجين، لم يعد بإمكاننا ممارسة التمارين بنفس الكثافة – والنتيجة النهائية هى التعب. هل تم حل المشكلة؟
- The three primary glycogen clusters are sub-sarcolemmal
- المجموعات الثلاث الأساسية من الجليكوجين هى تحت الساركوما
- glycogen (located just under the sarcolemma, or muscle fibre membrane), inter myofibrillar glycogen (located between myofibrils), and intra myofibrillar glycogen (located within the myofibrils, near the muscle z-line).
- الجليكوجين (الموجود أسفل غشاء الساركوليما أو غشاء ألياف العضلات)، والجليكوجين بين الألياف العضلية (الموجود بين الألياف العضلية)، والجليكوجين داخل الألياف العضلية (الموجود داخل الألياف العضلية، بالقرب من خط Z للعضلة).

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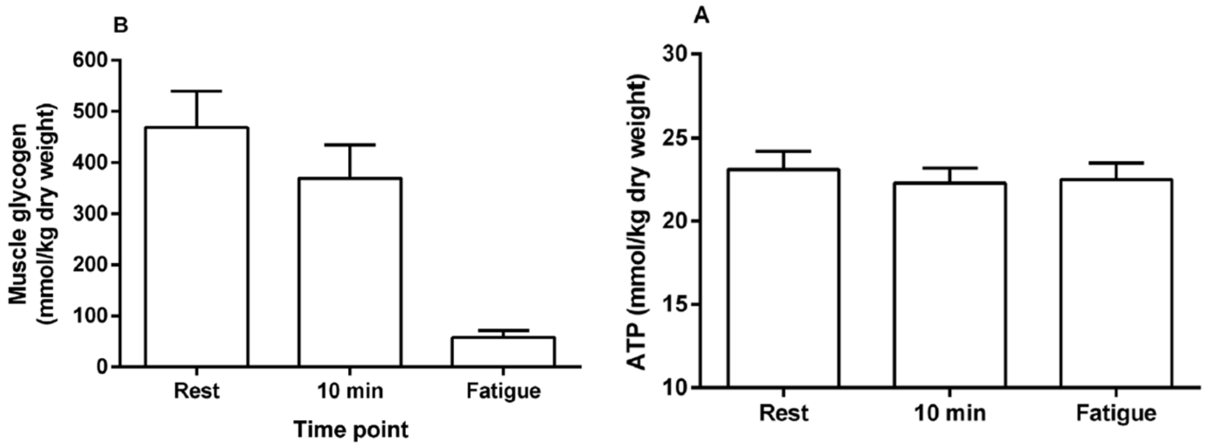
Glycogen depletion



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Glycogen depletion

استنزاف الجليكوجين

- **Potential carbohydrate-related causes of fatigue during exercise**
- **الأسباب المحتملة للإرهاق المرتبط بالكربوهيدرات أثناء ممارسة الرياضة**
- GLYCOGEN DEPLETION CAUSES HYPOGLYCAEMIA, WHICH LEADS TO FATIGUE
- يؤدى نقص الجليكوجين إلى نقص سكر الدم، مما يؤدى إلى التعب
- The pattern of use of the four primary fuel sources (muscle glycogen, muscle triglycerides, blood glucose, free fatty acids) during exercise will depend on:
- يعتمد نمط استخدام مصادر الوقود الأساسية الأربعة (جليكوجين العضلات، والدهون الثلاثية فى العضلات، وجلوكوز الدم، والأحماض الدهنية الحرة) أثناء التمرين على:
- exercise mode, intensity, and duration, the training status, metabolic makeup, and pre-exercise fuel status of the athlete, and environnemental conditions, particularly ambient température.
- وضع التمرين وكثافته ومدته، وحالة التدريب، والتكوين الأيضي، وحالة الوقود قبل التمرين للرياضي، والظروف البيئية، وخاصة درجة الحرارة المحيطة.

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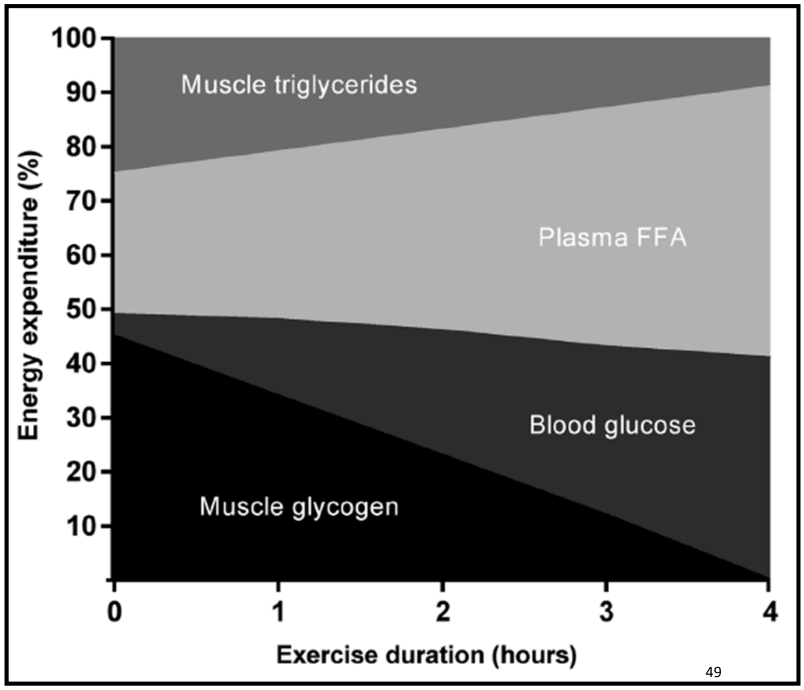
Glycogen depletion



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Glycogen depletion

- **Potential carbohydrate-related causes of fatigue during exercise**
- GLYCOGEN DEPLETION CAUSES HYPOGLYCAEMIA, WHICH LEADS TO FATIGUE
  - يؤدى نقص الجليكوجين إلى نقص سكر الدم، مما يؤدى إلى التعب
- Intramuscular fuel sources (glycogen and triglycerides) are predominant for approximately the first 90 minutes of exercise.
  - تشكل مصادر الوقود العضلي (الجليكوجين والدهون الثلاثية) الغالبية العظمى من التمارين الرياضية لمدة ٩٠ دقيقة تقريبًا.
- During prolonged exercise, blood glucose is an important fuel for working muscles and the central nervous system (CNS). Brain glucose stores are limited; therefore, the uptake of blood glucose is crucial for the brain.
  - أثناء ممارسة التمارين الرياضية لفترات طويلة، يعد جلوكوز الدم وقودًا مهمًا للعضلات العاملة والجهاز العصبي المركزى. تكون مخزونات الجلوكوز فى المخ محدودة؛ وبالتالى فإن امتصاص جلوكوز الدم أمر بالغ الأهمية للدماغ.

