Physiology, neuromuscular aspects and tiredness in the racket sports

Presented By Olivier GIRARD
Popular sports played worldwide by millions of people of various levels
Activity profile

• Racket sports are based on **unpredictability** (point length, match duration, shot selection, strategy, weather, opponent)

• In racquet sports, the activity pattern is **intermittent**; i.e. characterised by repetitions of fast starts and stops (*Fernandez Fernandez et al. 2006; Lees, 2003*).

  ➡️ EXERCISE (High-intensity) / REST (Lower intensity)

• To successfully endure tournament competition, racquet sport players must accelerate, decelerate, change direction, move quickly, maintain balance and repeatedly generate optimum stroke production.

• Racket sports involve many aspects of **performance** including speed, power, agility, flexibility, strength, … and **muscular endurance**.

  ➡️ Rapid on-court movement and explosive stroke production
  ➡️ During extended matches (1-5 h)
Components of performance in racket sports

- Many sports require high levels of physical fitness in a few components (e.g. aerobic fitness).

- Performance in racket sports, however, arises from complex interaction between technical, tactical, physiological and psychological skills.

(Lees, 2003)
Components of performance in racket sports

- **Sport-specific skills** are predominant factors *(Reid et al. 2007)*

- **Advanced shots** require well-developed physical fitness
Research publications and racket sports

Tennis articles accounts for 80% of published articles

Physiology-related articles accounts for 1/3 of published articles
- **Activity profile**
- **Major physical components and energy requirements**
  - Game intensity
  - Neuromuscular aspects
- **Manifestation of fatigue**
  - Activity-specific protocols
  - Match play
- **Factors responsible for fatigue**
  - Metabolic factors
  - Neuro-mechanical factors
  - Homeostatic perturbations

Useful information that may help coaches, trainers and sport scientists to identify talent, monitor progress and maintain motivation of their players.
Tennis

Badminton

85% of rallies shorter than 9 s

Squash

1/3 of rallies longer than 21 s

Large variety of work/rest ratio profiles across racket sports
Notational analysis in racket sports

- The **duration of competition** vary from 30 to 60 min in squash and badminton to more than 5 h in tennis, but average duration of 30 to 90 min are common in all racket sports.

- **Match activity varies** widely across racket sports but also for a given activity due to the **uniqueness of the match**.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Rally duration (s)</th>
<th>Rest duration (s)</th>
<th>Effective playing Time (%)</th>
<th>Work:Rest ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table tennis</td>
<td>3-4</td>
<td>8</td>
<td>30-35</td>
<td>1:3</td>
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<tr>
<td>Tennis</td>
<td>5-12</td>
<td>15-20</td>
<td>20-30</td>
<td>1:4</td>
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<tr>
<td>Badminton</td>
<td>4-8</td>
<td>10-16</td>
<td>40-50</td>
<td>1:2</td>
</tr>
<tr>
<td>Squash</td>
<td>15-20</td>
<td>8-10</td>
<td>50-70</td>
<td>1:1</td>
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</tbody>
</table>
#1 The physiology of racket sports is complex due to the start and stop nature and inconsistent length of matches. Therefore, rigid and strict training guidelines are inappropriate. Emphasis should be placed on developing intermittent, anaerobic performance rather than long-duration, moderate intensity aerobic exercise.

#2 As speed, agility, and maximum velocity movements respond to specific and individualized training, it is important that racquet sport players focus on training distances seen during match play (table tennis: < 10 meters; squash and badminton: < 15 meters; tennis: < 20 meters), with drills combining linear, lateral, and multidirectional movements.

