

Dr/ Fethi DERBAL

Sports Tests and Measurements

University of Science and Technology Mohammed Boudiaf ORAN

Institute of Science and Techniques of Physical and Sports Activities

COURSE PLAN

Sports Tests and Measurements

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Field: Sports training

Specialty: physical and sports preparation

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I- Course Information:

Institute: Science and Techniques of Physical and Sports Activities

Department: Sports Training + Physical Education and Sports

Target Audience: 1st Year Master's in Sports Training and Physical Education and Sports

Course Title: Sports Tests and Measurements

VHS: 45 H (14 - 16 weeks)

Semester n= 01

UEM: Methodological

VHH: 1:30 lecture

VHH personal work: 1:30

Coefficient: 01

Credit: 02

Schedule: Saturday and Tuesday from 8:00 AM to 12:00 PM

Room: 06

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Laboratory Availability: Saturday, Tuesday from 8:00 AM to 12:00 PM

By email: all correspondence made by email will receive a response through the same channel.

II. Course Presentation:

This course is intended for first-year master's students in sports training and physical education, in accordance with the new LMD system program.

It primarily focuses on the basic concepts of sports fitness assessment.

This course is structured as follows:

Conference No.1: Introduction to Measurement and Evaluation in Sports Training

Conference No.2: Assessment of Basal Metabolism and Energy Expenditure in Sports Training

Conference No.3: Assessment of Training Load and Technological Measurement Tools

Conference No.4: Physiological, Biomedical, and Cardiorespiratory Assessment of Athletes

Conference No.5: Anthropometric, Morphological, and Biomechanical Assessment of Athletes

Conference No.6: Nutritional Monitoring and Annual Dietary Intake Assessment of Athletes

Conference No.7: Assessment of Sports Fitness and Fundamental Physical Qualities

Conference No.8: Assessment of Immediate and Chronic Fatigue and Prevention of Overtraining in Athletes

Conference No.9: Assessment of Energy Systems – Aerobic, Anaerobic Lactic, and Anaerobic Alactic

Conference No.10: Assessment of Recovery and Regeneration

Conference No.11: Assessment of Neuromuscular Adaptations Resulting from Training

Conference No.12: Psycho-pedagogical Assessment and Competitive Stress in the Development of Sports Performance

Conference No.13: Design of Field Test Batteries According to Sports Specialty

Conference No.14: Measurement and Evaluation in Specific Training Environments

Conference No.15: Analysis of Test Results and Decision-Making in Training

Conference No.16: Measurement Tools and Digital Tracking with Wearable Technologies

III - Content:

Conference n°1: Introduction to Measurement and Evaluation in Sports Training. P : 01 - 08

Fundamental Concepts

Importance of Measurement and Evaluation in Training

Psychometric Qualities of a Good Test

Norms and Criteria

Conference n°2: Assessment of Basal Metabolism and Energy Expenditure in Sports Training . P : 09-19

Definition and Importance of BMR

Components of Total Energy Expenditure (TEE)

Factors Influencing BMR and TEE

Methods for Evaluating BMR

Methods for Evaluating TEE and Physical Activity

Conference n°3: Assessment of Training Load and Technological Measurement Tools. P : 20 -25

Definitions and Key Concepts

Modern Monitoring Technologies

Operational Protocol for Data Collection and Analysis

Practical Applications in Sports Training

Conference n°4: Physiological, Biomedical, and Cardiorespiratory Assessment of Athletes . P : 26 - 34

Importance of Cardiorespiratory Indicators

Evaluation Methods

Relationship with Performance and Recovery

Standardized Testing Conditions

Tools and Modern Technologies

Conference n°5: Anthropometric, Morphological, and Biomechanical Assessment of Athletes . P : 35 -46

Anthropometric and Morphological

Biomechanics

Analysis Methodology

Analysis Tools

Conference n°6: Nutritional Follow-up and Annual Dietary Intake Assessment of Athletes . P : 47 -52

Objectives of the Annual Dietary Assessment

Methods for Evaluating Eating Habits

Analysis of Nutritional Components

Conference n°7: Assessment of Sports Fitness and Fundamental Physical Qualities. P : 53 - 62

Definitions and Scope of "Sporting Fitness"

Conceptual Framework and Classification of Qualities

Modeling "Fitness": From Historical Models to Modern Monitoring

Conference n°8: Assessment of Immediate and Chronic Fatigue and Prevention of Overtraining in Athletes . P : 63 - 70

Fatigue: Definitions and Taxonomy

Physiological Indicators of Fatigue

Biological and Psychological Warning Signs

Conference n°9: Assessment of Energy Systems – Aerobic, Anaerobic Lactic, and Anaerobic Alactic . P : 71 - 81

Bioenergetic Reminder

Key Variables to Measure

Laboratory Tests

Field Tests

Conference n°10: Assessment of Recovery and Regeneration . P : 82 - 88

Objectives and Model of Recovery

Recovery Indicators:

Tests to Evaluate Recovery

Field Technologies

Conference n°11: Assessment of Neuromuscular Adaptations Resulting from Training .