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Chapter 3

Metabolic acidosis

51

Introduction

- Although our knowledge of the processes involved in metabolic acidosis has developed significantly, the exact causes of metabolic acidosis, and its role in fatigue during exercise, are still keenly debated.
- back to research carried out in the early 1900s.
- lactic acid concentrations were lowest in muscles that were exposed to oxygen.
- it was concluded that increases in lactic acid were greatest under anaerobic conditions.

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Introduction

- the conclusion was made that during intense work muscles contract in the absence of an adequate oxygen supply (in ‘anaerobiosis’), thereby producing lactic acid which causes muscle acidosis that leads to fatigue.
- In the 1970s, a linear relationship was found between lactate accumulation and loss of muscle force in frogs and later, in human thigh muscle.
- Simply put, while acidosis and fatigue may correlate, it cannot be said that acidosis *causes* fatigue. Indeed, much of the research that showed a correlation between lactic acid and fatigue also showed relationships between other metabolic measures and fatigue.

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How might lactic acid cause fatigue?

- First, a reduced muscle pH, caused by lactic acid production, may impair muscle contraction via a decline in isometric muscle force production and muscle shortening velocity.
- Intramuscular acidosis was thought to do this by reducing sarcoplasmic reticulum calcium (Ca2+) release and calcium sensitivity.
- Second, intramuscular acidosis could cause fatigue by inhibiting glycolysis.
- reduced activity of key enzymes that regulate glycolysis during exercise that causes notable reductions in muscle pH.
- Potential causes of lactic acid-induced fatigue include impaired isometric muscle force and contraction velocity, and inhibition of glycolysis due to a reduction in intramuscular pH.

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Metabolic acidosis and exercise fatigue: the counter-view

- An important question to answer when discussing the biochemistry of lactic acid is 'What does the body produce during exercise – lactic acid or lactate'?
- Reading lay articles, or even scientific papers on the subject, you will often see that the terms lactic acid and lactate are used interchangeably as though they mean the same thing.
- Lactic acid is, as the name suggests, an acidic compound that has the potential to release a proton (hydrogen ion, H+) into a solution, thereby making that solution more acidic.
- Conversely, lactate does not release H+;

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Metabolic acidosis and exercise fatigue: the counter-view

- During exercise, ATP is resynthesized via anaerobic glycolysis (Figure 3.2) and oxidative phosphorylation via β-oxidation of fatty acids and breakdown of pyruvate in the Krebs cycle and electron transport chain.
- To prevent pyruvate accumulation, which would inhibit glycolysis and thereby impair both anaerobic and oxidative ATP resynthesize, pyruvate can be converted, via the lactate dehydrogenase reaction, to lactate.

$$\text{Pyruvate} + \text{NADH} + H^+ \xrightarrow[\text{dehydrogenase}]{\text{lactate}} \text{Lactate} + \text{NAD}^+ \qquad (3.1)$$

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Metabolic acidosis and exercise fatigue: the counter-view

- Simply put, the production of lactate via the lactate dehydrogenase reaction is alkalinizing to the cell, not acidifying.
- Lactate may also facilitate H+ removal from the cell via monocarboxylate (MCT) transporters present in cell membranes.
- These transporters also serve to remove H+ from the cell, meaning that the removal of lactate also removes H+ from the muscle.

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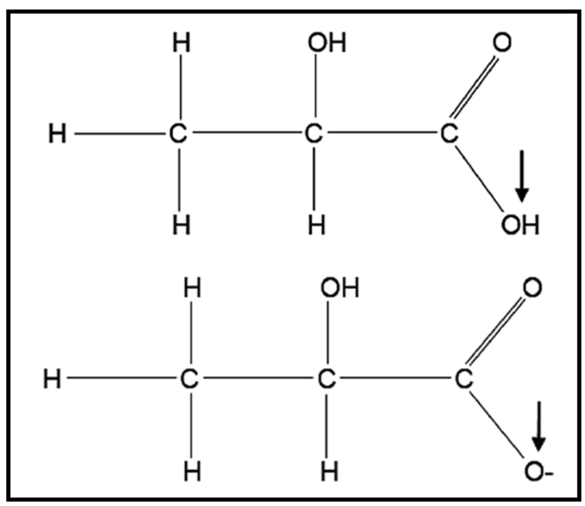
Metabolic acidosis and exercise fatigue: the counter-view

The chemical structure of lactic acid (top) and lactate (bottom). Lactic acid contains hydrogen that dissociates and moves into the surrounding solution as a hydrogen ion (H_+), increasing its acidity.



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Metabolic acidosis and exercise fatigue: the counter-view

- As stated above and shown in Figure 3.2, lactate, not lactic acid, is produced in glycolysis.
- This means that any lactic acid present in the body would dissociate to lactate and H+.

Metabolic acidosis and exercise fatigue: the counter-view

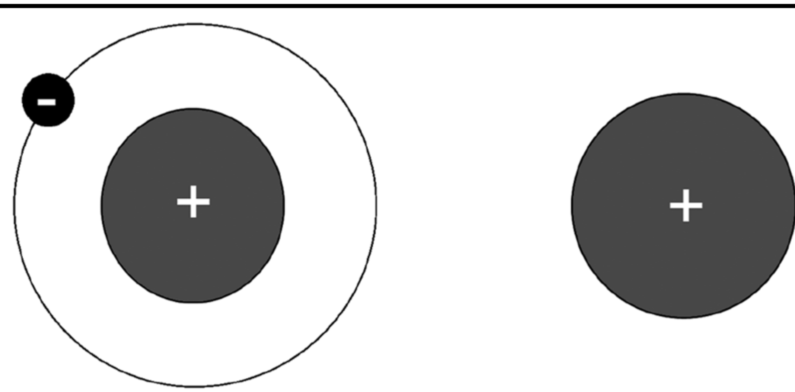

Figure 3.3 A hydrogen atom (left), composed of a single proton (positive charge, +) and a single electron (negative charge, –). The loss of the single electron in an oxidation reaction leaves the single positively charged proton remaining (right). This single proton is referred to by the abbreviation H^+.

Metabolic acidosis and exercise fatigue: the counter-view

- As stated above and shown in Figure 3.2, lactate, not lactic acid, is produced in glycolysis.
- This means that any lactic acid present in the body would dissociate to lactate and H+.
- The production of lactate does not produce H+, and therefore does not directly make its environment more acidic. However, lactate production may alter the behaviour of intracellular water, thereby indirectly causing H+ production.

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The impact of hydrogen production on muscle function

- ***Sarcoplasmic reticulum Ca2+ release and Ca2+ binding to troponin C***
- Originally, it was thought that metabolic acidosis caused a reduction in muscle force by reducing the rate of Ca2+ release from the sarcoplasmic reticulum.
- The release of Ca2+ is crucial for muscle contraction, and if insufficient Ca2+ is released the muscle may contract with less force.