#3 Most training drills should simulate the time requirements experienced during match play with appropriate work to rest ratios (from 1:2 for badminton/squash to 1:5 for tennis/table tennis).
OUTLINES

• Activity profile
• Major physical components and energy requirements
  – Game intensity
  – Neuromuscular aspects
• Manifestation of fatigue
  – Activity-specific protocols
  – Match play
• Factors responsible for fatigue
  – Metabolic factors
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Useful information that may help coaches, trainers and sport scientists to identify talent, monitor progress and maintain motivation of their players
Racket sport practice requires a combination of **aerobic** and **anaerobic energy systems**, and the involvement of these systems depends on the **intensity** of the **rally** and the **duration** of the **recovery** (Fernandez et al. 2006).

Metabolic specificity

- **Aerobic** systems are involved in prolonged activities and rely on oxygen for energy production. Examples include aerobic endurance activities such as 200-400 m dash, 100-m swim, and activities beyond 800 m run.

- **Anaerobic** systems are involved in short-term, high-intensity activities and do not rely on oxygen. Examples include anaerobic power-endurance activities such as 200-400 m dash, 100-m swim, and activities beyond 800 m run.

- **Anaerobic-oxidative system** combines both aerobic and anaerobic systems, allowing for a more sustained output of energy, as seen in activities like cycling and swimming.

- **Immediate/short-term non-oxidative systems** are involved in activities requiring rapid energy production without the use of oxygen, such as power lifts, high jump, shot put, golf swing, and tennis serve.

- **Electron transport-oxidative system** is involved in sustained power activities that require the use of oxygen, such as sprints, fast breaks, and football line play.

- **Strength-power** activities require both short-term and immediate energy production, combining elements of both aerobic and anaerobic energy systems.

The diagram illustrates the time duration and predominant energy pathways involved in different types of performance.
• Energy demands associated with the repeated bursts of intense, brief activity are met by the anaerobic processes.

• The aerobic metabolism supplies the energy to enable the player to last for the duration of the match.

Racket sports are predominantly anaerobic activities, requiring high levels of aerobic conditioning to avoid fatigue and aid in the recovery between points.
Intensity (HR) might come from other non-physiological sources, such as psychological factors (mental stress and releasing hormones such as cortisol, adrenaline, and noradrenaline).
Despite the start-and-stop nature of the game, physiologic variables during games are not decisively different from recovery periods.

3 squash games (elite players)

\[ \approx 86\% \text{VO}_{2\text{max}} \]

\[ \approx 92\% \text{HR}_{\text{max}} \]

Prolonged tennis playing (3 h)

Distinct variations throughout a game related to match characteristics

Girard et al. (2006)
Game intensity – Particular aspects

**Tennis match play**

- Physiological stress ➤ serving vs. return games

- 3 squash games (elite players)

**Racket Sports** = **DUAL ACTIVITIES**

- △ VO₂ between 2 players
- △ Ranking between 2 players

Girard et al. (2007)
7 males of the German junior national table tennis team (age: 14 ± 1 years) => **Cardiovascular load** during six **training sessions** and an **international match**.

![Heart Rate Graph](image)

Average HR: 164 bpm (80% HR\textsubscript{max})

[La]: 1.8 (mmol.l\(^{-1}\))

<table>
<thead>
<tr>
<th></th>
<th>Mean (Peak) [La] (mmol.l(^{-1}))</th>
<th>Heart rate</th>
<th>Oxygen uptake</th>
<th>Energy expenditure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Training</td>
<td>1.2 (4.5)</td>
<td>135 (184)</td>
<td>23.5 (43.0)</td>
<td>6.8 (11.2)</td>
</tr>
<tr>
<td>Competition</td>
<td>1.1 (1.6)</td>
<td>126 (189)</td>
<td>25.6 (45.9)</td>
<td>4.8 (9.6)</td>
</tr>
</tbody>
</table>

**Low cardiorespiratory and metabolic demands** during table tennis training and match play in internationally competing juniors
2 x 15 min simulated badminton games

Faude et al. (2007)

Comparable cardiovascular and metabolic strain between genders?