P : 89 - 93

Concepts of Neuromuscular Adaptations

Key Neuromuscular Variables

Tools for Measuring Neuromuscular Activation

Conference n°12: Psycho-pedagogical Assessment and Competitive Stress in the

Development of Sports Performance . P : 94 - 101

Self-Determination Theory (SDT) and Self-Regulation

Sport Stress and Performance

Concepts of Psychological Measurement in Sports Training

Conference n°13: Design of Field Test Batteries According to Sports Specialty. P:102-108

Deterministic Analysis of Performance (The "What" to Evaluate)

Reasoned Selection of Measurement Tools (The "How" to Evaluate)

Standardization of the Testing Protocol

Data Processing and Interpretation

Conference n°14: Measurement and Evaluation in Specific Training Environments.

P:109 - 114

Influence of Specific Environments on Sports Performance

Altitude (Hypobaric Hypoxia)

Heat (Thermal Stress)

Extreme Humidity

Cold (Cold Stress)

Conference n°15: Analysis of Test Results and Decision-Making in Training.P:115-119

Processing and Organizing Results

Statistics Applied to Sports Data

Conference n°16: Measurement Tools and Digital Tracking with Wearable

Technologies . P : 120 - 128

Strategic Positioning of Technologies

Wearables – Performance and Validity

Artificial Intelligence – Pipelines and Models

IV- Prerequisites:

To maximize the benefits of this course, the student must have acquired the following knowledge:

1. The basics of sports training and its main components.
2. The principles of physical fitness and its characteristics (strength, speed, endurance, agility, flexibility).
3. The fundamental principles of physiology related to physical performance.
 - Anatomy and human physiology: It is important to understand the basics of how the human body functions in order to choose and use tests appropriately.
 - Biomechanics: Knowledge of the principles of biomechanics allows for the analysis of athletes' movements and understanding the factors that influence performance.
 - Statistics: Students must be familiar with basic statistical concepts in order to analyze test results.
 - Understanding the basic principles of sports measurement and knowing the types of tests applied in sports.

V- Learning Objectives and Aims:

1. Identify the theoretical and practical foundations of tests and measurements in the sports field.
2. Understand the link between measurement, evaluation, and planning of sports training.
3. Select, design, and implement physical and aptitude tests that align with training objectives.
4. Analyze test results using appropriate statistical tools.
5. Use test results to evaluate players' performances and identify their strengths and weaknesses.
6. Develop research skills in the field of sports measurement and evaluation.
7. Use modern measurement tools and technologies effectively and professionally.

- Learning objectives:

By the end of this module, students will be able to:

1. **Understand the foundations of tests and measurements in sports.**
 - Define key concepts of sports performance evaluation.

- Identify the different types of tests and measurements.
- Understand physical qualities and the associated tests.
- Explain the principles of validity, reliability, and objectivity of tests.

2. Master the different types of tests and measurements.

- Choose the most suitable test for a given situation.
- Administer tests in a standardized and safe manner.
- Collect data accurately and reliably.
- Analyze test results using appropriate statistical methods.
- Interpret test results and use them to optimize training.

3. Know how to choose and use tests appropriate for a given situation.

- Determine the objectives of the evaluation.
- Identify the characteristics of the population to be tested.
- Choose the most relevant test based on objectives and population.
- Adapt the testing protocol according to specific needs.
- Ensure the safety of participants during the test.

4. Interpret test results and use them to optimize training.

- Identify the strengths and weaknesses of athletes.
- Compare test results to standards and references.
- Determine the factors that influence performance.
- Individualize training based on test results.
- Monitor performance evolution over time.

5. Develop critical thinking about sports performance evaluation.

- Identify the limitations and biases of tests and measurements.
- Evaluate the ethical and deontological impact of performance evaluation.
- Develop a reflective and responsible approach to the use of tests and measurements.
- Analyze the reliability and validity of the tests used, as well as their reproducibility and applicability in different training environments.

- Use modern techniques and tools for sports measurement, applying them in an ethical and professional framework.
- Distinguish between types of tests (field, laboratory, standardized, and verbal).

VI. Learning Assessment Methods:

The final assessment is conducted through:

a- Continuous and regular assessment, representing 25% of the final grade, allows you to earn points throughout the semester. This assessment is carried out through various forms:

- ✓ attendance
- ✓ participation
- ✓ homework assignments

b- The written assessment covers everything you have studied in the course chapters. The score from the assessment represents 25% of the final grade.

c- A final exam that covers everything that has been taught to you during the semester. This exam counts for 50% of the final grade.

VII. Teaching-learning activities:

Understanding and mastering evaluation tools and methods is crucial for your success. To support you in this learning, we have designed a comprehensive program combining in-person and distance activities.