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The impact of hydrogen production on muscle function

- ***Sarcoplasmic reticulum Ca2+ release and Ca2+ binding to troponin C***
- However, it appears that the normal processes of Ca2+ release from the sarcoplasmic reticulum are not impaired, even when muscle pH levels are as low as 6.2 (from a normal resting pH of ~7.1).
- It therefore appears that the influence of acidosis on Ca2+ movement from its intramuscular storage site is minimal.
- Hydrogen competes with Ca2+ to bind to troponin C, and for this reason it was thought that intramuscular H+ accumulation would reduce muscle force.

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The impact of hydrogen production on muscle function

- ***Sarcoplasmic reticulum Ca2+ release and Ca2+ binding to troponin C***
- However, increased intramuscular acidity also causes a reduction in the binding of Ca2+ to other locations in the muscle fibre, such as the sarcoplasmic reticulum Ca2+ pump.
- Intramuscular acidosis causes changes to Ca2+ kinetics, but these changes have, at most, only a small effect on muscle force production. In fact, some of these changes may actually favour an increase in muscle force development under acidic conditions.

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The impact of hydrogen production on muscle function

- ***Muscle membrane excitability***
- Research into the effect of H+ on the excitability of skeletal muscle (the ability of the electrical signal to move across the muscle membrane and into the muscle to stimulate Ca2+ release) is a good example of how H+ can exert positive effects on muscle function.

The impact of hydrogen production on muscle function

- ***The rate of glycolysis***
- The suggestion that acidosis inhibits glycolytic enzymes and therefore slows the rate of glycolysis is controversial, with some research demonstrating no associations between muscle pH and muscle force production or high intensity exercise performance.

The impact of hydrogen production on muscle function

- ***The cross-bridge cycle***
- Hydrogen production can impair cross-bridge force production, thereby reducing muscle force. Hydrogen production may also reduce the maximum velocity of muscle contraction, although this is dependent on the extent of acidosis, muscle temperature, and Ca2+ kinetics. The potential influence of H+ on muscle force and velocity indicates that it may also impair muscle power output.

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Chapter 4

Dehydration and hyperthermia

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Dehydration and exercise fatigue

- *Hydration* or *euhydration* refers to a normal (or, more accurately, appropriate) body water content for an individual.
- *Hyperhydration* refers to a state of excess body water content.
- The dynamic process of losing body water is termed *dehydration*.
- Dehydration and hypohydration are closely related, but do not mean the same thing.
- Dehydration is the process of body water loss; hypohydration is the end result of this loss.

69

The importance of water in the body

- A person can survive for several weeks without consuming food, and can survive losses of up to 40% of their BM in fat, carbohydrate, and protein.
- However, a matter of days without water, or a water loss of only 9–12% of BM, can be fatal.
- Approximately two thirds of body water content is contained inside our cells (intracellular fluid), with the other third outside the cells (extracellular fluid).

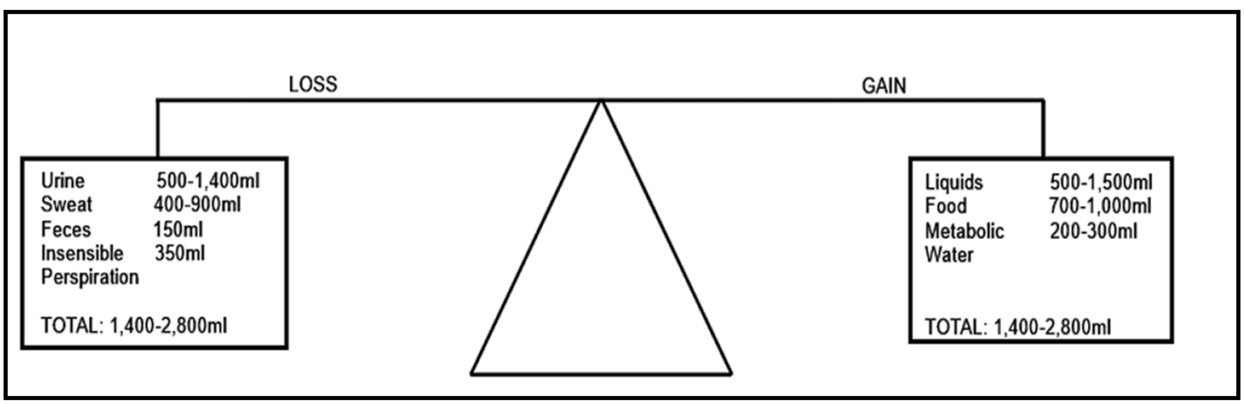
70

The importance of water in the body

Table 4.1 Important functions of water within the human body

1	Forms the fluid portion of blood, allowing the transport of nutrients, waste products, oxygen, and immune cells to all parts of the body.
2	Maintains appropriate blood volume; crucial for function of the cardiovascular system.
3	Plays a role in metabolic reactions.
4	Acts as a solvent for proteins, glucose, vitamins and minerals.
5	Plays an important role in maintenance of electrolyte balance.
6	Forms the fluid portion of sweat, allowing thermoregulation to occur.
7	Transports heat from deeper regions of the body to the skin surface, further assisting thermoregulation.
8	Helps to lubricate joints.
9	Major constituent of spinal and eye fluid.

The importance of water in the body



The importance of water in the body

- It is recommended that normal adults should consume 1–1.5 ml of water for every Kcal expended, and athletes should consume 1.5 ml of water for every Kcal expended.
- Body water balance is influenced by factors that vary greatly between people. As a result, water requirements can vary significantly from person to person.

73

Classical mechanism of dehydration-induced performance decrement

- During exercise, sweat rate greatly increases. Sweating is the main way that the body dissipates heat produced from the increase in energy metabolism during exercise.
- The fluid portion of sweat comes from blood plasma, muscle tissue, skin and other internal organs.
- The loss of fluid from blood plasma causes a decrease in plasma volume.
- reduction in stroke volume
- and reduction cardiac output