<table>
<thead>
<tr>
<th></th>
<th>Total (N = 12)</th>
<th>Females (N = 8)</th>
<th>Males (N = 4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR (min⁻¹)</td>
<td>169 ± 9</td>
<td>170 ± 10</td>
<td>166 ± 6</td>
</tr>
<tr>
<td>HR (% HR_{peak})</td>
<td>89.0 ± 4.6</td>
<td>88.4 ± 5.1</td>
<td>90.3 ± 3.7</td>
</tr>
<tr>
<td>Lactate (mmol l⁻¹)</td>
<td>1.9 ± 0.7</td>
<td>1.9 ± 0.9</td>
<td>1.9 ± 0.1</td>
</tr>
<tr>
<td>VO₂ (ml min⁻¹ kg⁻¹)</td>
<td>39.6 ± 5.7</td>
<td>36.4 ± 2.8</td>
<td>46.0 ± 4.5*</td>
</tr>
<tr>
<td>VO₂ (% VO₂_{peak})</td>
<td>73.3 ± 6.5</td>
<td>72.6 ± 7.2</td>
<td>74.8 ± 5.3</td>
</tr>
<tr>
<td>RER</td>
<td>0.99 ± 0.07</td>
<td>0.99 ± 0.08</td>
<td>0.99 ± 0.06</td>
</tr>
<tr>
<td>VE (l min⁻¹)</td>
<td>72.2 ± 18.1</td>
<td>61.1 ± 8.7</td>
<td>94.3 ± 6.4*</td>
</tr>
<tr>
<td>b_l (min⁻¹)</td>
<td>45.7 ± 5.9</td>
<td>44.9 ± 5.9</td>
<td>47.4 ± 5.9</td>
</tr>
<tr>
<td>EE (kJ min⁻¹)</td>
<td>53.3 ± 12.7</td>
<td>45.9 ± 6.7</td>
<td>68.0 ± 7.5*</td>
</tr>
<tr>
<td>EE (kJ kg⁻¹ min⁻¹)</td>
<td>0.84 ± 0.12</td>
<td>0.77 ± 0.06</td>
<td>0.97 ± 0.10*</td>
</tr>
</tbody>
</table>

Importance of anaerobic and aerobic energy production in competitive badminton.
Blood lactate concentration \([\text{[La]}]\) reflect the involvement of anaerobic glycolytic process to supply energy.

Numerous opportunities are available for lactate to be cleared (Fernandez et al. 2008).

Lower values in table tennis, tennis \(< 4 \text{ mmol.l}^{-1}\) or badminton \(< 6 \text{ mmol.l}^{-1}\) than in squash \(> 5 \text{ mmol.l}^{-1}\).

Sampling time is restricted to disruptions to standard match condition and only reflect the level of activity during the few minutes before sampling.
Game intensity – Particular aspects

- **Temporary increases** (up to 8-10 mmol.l\(^{-1}\)) during **long and intense rallies** may determine the **outcome of crucial situations** in the game (decreased technical and tactical behavior)

![3 squash games (elite players)](image)

World-standard squash is predominantly a high-intensity aerobic activity with great emphasize on the anaerobic energy systems ([La] = 8 mmol.l\(^{-1}\))
Typical physiological strain experienced in racket sports

<table>
<thead>
<tr>
<th>Activity</th>
<th>%VO$_{2\text{max}}$</th>
<th>%HR$_{\text{max}}$</th>
<th>[La] (mmol.l$^{-1}$)</th>
<th>Work:Rest ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table tennis</td>
<td>55-65</td>
<td>80-85</td>
<td>2</td>
<td>1:3</td>
</tr>
<tr>
<td>Tennis</td>
<td>60-80</td>
<td>70-85</td>
<td>2-4</td>
<td>1:4</td>
</tr>
<tr>
<td>Badminton</td>
<td>75-85</td>
<td>75-90</td>
<td>3-6</td>
<td>1:2</td>
</tr>
<tr>
<td>Squash</td>
<td>80-85</td>
<td>80-92</td>
<td>5-10</td>
<td>1:1</td>
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</tbody>
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Uniqueness of the game!
• Perceived exertion can be defined as “the subjective intensity of effort, strain, discomfort and/or fatigue that is experienced during physical exercise”.