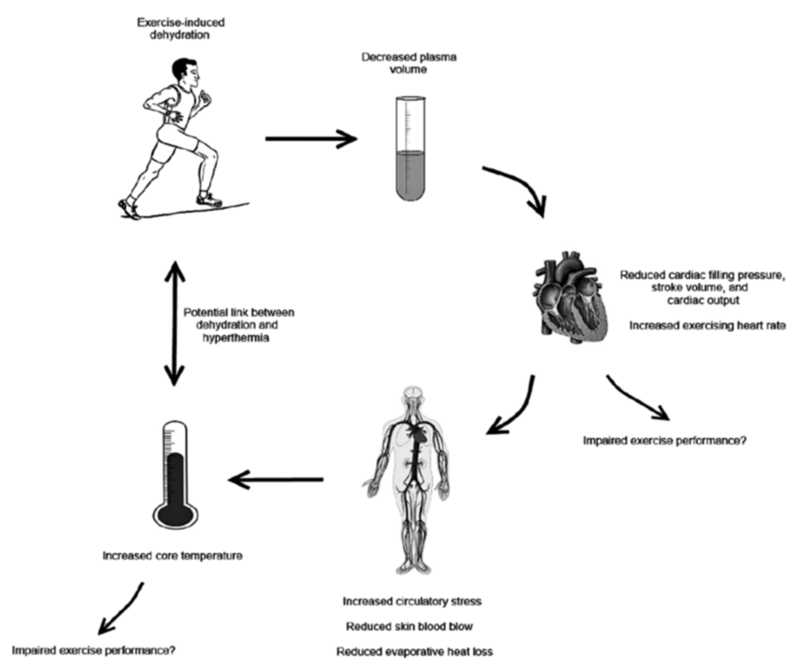
74

Classical mechanism of dehydration-induced performance decrement

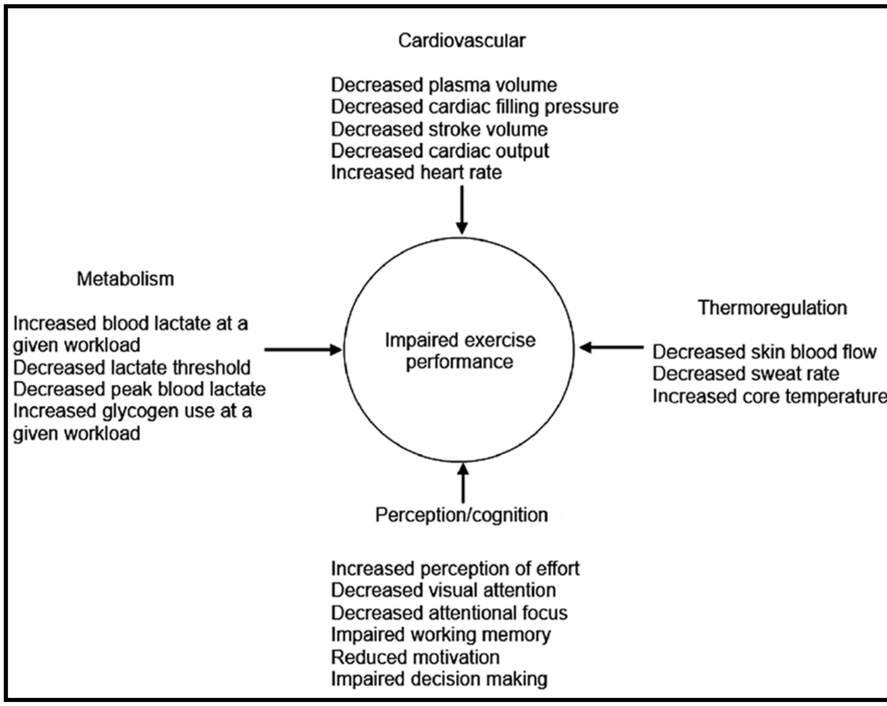
- This reduction in cardiac efficiency may in itself lead to impaired exercise performance, with an approximate increase in exercising heart rate of 3–5 beats per minute for every 1% loss of BM due to dehydration.
- However, if water loss and exercise continue, the reduced plasma volume may lead to competition for blood flow between core organs and tissues and the skin.
- Therefore, according to the classical theory, dehydration may impair performance directly through alterations in cardiac efficiency, and indirectly by contributing to the development of hyperthermia.

75

Classical mechanism of dehydration-induced performance decrement



Classical mechanism of dehydration-induced performance decrement



Classical mechanism of dehydration-induced performance decrement

- Early research established an apparent 'threshold' hypohydration level of 2% body mass, above which aerobic exercise performance is impaired.
- This threshold has become established as a cornerstone of fluid intake recommendations and guidelines.
- *Marino* et al. These authors found that ingesting no fluid during 60 minutes of self-paced high-intensity cycling in moderate (hypohydration 1.7% BM) or warm (hypohydration 2.1% BM) conditions did not impair performance compared with consuming enough fluid to maintain BM.
- Interestingly, the authors provided evidence to suggest that the neuromuscular system altered muscle recruitment in response to different hydration levels, thereby enabling a similar performance level despite differences in hydration status.

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Classical mechanism of dehydration-induced performance decrement

- *Nolte* et al. This study was a little different to some of the other hydration research, as it investigated the relationship between fluid intake and time to complete a 14.5 km march in soldiers. Interestingly, no relationship between fluid intake and exercise time, or BM loss and exercise time, was found.
- Furthermore, the soldiers' hydration status was maintained despite BM losses of around 2%.

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Classical mechanism of dehydration-induced performance decrement

- *Zouhal* et al. This study investigated the relationship between BM change (as an indicator of hydration) and marathon finishing time. The authors found that the greater the BM loss, the faster the marathon finishing time. Put another way, the people who lost more weight, and therefore were, perhaps, more hypohydrated, tended to perform better than those who maintained a stable hydration status or who drank more fluid than they lost during the run.

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Classical mechanism of dehydration-induced performance decrement

- *Overall summary:* The research studies discussed above, and others that have found either no effect or a minimal effect of dehydration on exercise performance.
- Studies using self-paced exercise demonstrate that fluid loss does not impair exercise performance. A review of the literature further states that dehydration only impairs exercise performance during fixed workload exercise.
- Reduced body mass during exercise does not necessarily mean that a person's hydration status has been negatively affected. Body mass loss does not necessarily equate with fluid loss.

81

Classical mechanism of dehydration-induced performance decrement

- Only people with specific characteristics may show improved exercise performance with high levels of body mass loss. Therefore, intentional body mass loss should not be recommended as a general strategy for improving performance.
- Hypohydration during exercise by an average of about 2.2% BM does not impair exercise performance, and in fact may cause a performance improvement.
- There is no relationship between percentage change in BM and percentage change in power output during exercise.

82

Classical mechanism of dehydration-induced performance decrement

- Both exercise duration and intensity are more important determinants of performance than dehydration.
- There is no significant difference in performance between exercise that results in a BM loss of less than 2% or a BM loss of more than 2%.

83

Hyperhydration during exercise

- Hypervolaemia is an abnormal increase in blood plasma volume which can be caused by overdrinking.
- Hyponatraemia is an abnormally low blood sodium level, caused by overdrinking and/or large sweat sodium losses.
- **Increased body water content can occur for many reasons:**
- Protein breakdown, which increases both plasma proteins and plasma volume.
- Increased plasma volume due to increased plasma sodium concentration
- Retention of sodium due to increased activity of aldosterone
- Increased plasma volume due to increased activity of vasopressin
- Impairment of renal function due to dehydration

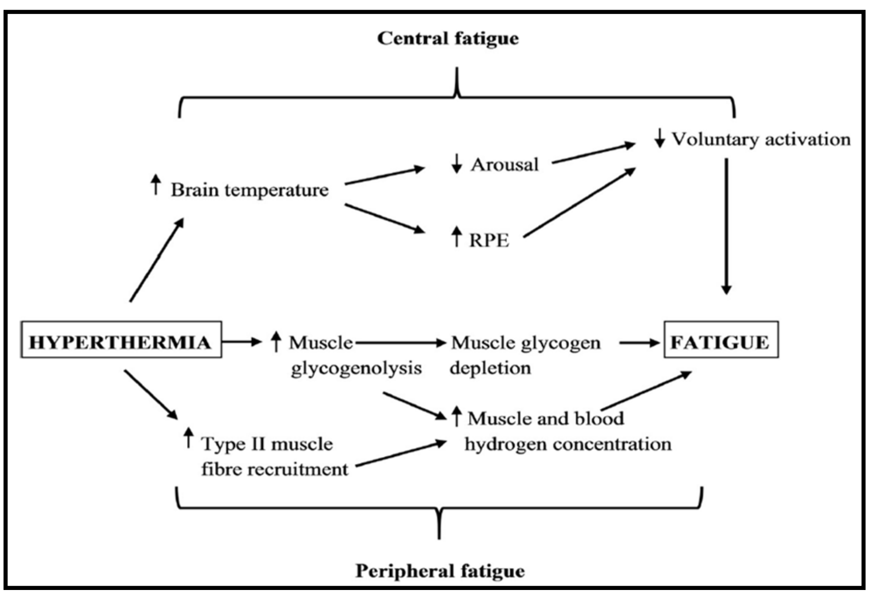
84

Hyperhydration during exercise

- Features of hyponatraemia can range from no or minimal symptoms such as weakness, dizziness, headache, nausea, and vomiting, to serious symptoms including fluid accumulation in the brain (cerebral oedema) leading to brain swelling, altered mental function, seizures, fluid accumulation in the lungs (pulmonary oedema), coma, and death.
- The primary cause of exercise-associated hyponatraemia is overdrinking during exercise. High sweat sodium concentrations can also increase the risk of hyponatraemia, as less fluid intake is required to dilute blood sodium to dangerous levels.

85

hyperthermia-induced fatigue during exercise



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Central fatigue associated with hyperthermia

- There is good evidence to show that hyperthermia reduces the ability to produce muscle force despite no change in the ability of the muscle itself to produce force. This suggests that central factors may be more important than peripheral factors in hyperthermia-induced fatigue.
- During exercise in hyperthermia, brain metabolic rate increases but both blood flow to the brain and brain electrical activity decrease. These changes are associated with a progressive increase in the perception of exercise effort, demonstrating a link between brain blood flow and function, and exercise performance.

Central fatigue associated with hyperthermia

- The ‘critical’ core temperature of approximately 40°C is much lower than the temperature required to cause cellular damage. Therefore, the relevance of this temperature as a limiting factor in exercise performance should be questioned.
- Elevated skin temperature increases skin blood flow requirements, potentially impairing cardiovascular responses to exercise. High skin temperature may also reduce brain blood flow and oxygen delivery.

The Use of Post-exercise Recovery Strategy

89

Definition of Central Terms

- Recovery is regarded as a multifaceted (eg, physiological, psychological) restorative process relative to time.
- Regeneration in sport and exercise refers to the physiological aspect of recovery and ideally follows physical fatigue induced by training or competition.
- strategies such as cold-water immersion (CWI) and sleep.
- In contrast, mental fatigue (ie, cognitive exhaustion) can mainly be compensated by using psychological recovery strategies such as cognitive self regulation, resource activation, and psychological relaxation techniques.

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Definition of Central Terms

- Furthermore, Kellmann distinguishes between passive, active, and proactive approaches to recovery.
- Passive methods may range from the application of external methods (eg, massage) to implementing a state of rest characterized by inactivity.
- Active recovery (eg, cool down jogging) involves mainly physical activities aimed at compensating the metabolic responses of physical fatigue.
- Proactive recovery (eg, social activities) implies a high level of self-determination by choosing activities customized to individual needs and preferences.

91

Definition of Central Terms

- A certain degree of fatigue resulting in functional overreaching is required for performance enhancement and can be compensated through comprehensive recovery.
- Functional overreaching describes a short-term decrement of performance without signs of maladaptation as a consequence of intensive training.
- In case systematic and individualized recovery is not achieved after training and functional overreaching, a continuous imbalance of inadequate recovery and excessive demands could initiate a cascade of deleterious conditions including under recovery and nonfunctional overreaching (NFO).

92

Definition of Central Terms

- Under recovery and NFO represent 2 closely related though slightly different concepts.
- While under recovery appears to delineate a broader condition of insufficient recovery in reaction to general stress (eg, family, media).
- Meeusen et al characterize NFO as training-specific negative psychological and hormonal alterations and subsequent decreased performance.
- Continuous under recovery and NFO often serve as a precursor for overtraining syndrome (OTS).

93

Definition of Central Terms

- OTS is marked by physical symptoms such as continuous muscle soreness, pain sensations, or clinical and/or endocrinological disturbances.
- Under recovery and early-stage NFO can be compensated by systematically applying recovery strategies and rest, along with lifestyle-related strategies like sleep, diet, and social activities.
- However, recovering from OTS requires a continuous restoration consisting of long rest and recovery periods lasting from weeks to months accompanied by reduced performance.

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Different protocols

- Different protocols describe specific recovery methodologies that can be employed in order to achieve more efficient recovery processes, these include:
- (1) recovery strategies [2,3] —foam roll [4,5], massage [6], compression garments [7,8], stretching [9], nutrition [10], active recovery [11], sleep [12], water immersion [13], (2) combinations of recovery strategies [14,15], (3) sport-specific recovery characteristics—soccer [16,17], basketball [18,19], volleyball [20], rugby [21], and combat sports [22], and (4) emerging recovery strategies [23].

95

Different protocols

- Additionally, factors, such as recovery time-periods—post-match [16,17] and during congested schedules.
- However, it is notable that the recovery of coaching and performance staff in elite sports seems to have been forgotten.

96

Recovery Domains

- Recovery is a complex, multifactorial issue.
- Collectively, the scientific literature reports that the primary aim of recovery methods is to accelerate the biological recovery process in shorter time periods.
- Bird [3] described four essential recovery domains, these being neural, muscular, substrate, and psychological (Table 1).
- Additionally, self perception of perceived recovery is also an important consideration, which may affect the balance between happiness and wellness in elite sports athletes.

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Recovery Domains

- Key observations from research on recovery in team sports highlight the fatiguing effect of traveling [29,30] in addition to training and competing [31].
- As a result, new approaches and practical applications of recovery strategies have been discussed to optimize travel and minimize its negative effects on health and performance in team sports athletes.