• Perceived exertion through the **Borg scale** has been shown to linearly increase (from 11 or “light” to 14 or “somewhat hard”) throughout a 3-h tennis match play (Girard et al. 2006).

![Graph showing prolonged tennis playing (3 h)](image)

- Greater rating of perceived exertion values are generally reported by service than return male tennis players (*in line with higher cardiovascular strain*) (Fernandez et al. 2005).
In racquet sports, the physical and physiological demands may vary to a large extent and are influenced by a multitude of factors as:

- The style of the player,
- The gender,
- The level and style of the opponent,
- The playing surface,
- The equipment (i.e. missile and racquet characteristics) and
- The environmental factors (i.e. temperature and humidity)

(Girard & Millet, 2004)
• In racquet sports, the physical and physiological demands may vary to a large extent and are influenced by a multitude of factors as:
  – The **style** of the **player**,  
  – The **gender**,  
  – The **level and style of the opponent**,  
  – The **playing surface**,  
  – The **equipment** (*i.e.* missile and racquet characteristics) and  
  – The **environmental factors** (*i.e.* temperature and humidity)

<table>
<thead>
<tr>
<th>Increased AEROBIC demands</th>
<th>Increased ANAEROBIC demands</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Being female,</td>
<td>• Being male,</td>
</tr>
<tr>
<td>• Slower surfaces,</td>
<td>• Fast surfaces,</td>
</tr>
<tr>
<td>• Type 3 balls,</td>
<td>• Type 1 balls,</td>
</tr>
<tr>
<td>• Longer match duration</td>
<td>• Shorter match duration</td>
</tr>
<tr>
<td>• Baseline play.</td>
<td>• Serve and volley play.</td>
</tr>
</tbody>
</table>
#4 The **critical phases** (serve, stroke, quick acceleration to the ball) are likely to be metabolically dependent on **anaerobic pathways** of energy supply, which would be superimposed on a background of largely **aerobic** submaximal activities (**rest periods**).

The training of competitive players should focus on improving their ability to **repeatedly perform high-intensity exercise** and to recover rapidly from it (**intense interval training, repeated sprints**)．

#5 The **physical and physiological requirements** of racket sport can **vary** depending on **numerous factors** (player’s level, playing style, sex, climatic conditions), which have **important implications when designing on-court and off-court training programs**．
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Useful information that may help coaches, trainers and sport scientists to identify talent, monitor progress and maintain motivation of their players
The assessment of fatigue

**FATIGUE** = Transient decrease in the capacity to perform physical actions

<table>
<thead>
<tr>
<th>Muscle Physiologists</th>
<th>Decline in muscle force (Reductionist approach)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unaware of how altered muscle function impacts sport performance?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sport Scientists</th>
<th>Exercise-induced impairment of performance (Holistic approach)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unclear about which neuromuscular processes underpin fatigue symptoms during sport events?</td>
</tr>
</tbody>
</table>

Limitations to understand the symptoms and mechanisms of fatigue during racquet sport competitions
Quantifying the manifestation of fatigue

Assessment of single whole-muscle function

Assessment of whole-body exercise abilities

Assessment of sport abilities during sport events

Muscle cell function

Muscle Performance Tests

Exercise Performance Tests

Competition Performance Symptoms

Results

Afferent feedback

Motor drive

Central Nervous System

- External/body environment e.g. temperature, oxygen levels, hydration status, fuel availability, hormonal levels, respiratory/cardiac input, muscle perfusion.