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Recovery Domains

Table 1. Essential recovery domains.

Domain	Recovery Strategy Examples	Evidence	Reference
Neural	Compression, Massage	↑ ↔	[6–8]
Muscular	Hydrotherapy, Contrast water therapy, Massage	↑ ↑ ↔	[13,14]
Substrate	Nutrition, Hydration	↑ ↑	[2,10]
Psychological	Sleep, Mindfulness	↑ ↑	[34–36]
Sociological	Social interactions (family-friends)	↑	[37]

Level of evidence: Strong = ↑, Inconsistent = ↔.

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Recovery Domains

- Schematic of professional team organizational structure dynamics comprised of the Team Sport Staff (green shade) and Performance Staff (blue shade) centered around the Team (orange shade). Within the organizational structure, each staff provides expertise related to the attainment of specific key performance indicators.

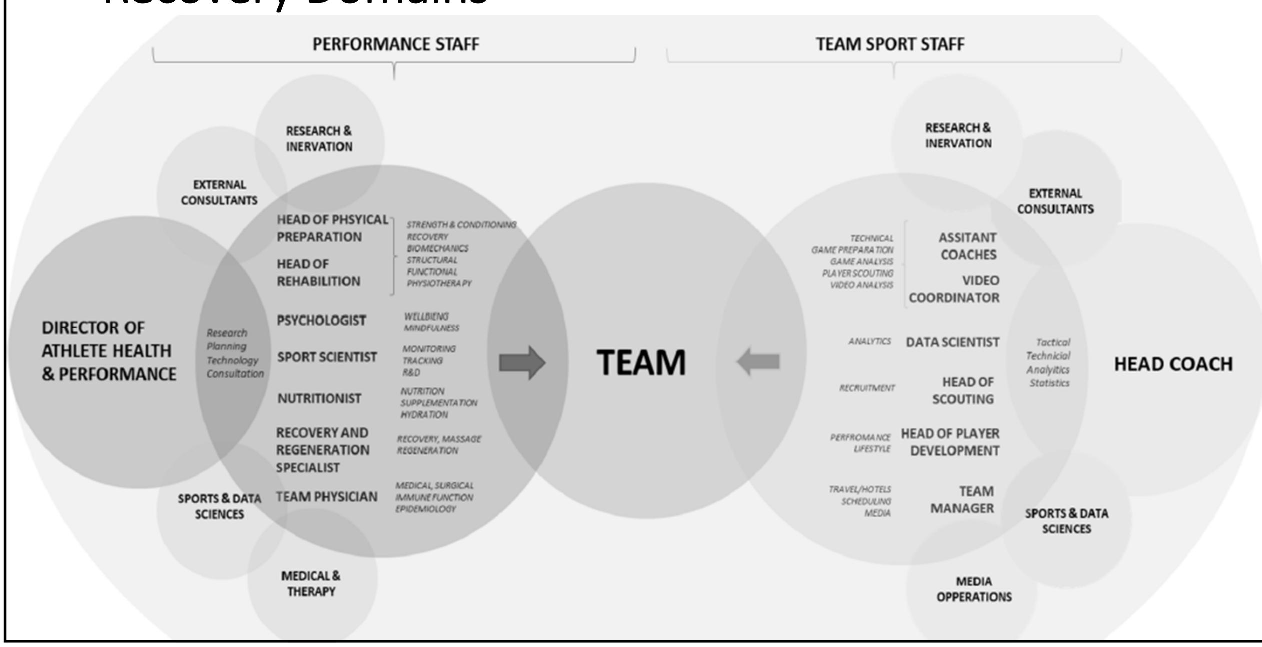
100

Recovery Domains

- Schematic of professional team organizational structure dynamics comprised of the Team Sport Staff (green shade) and Performance Staff (blue shade) centered around the Team (orange shade). Within the organizational structure, each staff provides expertise related to the attainment of specific key performance indicators.

101

Recovery Domains



Recovery Domains

- Schematic of professional team organizational structure dynamics comprised of the Team Sport Staff (green shade) and Performance Staff (blue shade) centered around the Team (orange shade). Within the organizational structure, each staff provides expertise related to the attainment of specific key performance indicators.

103

Fatigue in Team Staff Members

- Coaches, like athletes, strive to gain employment at an elite level in high-performance sports.
- However, Kellmann and colleagues [44] highlight that coaching in elite sports is “capricious and dependent upon winning performances and players’ satisfaction”.
- The high-performance sports setting is considered an uncontrollable, unpredictable, and complex environment, with coaches subjected to a multitude of internal and external stressors (i.e., athlete performance, expectations, external scrutiny), that often result in recovery–stress imbalance.

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Fatigue in Team Staff Members

- This may result in coaches presenting with symptoms associated with psycho-socio physiological fatigue burden [46–49], which can be exacerbated by dehydration, hormonal disturbances, caloric restrictions, or sleep disturbances.
- Regarding team staff members (sports coaches and performance staff), common daily tasks and responsibilities can serve as potential causes of mental fatigue-related issues, with experience and personality as factors of individual susceptibility [50].

105

Fatigue in Team Staff Members

- Educational programs may be useful for some coaches to manage psychological states during competition [51].

106

Recovery Considerations for Team Staff Members

- To better cope with the challenges of daily work and with various fatigue sources, support team staff members need to maintain a high level of health, fitness, and mental wellbeing.
- Fitness, in addition to health protection, plays an important role in mental wellbeing and adaptation to demanding cognitive and social situations [54].
- Like athletes, if team staff members possess high levels of health, fitness, and mental wellbeing, they may tolerate fatigue better—that is to say, when in fatigued situations (physical and/or psychological), their capacity to maintain performance will be less affected.

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Recovery Considerations for Team Staff Members

- The development of educational recovery resources for team staff members may also help address the identified barriers and improve knowledge [3,55,56].
- For example, while team staff members have adequate overall sleep hygiene knowledge [57], some specific areas (e.g., sleep-wake cycle behaviors) warrant further education.
- This may be linked to the negative influence of travel, and possible time zone changes [30,32] is another area where education would be beneficial.

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Recovery Considerations for Team Staff Members

- Additionally, it would be helpful to have access to a sport psychologist role to address the psychological needs of team staff members.
- Recently, diaphragmatic breathing has been reported to reduce physiological and psychological stress [62].
- The potential beneficial effects of diaphragmatic breathing and neural stretching techniques (nerve-directed stretching) [63] may reduce postural tension.

109

Recovery Considerations for Team Staff Members

- The majority of coaches, regardless of their culture, seem to face difficulties in obtaining professional work and family life (work/family balance).
- Work ily balance require special consideration because they have a direct impact on their work performance and potentially on their athletes.