- Subjective fatigue sensations

- Technique: motor skill execution or motor skill outcomes

- Decision making

- Psychological aspects
Common manifestations of fatigue during exercise or sport competition

**Competition Performance Symptoms**

= Impairment of movement abilities/outcomes as they appear during sport events

\[ \downarrow \text{Whole-body work rate/velocity}, \ \text{inability to surge, } \uparrow \text{rest periods}, \ \text{cessation of exercise} \]
\[ \downarrow \text{Technical execution (tired looking movements)} \]
\[ \downarrow \text{Hitting, kicking or throwing velocity} \]
\[ \uparrow \text{Error rate (e.g. } \downarrow \text{accuracy of hitting)} \]
\[ \uparrow \text{Mental lapses (i.e. } \downarrow \text{concentration, } \uparrow \text{tiredness, slower/inaccurate decisions)} \]

**Test measures**

**PHYSICAL EXERCISE**
\[ \downarrow \text{Muscle force (e.g. peak MVC, isokinetic, or tetanic forces)} \]
\[ \downarrow \text{Muscle, limb/joint, or whole-body power} \]
\[ \uparrow \text{Time (i.e. endurance, sprint, agility repeated sprint)} \]
\[ \downarrow \text{Stride frequency, } \downarrow \text{stroke length, } \downarrow \text{pedal rate, } \downarrow \text{range of motion} \]

**TECHNIQUE**
\[ \downarrow \text{Motor skill execution (} \downarrow \text{foot or hand speed)} \]
\[ \text{Motor skill outcome (} \downarrow \text{ball velocity or accuracy)} \]

**SUBJECTIVE SENSATIONS**
\[ \uparrow \text{Sense of effort (rating of perceived exertion)} \]
\[ \uparrow \text{Sense of generalized fatigue/tiredness} \]
\[ \uparrow \text{Sense of force (includes } \uparrow \text{sense of heaviness)} \]
\[ \uparrow \text{Ratings of muscle soreness, } \uparrow \text{discomfort, } \uparrow \text{pain} \]

The uniqueness of each competition complicates the interpretation of fatigue effects
Fatigue impairs racket sport performance

Performance $\Rightarrow$ player’s ability to generate power repeatedly $\Rightarrow$ Rapid on-court movement $\Rightarrow$ Explosive stroke production

FATIGUE
(Duration and intensity of match play $\Rightarrow$)

- Time to complete shuttle runs
- Number of balls that can not be reached
- Accuracy and velocity of the serve and ground strokes
- Poor positional play
- Mistimed shots

FATIGUE $\Rightarrow$ TENNIS PERFORMANCE

Coaches
Metabolic factors

Protocol:
- 30 strokes and sprints subdivided into 6 x 5 repetitions with a 1 min rest between series.
- The rest between each stroke-and-sprint lasted either 10 s or 15 s.

Running speed and stroke quality during intermittent tennis drills are highly dependent on the duration of recovery time.

Ferrauti et al. (2001)
Methods to induce fatigue ≠ from match conditions (format of the protocol, using a ball machine)

Measuring only performance outcomes (ball speed and accuracy) rather than stroke kinematics
After a prolonged (2h 30 min) tennis match, **ball velocity remains unchanged** while the effects of **fatigue** on the **lower limb drive** are **different according to the service type**.

**Expertise enhances potential to adjust motor coordination strategies under fatigue**

In the fatigued state, **forehand drive accuracy** was **maintained** by elite table tennis players but with **altered movement patterns**, whereas recreational players **lost precision** (Aune et al. 2008).
Manifestation of fatigue – *Match play*

**SIMULATED TENNIS MATCH PLAY (3-h)**

<table>
<thead>
<tr>
<th></th>
<th>T₀</th>
<th>T₃₀</th>
<th>T₆₀</th>
<th>T₉₀</th>
<th>T₁₂₀</th>
<th>T₁₅₀</th>
<th>T₁₈₀</th>
<th>Recovery</th>
<th>T₊₃₀</th>
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<tbody>
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</table>

**Vertical jump tests**

Unchanged explosive strength under fatigue (*movement reorganization?*)