110

THE EFFECTS OF SELF-MYOFASCIAL RELEASE USING A FOAM ROLL OR ROLLER MASSAGER ON JOINT RANGE OF MOTION, MUSCLE RECOVERY, AND PERFORMANCE: A SYSTEMATIC REVIEW

111

Foam Roller

- Macdonald et al measured the effects of foam rolling as a recovery tool after exercise induced muscle damage.
- All subjects went through the same protocol which included an exercise induced muscle damage program consisting of 10 sets of 10 repetitions of the back squats (two minutes of rest between sets) at 60% of the subjects one repetition maximum (RM) and four post-test data collection periods (post 0, post 24, post 48, post 72 hours).
- At each post-test period, the experimental group used the foam roll for a 20 minute session.

112

Foam Roller

- The foam roll intervention consisted of two 60 second bouts on the anterior, posterior, lateral, and medial thigh.
- The subjects used their own body weight with no standard cadence.
- Foam rolling reduced subjects pain levels at all posttest points while improving post-test vertical jump height, muscle activation, and joint ROM in comparison with the control group.

113

Foam Roller

- Pearcy et al measured the effects of foam rolling as a recovery tool after an intense bout of exercise.
- The authors recruited eight male subjects who served as their own control and were tested for two conditions:
- DOMS exercise protocol followed by foam rolling or no foam rolling.
- A four week period occurred between the two testing session. All subjects went through a similar DOMS protocol to that, utilized by Mac Donald et al, which included 10 sets of 10 repetitions of the back squats (two minutes of rest between sets) at 60% of the subject's one RM.

114

Foam Roller

- For each post-test period, subjects either foam rolled for a 20 minutes session (45 seconds, 15 second rest for each hip major muscle group) or did not foam roll.
- For foam rolling, the subjects used their own body weight with a cadence of 50 BPM. Measurements were taken pre-test and then during four post-test data collection periods (post 0, post 24, post 48, post 72).

115

Foam Roller

- The main outcome measures were pressure pain threshold of the quadriceps using an algometer, 30m sprint speed, standing broad jump, and the T-test.
- Foam rolling reduced subjects pain levels at all post treatment points (Cohen d range 0.59-0.84) and improvements were noted in performance measures including sprint speed (Cohen d range 0.68-0.77), broad jump (Cohen d range 0.48-0.87), and T-test scores (Cohen d range 0.54) in comparison with the control condition.

116

Types of foam rollers

- Foam rollers can vary in size and firmness to bring about different results.
- **Soft, low-density foam rollers** are a gentle option suitable for people new to foam rolling or with a lot of sensitivities.
- **Firm, high-density foam rollers** put more pressure on your body.
- **Textured foam rollers** have ridges, grids, or knobs on them. They target your muscles more deeply.
- **Vibrating foam rollers** use various settings to deeply loosen your muscles and release muscle knots. They can help to enhance circulation and flexibility.

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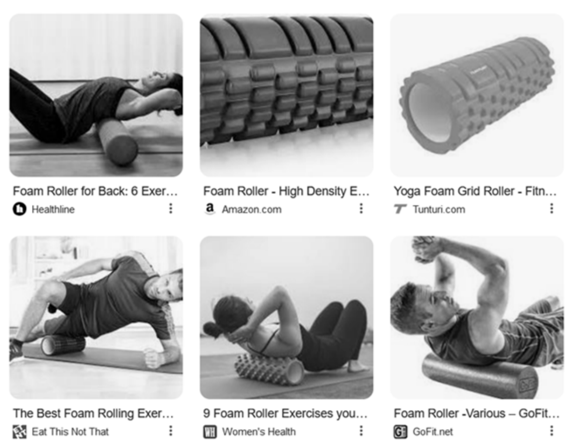
Types of foam rollers

- **Heat and cold foam rollers** can be heated or cooled to deepen muscle relaxation and relieve discomfort.



118

Roller Massage

- Jay et al measure the effects of roller massage as a recovery tool after exercise induced muscle damage to the hamstrings.
- 22 healthy untrained males into an experimental and control group.
- All subjects went through the same DOMS protocol, which included 10 sets or 10 repetitions of stiff-legged deadlifts using a kettlebell, with a 30 second rest between sets.
- The roller massage intervention included one session of 10 minutes of massage in the sagittal plane to the hamstrings using “mild pressure” at a cadence of 1-2 seconds per stroke by the examiner

Roller Massage

- The outcomes were measured immediately post-test, and 10, 30, and 60 minutes thereafter. The roller massage group demonstrated significantly ($p<0.0001$) decreased pain 10 minutes.

After an intense bout of exercise, does self myofascial release with a foam roller or roller massager enhance post exercise muscle recovery and reduce DOMS?

- The research suggests that foam rolling and roller massage after high intensity exercise does attenuate decrements in lower extremity muscle performance and reduces perceived pain in subjects with a post exercise intervention period ranging from 10 to 20 minutes.
- Continued foam rolling (20 minutes per day) over 3 days may further decrease a patient's pain level and using a roller massager for 10 minutes may reduce pain up to 30 minutes.

121

After an intense bout of exercise, does self myofascial release with a foam roller or roller massager enhance post exercise muscle recovery and reduce DOMS?

- It has been postulated that DOMS is primarily caused by changes in connective tissue properties and foam rolling or roller massage may have an influence on the damaged connective tissue rather than muscle tissue. This may explain the reduction in perceived pain with no apparent loss of muscle performance.
- Another postulated cause of enhanced recovery is that SMR increases blood flow thus enhances blood lactate removal, edema reduction, and oxygen delivery to the muscle.

122

Massage and post exercise recovery: the science is emerging

Thomas M Best, Scott K Crawford

123

Introduction

- Athletes use a variety of post exercise recovery techniques with the belief that they are effective at enhancing return to competition and training.
- Common modalities include massage, cold water immersion, compression, electrical stimulation, vibration therapy and a combination of one or more of these strategies.
- Other approaches include diet and hydration protocols, active recovery and sleep.

124

Introduction

- Clinical studies have investigated the long-held claims that massage mediates leucocyte migration and attenuates the inflammatory response to exercise, as well as decreases pain, muscle tone and hyperactivity.
- These reports suggest that massage mediates molecular processes linked to inflammation, specifically by decreasing nuclear factor κβ (NF-κβ), various proinflammatory cytokines and tumour necrosis factor-α (TNF-α).
- The demargination of leucocytes is perhaps due to increased peripheral blood flow and blood perfusion.

Introduction

- A meta-analytical review points out that massage benefits on performance recovery are highly dependent on the type of exercise protocol used to induce fatigue.
- The training status of the athlete may also influence the effectiveness of post exercise massage, perhaps due to the perception of pain and soreness following training and competition.
- timing and dose of massage, can be examined.

Introduction

- Arguably, massage has significant psychological benefits, including increased relaxation and decreased expression of stress biomarkers (ie, cortisol).
- Animal studies have addressed important questions regarding the dosage and timing of massage on the recovery of muscle contractile properties, indicating that recovery is dependent on the magnitude of compressive force and frequency of the massage.
- Poppendieck et al noted that shorter sessions of massage (5–12 min) were most beneficial in improving performance measures.