*Girard et al. (2006)*
Manifestation of fatigue – *Match play*

Maximal voluntary contraction torque (Nm)

**Knee extensors**

**Plantar flexors**

**Strength loss**

- Different patterns
- Modest losses (19 to 35%) compared to continuous prolonged exercises

*Millet & Lepers, 2004*

*Millet & Lepers, 2004*

*Millet et al., 2008*

*Millet et al., 2011*
Manifestation of fatigue – *Match play*

Some of the fatigue-induced decrement in “on-court” movements might be partially explained by alterations in the mechano characteristics of the muscle-tendon complex.

- **Preactivation**
- **Stretch**
- **Shortening**

*Girard et al. (2006)*

↑ work during push-off phase

loss of elastic energy potential

Deteriorated Muscle function

**Leg stiffness (kN.m)**

<table>
<thead>
<tr>
<th>T0</th>
<th>T30</th>
<th>T60</th>
<th>T90</th>
<th>T120</th>
<th>T150</th>
<th>T180</th>
<th>T+30</th>
</tr>
</thead>
<tbody>
<tr>
<td>21.7</td>
<td>20.6</td>
<td>20.2</td>
<td>21.3</td>
<td>19.5</td>
<td>20.2</td>
<td>19.9</td>
<td>19.7</td>
</tr>
</tbody>
</table>

*Hopping test*
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Useful information that may help coaches, trainers and sport scientists to identify talent, monitor progress and maintain motivation of their players.
Potential causes of muscle fatigue

Exercise-induced impairments in racket sport specific skills

UNDERPINNING FACTORS

METABOLIC
- Muscle excitability
- Muscle contractility
- Acidosis
- PCr availability
- Muscle glycogen

NEUROMECHANICAL
- Muscle activation strategies
- Leg stiffness

HOMEOSTATIC PERTURBATIONS
- CHO supplementation
- Dehydration
- Playing in hot conditions

No global mechanism responsible for muscle fatigue (Task-dependency)

(Mendez-Villanueva et al. 2007)
Potential sites of muscle fatigue

(Bigland-Ritchie et al. 1981)
Quantifying neuromuscular fatigue - Approach to the problem

Percutaneous stimulation

Motor cortex (supraspinal)

Spinal cord (spinal)

Neurostimulation (evoked contractions)

Muscle (peripheral)

Evoked potential

Voluntary contraction

Evoked potential

Mechanical response

Torque (MVC)

EMG

M-wave

EMG activity

Torque
Potassium ([K⁺]) has an important role in skeletal muscle excitability regulation. Under fatigue, Na⁺-K⁺ pump cannot readily re-accumulate the potassium (K⁺) efflux out of the muscles cells, inducing an ↑ of muscle extra-cellular [K⁺].

These modifications will impair cell membrane excitability and depress force development, probably by slow inactivation of Na⁺ channels.
**M-wave** (Surface EMG recordings) during evoked contractions in resting conditions

Muscle excitability

**Well preserved sarcolemmal excitability**

**Temporary fatigue?**
(Exhausting or consecutive intense rallies)
Muscle metabolites

❖ twitch mechanical response following tennis and squash match play (Girard et al. 2008/2010)

Before

After

Twitch contractile properties of the quadriceps muscle before and after the 1-h squash match.

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th>After</th>
<th>Changes (%)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pt (Nm)</td>
<td>53.8 ± 10.9</td>
<td>43.1 ± 9.7</td>
<td>−19.9 ± 9.8</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

❖ ❖ Ca²⁺ release from sarcoplasmic reticulum (Westerblad et al. 2002)
Metabolic energy supply

- **Maximal sprint** exercise of short duration requires **high rates of ATP generation**

- Provided mainly by **anaerobic pathways**:
  - **PCr breakdown**
  - Degradation of **muscle glycogen** to lactate (anaerobic glycolysis)

![First Sprint](chart1.png)

- ATP: 8%
- PCR: 6%
- Glycolysis: 46%
- Aerobic: 40%
- Remove H+
- Replenish PCR

![Last Sprint](chart2.png)

- ATP: 2%
- PCR: 40%
- Glycolysis: 9%
- Aerobic: 49%

*(Gaintanos et al. 1993)*
Limitations in energy supply (PCr)

- After a bout of intense/maximal work, a drop in PCr stores occurs, and the complete replenishment can last between 3 and 5 minutes.

The ability to perform subsequent sprints depends on the degree to which PCr is resynthesized during the recovery periods between multiple sprints.
Muscle recruitment strategies

Twitch interpolation (% Voluntary activation)

\[ VA(\%) = \left[1 - \frac{\text{Superimposed twitch}}{\text{Potentiated twitch}}\right] \times 100 \]

= Number of recruited motor units and their discharge rate
  (with no possible distinction)

Surface EMG = Muscular activation

EMG activity

Force

Fresh

Fatigued

Central activation deficit

No increment

Superimposed twitch (contraction)

Potentiated twitch (rest)
Muscle recruitment strategies

3 h tennis match play

Plantar flexors

NEURAL DRIVE TO THE MUSCLE
Assessment of neuromuscular function before and after a 1 h squash match

Muscle recruitment strategies

CENTRAL ACTIVATION DEFICIT
Neuromuscular fatigue in racket sports – Mind over muscle?

Match-induced fatigue

Supraspinal:
- Change in neurotransmitter concentration (serotonin, dopamine)

Spinal:
- Inhibition of motoneuron excitability (reflex adjustments)

Peripheral:
- Reduced membrane excitability (ionic disturbances)
- Failure of excitation-contraction coupling (calcium movements)

Altered cortical excitability

Hyperthermia/Dehydration

Metabolic accumulation

Energy supply (hypoglycaemia)

Motivation

Altered performance

(Girard & Millet, 2008)
#6 The aetiology of muscle fatigue in racquet sports is a complex phenomenon (*i.e.* distinction between temporary fatigue and fatigue occurring in the final stage of a competition) that might involve impairment in both neural (suboptimal muscle activation) and contractile (accumulation of metabolites) processes.

#7 The mechanisms underlying fatigue (and therefore the strategies that could be implemented to combat the underpinning limiting factors) are probably different between across racquet games.

#8 Postponing fatigue …
- Delaying central fatigue (*resistance & electromyostimulation*)
- Improving muscular aerobic metabolism (*High-intensity interval training*)
- Reducing inorganic phosphate build up at the onset of exercise (*prefatiguing situation: bouncing, in-depth jumping, plyometric exercises, medicine-ball followed by on court high-intensity interval-training*)
- Reducing ion-disturbances & systemic disturbances of acid / base balance
Playing tennis in the heat

- The attainment of **high internal temperatures (> 38.5° C)** can impair **CNS function**, resulting in a level of central cognitive or neural drive to the muscle, which in turn might **performance** *(ASPETAR research group)*.

- **Acclimatization**: when playing in hot/humid environments, the acclimatized (6-8 days with daily exposures) athletes will:
  - Begin to sweat earlier and have a higher sweat rate for a longer period,
  - Reduce their heart rate
  - Lose fewer electrolytes in sweat

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![Graph showing rectal temperature vs. time and heart rate vs. rectal temperature](image-url)

Morantes et al. (2007)
Playing tennis in the heat

- A carbohydrate/electrolyte sports beverage may be more effective than water in minimizing fluid deficits and thermal strain during tennis training in the heat in highly skilled, acclimatized adolescent tennis players (Bergeron et al. 2006).

- Carbohydrate (CHO) supplementation before or during exercise aims to limit depletion of muscle glycogen stores by attenuating the rise in free fatty acids, which in turn contributes to limiting the augmentation of some precursors of central fatigue (i.e., plasma-free tryptophan:BCAA ratio).
Fluid and hydration

- No apparent benefit in including CHO in fluid-replacement drinks during < 2h tennis play.