127

Introduction

- The effects of multiple bouts of massage, either daily or at regular intervals over the course of an athletic season, still need to be investigated.
- Massage, in combination with other recovery strategies, may be an area worthy of investigation as we continue to advance the science for these therapies and ultimately their most useful translation to our athletes and other active people seeking their use for recovery from exercise as well as enhanced performance.

128

Compression Garments and Recovery from Exercise: A Meta-Analysis

129

Definition of Central Terms

Key Points
Small, significant and very likely benefits on exercise recovery can be achieved through use of compression garments (CG).
The greatest benefits from CG are evident in recovery of strength performance and from resistance exercise, which may imply that CG ameliorate muscle damage.
Next day cycling performance was also subject to large, very likely benefits following the use of CG.

130

Introduction

- Establishing effective recovery methods for elite athletes is essential in order to increase the likelihood of victory, and to maintain training intensity in the face of ever improving performances and increasing training loads.
- In short, athletes who recover faster are likely to perform better and train harder.
- Recent years have seen the emergence of a number of interventions aimed at accelerating recovery, including cold water immersion [7], contrast bathing [8], and compression garments (CG) [9].

131

Introduction

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132

Introduction

- However, recovery demands following training are highly specific to the intensity, duration and modality of exercise [10].
- For example, while cycling performance is limited by metabolite accumulation and substrate depletion [11], it is also subject to relatively low levels of muscle damage in comparison to load-bearing exercise.
- Proper consideration of both exercise modality and subsequent performance outcome is therefore integral to the efficacy of any recovery strategy [10, 13].

Introduction

- Compression has been proposed to prevent performance deterioration and improve recovery by accelerating nutrient delivery [15, 16] and metabolite removal [17, 18], as well as by ameliorating post-exercise oedema, delayed onset muscle soreness (DOMS), and muscle damage [19].
- More importantly, such physiological benefits to recovery are frequently observed alongside accelerated recovery of muscular power [20], strength [21, 22] and endurance.

Introduction

- One of the most thoroughly investigated mechanisms for the benefits of CG [16, 19, 21] is the potential of such garments to minimize the symptoms of the exercise induced muscle damage (EIMD) that typically occurs as a result of unaccustomed or eccentric exercise [23].
- Whilst eccentric exercise is beneficial for training power [24, 25], strength and hypertrophy [26], such exercise is extremely damaging. Strength production may be impaired for up to 10 days [27, 28], swelling and DOMS, which typically peak between 36 and 48 h.

135

Introduction

- Furthermore, as any load-bearing exercise will induce EIMD because of the inherent eccentric nature of running [12], muscle damage is an inescapable part of training for the majority of athletes.
- Whilst the mechanisms behind the recovery benefits of CG are still unclear, the application of external compression is known to influence several areas of haemodynamic and cellular function [29].

136

Introduction

- In a clinical setting, CG have been shown to compress dilated veins and reduce venous reflux to enhance venous return and reduce oedema [30].
- This also increases ‘‘muscle pump’’ to accelerate blood flow [31].
- While the successful management of oedema helps to reduce DOMS and increase mobility [16], this effect may also attenuate the progression of muscle damage.

137

Introduction

- Fluid accumulation in muscle tissue increases osmotic pressure and subsequent cell lysis [32], while CG have been shown to reduce cellular trauma alongside swelling [30, 32].
- Reductions in circulating levels of the intramuscular protein creatine kinase (CK) are frequently reported when CG are worn following exercise [19, 20, 33].
- Haemodynamic effects of CG have also been postulated to aid recovery by enhancing levels of nutrient delivery [15, 16] and metabolite removal [34, 35].

138

Introduction

- Accordingly, observations of reduced muscle damage following post-exercise compression have been suggested to reflect enhanced cellular regeneration and protein synthesis [16] made possible by enhanced circulation [17].
- Training history may therefore influence the efficacy of CG. In addition, variation in the duration of CG application, whether CG are worn during and after, or after exercise only, as well as the assessment of recovery at different time points, all continue to obstruct researchers' ability to draw definitive conclusions.

139

Introduction

- The relationship between the pressures exerted by CG and the ensuing recovery benefits has yet to be elucidated.

140

Effects of Water Immersion Methods on Post exercise Recovery of Physical and Mental Performance

141

Introduction

- Athletic recovery modalities include active recovery, stretching, massage, anti-inflammatory drugs, compression garments, electrical stimulation, and the combinations of these recovery methods (3).
- In addition, water immersion methods are common among athletes, and they can be divided into 4 different categories:
- cold water immersion also known as cryotherapy (CWI;#20°C),
- hot water immersion (HWI; $36° C),
- thermoneutral water immersion (TWI; 21–35° C), and
- contrast water therapy (CWT; alternating CWI and HWI) (32).

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thermoneutral water immersion

- Since thermoneutral head-out water immersion induces an increase in central blood volume and cardiac output along with a decrease in peripheral vascular resistance.
- (34.5 degrees C)
- Water immersion techniques have been examined in the scientific literature (32), but the results of their effectiveness in enhancing recovery are conflicting.
- It seems that active recovery methods are largely ineffective for improving most psychophysiological markers of post exercise recovery.

143

Introduction

- Compared with passive recovery and other water immersion methods, CWI has been found to be effective in improving the recovery of strength and power capacities after exercise protocols in several team sports and interval-based endurance exercise.
- but not after eccentric strength loadings.
- After team sport exercise, the recovery of maximal and explosive strength and sprint performance was found to improve when the subjects used CWI compared with passive recovery and other water immersion methods.

144

Introduction

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- After team sport exercise, the recovery of maximal and explosive strength and sprint performance was found to improve when the subjects used CWI compared with passive recovery and other water immersion methods.

Introduction

- Thermoneutral water immersion was found to promote the recovery of explosive strength compared with passive recovery.
- However, the aerobic movement in the water could have affected the recovery (32), and several studies have been shown that TWI did not enhance recovery (5,26,27).
- There are inconsistent results concerning the benefits of water immersion methods on the markers of exercise-induced muscle damage (EIMD).

Introduction

- Cold water immersion was found to prevent EIMD after endurance and team sport exercise protocols compared with active and passive recovery and other water immersion methods.
- but not after single-joint eccentric exercise.
- Cold water immersion was also found to prevent the increase of serum creatine kinase (CK) activity after endurance and team sport exercise protocols.

147

Introduction

- Cold water immersion was found to increase acute serum cortisol concentrations immediately or 30 minutes after water immersion (14,17), but after an hour of immersion, they had returned to baseline levels.
- In addition, there were no differences in serum testosterone and plasma epinephrine and norepinephrine concentrations between CWI and passive recovery at 40–60 minutes after immersion.

148

Introduction

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