<table>
<thead>
<tr>
<th>Study</th>
<th>Exercise</th>
<th>Interventions</th>
<th>Performance measures</th>
<th>Results</th>
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<tbody>
<tr>
<td>Burke and Ekblom[47]</td>
<td>2h simulated tournament tennis (n = 5)</td>
<td>CHO polymer vs water, no fluid control and thermal dehydration</td>
<td>Ground stroke accuracy (BMT)</td>
<td>Maintained with CHO only ↑ 11.6 % with CHO</td>
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<tr>
<td>Mitchell et al.[48]</td>
<td>2 × 3h tennis matches (n = 12)</td>
<td>CHO vs water (PLA)</td>
<td>Serve velocity 183m shuttle run test</td>
<td>No benefit from CHO</td>
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<tr>
<td>Ferrauti et al.[49]</td>
<td>4h interrupted tennis, 3 × 75 min matches (n = 18; 8 male, 8 female)</td>
<td>CHO vs CAF (4 mL/kg) vs PLA (double-blind)</td>
<td>Ground stroke accuracy (BMT) Games won during match play</td>
<td>No benefit from CHO CAF &gt; CHO and PLA (female) CAF &gt; CHO (male)</td>
</tr>
<tr>
<td>Vergauwen et al.[50]</td>
<td>2h strenuous training session (n = 13)</td>
<td>CHO vs CHO + CAF (5 mL/kg) vs PLA (double-blind)</td>
<td>Ground stroke quality (BMT) Serve quality 70.5m shuttle run test</td>
<td>No benefit from CHO CAF &gt; CHO and PLA (female) Improved with CHO (all)</td>
</tr>
<tr>
<td>Struder et al.[48]</td>
<td>4h interrupted tennis, 3 × 75 min matches (n = 8)</td>
<td>CHO vs CAF (4 mL/kg) vs PLA (double-blind)</td>
<td>Ground stroke accuracy (BMT) Games won during match play</td>
<td>No added effect of CAF over CHO No benefit from CHO or CAF</td>
</tr>
<tr>
<td>Magal et al.[50]</td>
<td>2h exercise-induced dehydration (n = 11)</td>
<td>Hyperhydration Glycerol vs water (double-blind)</td>
<td>Ground stroke and serve quality Repeat-effort agility test 5m and 10m sprint test</td>
<td>No performance benefit of glycerol over water (for all performance measures)</td>
</tr>
</tbody>
</table>

BMT = ball machine test; CAF = caffeine; CHO = carbohydrate; PLA = placebo; ↑ indicates increased.

- Tennis players can sweat >2.5 L.h, however the gastric emptying rate for beverages, rarely exceeds 1.2 L.h (Kovacs, 2006).
- Exercise performance is impaired when an individual is hypohydrated as little as 2% of their body mass (a loss of 5% can decrease work capacity by 30%).
#9 Hot environments and dehydration are worsening fatigue, whereas carbohydrate supplementation before or during competitions (> 2 h) may delay the fatigue.

Consumption of appropriate fluid levels is recommended:

1) 2h before exercise: 400-600 ml to be euhydrated (urine test)
2) During practice or competition: ≥ 200 ml every 15 min in mild temperatures (< 27° C WBGT) and ≥ 400 ml in hot/humid conditions (> 27° C WBGT)
3) Immediately after play: nutriment replacement emphasizing fluids, CHO (50 g every 2h) and Na⁺ supplementation (1.5 g.L) is recommended

NB: Electrolyte loss during sweating is Na⁺ (not K⁺), which has been linked with muscle cramping.

#10 CHO (6-8% solution) and electrolyte drink promotes fluid absorption to a greater degree than water alone. However, water consumption alone is sufficient for match and practice < 90 min.
Thank you

Questions?