In-person:

- Participatory debates: Stimulate your critical thinking and engage with your peers during lively discussions around key questions.
- Directed work: Apply your knowledge to concrete cases and strengthen your understanding of the concepts covered in each chapter.
- Practical laboratory work: Put into practice the various evaluation techniques in a controlled environment and benefit from personalized support.

At a distance:

- Interactive quizzes: Test your knowledge and identify your strengths and weaknesses using various quizzes (multiple choice, true/false, etc.).

- Educational writing: Strengthen your understanding by reformulating and synthesizing the key concepts of the course.

By combining these different approaches, you maximize your chances of success and develop a solid understanding of evaluation tools and methods.

VIII- Operational Modalities:

The course is organized into:

- ✓ Theoretical sessions to convey all the knowledge (basic definitions and different evaluation methods).
- ✓ Directed work sessions (TD) for each learning unit to help you mobilize the acquired knowledge.
- ✓ Practical work sessions to carry out all tests and measurements related to the taught aspects.

In addition to the in-person sessions held in class and in the pedagogical laboratory in physiology, there is distance learning conducted via the teaching platform to deepen the concepts seen in person.

IX -Support resources:

Resources are available to you on the platform:

- ✓ A pedagogical support: this resource is essential for preparing for the theoretical session (in-person).

TD sheets: this resource gathers all the methods and tools that will be needed during the TD sessions.

Conference No. 1 Introduction to Measurement and Evaluation in Sports Training

1. Introduction :

In the realm of high-performance sports training, measurement and evaluation are foundational pillars for optimizing performance, preventing injuries, and monitoring athletes' progress in an individualized manner. These practices enable the collection of objective data on performance, identification of each athlete's specific needs, and effective adaptation of training plans.

Evaluation serves as the initial step in the training process, acting as a diagnostic tool to establish a baseline for a given objective. It is also employed during the training cycle to monitor progress and make adjustments, as well as at the end of the cycle to assess achievements (summative evaluation).

2. Fundamental Concepts :

2.1 Measurement :

Measurement is the process of assigning numerical values to specific attributes or characteristics (e.g., strength, speed, heart rate) according to defined rules and standardized units (Stevens, 1946). It transforms qualitative observations into quantitative, comparable, and analyzable data.

- **Types:**
 - **Direct Measurement:** Utilizes sensors or chronometers (e.g., VO_2max via gas analyzer).
 - **Indirect Measurement:** Estimation through predictive equations (e.g., VO_2max derived from the Cooper test).
- **Examples in Sports:** Race time, jump height, maximum heart rate, anthropometric data (height, weight).

2.2 Test :

A test is a standardized procedure designed to assess a specific physical or functional capacity (e.g., Luc-Léger test, vertical jump test). It aims to obtain a sample of behavior or performance under controlled conditions, ensuring reproducibility and comparability.

- **Characteristics:** Standardized conditions (warm-up, instructions, environment).
- **Types:**
 - **Laboratory Tests:** Direct, precise measurements with limited access (e.g., VO_2max via calorimetry).

- **Field Tests:** Easy to implement but less precise, using indirect measurements.
- **Relevance:** Tests must align with the training methodology and the type of effort required by the sport, minimizing the influence of technical factors.

2.3 Evaluation :

Evaluation is the process of analyzing and interpreting data from measurements and tests to make judgments or decisions (e.g., orientation, adjustment). It gives meaning to raw data by comparing them to standards, previous performances, or individual objectives.

- **Example:** A jump height of 60 cm is a raw measurement; evaluation involves comparing this result to discipline-specific norms or past performances to assess the level.
- **Objective:** Adjust training, enhance specific qualities, or optimize recovery.

3.Importance of Measurement and Evaluation in Training :

Measurement and evaluation are critical for:

- **Tracking Progress:** Regular tests validate the effectiveness of the training program (e.g., a 5% improvement in CMJ over 6 weeks).
- **Identifying Weaknesses and Asymmetries:** Detection of specific imbalances (e.g., muscular asymmetries).
- **Injury and Overtraining Prevention:** Early indicators such as heart rate variability (HRV) or creatine kinase (CK) levels signal fatigue or risks (Buchheit & Laursen, 2013).
- **Individualizing Training Loads:** Designing tailored programs based on strengths and weaknesses (e.g., adjustments via anaerobic threshold, MAS, HRVT).
- **Performance Optimization:** Identifying limiting factors to plan peak performance (e.g., measuring physiological responses via HR or lactate).
- **Athlete Motivation:** Quantifiable progress enhances engagement.
- **Effective Communication:** Objective data facilitates exchanges between coaches, athletes, and support teams.

4.Psychometric Qualities of a Good Test :

A test must possess the following metrological qualities to be relevant:

4.1 Validity:

Validity ensures that the test measures what it is intended to measure.

- **Content Validity:** The test covers the entire concept being assessed (e.g., a strength test for weightlifters includes specific movements).
- **Criterion-Related Validity:**
 - **Concurrent Validity:** Correlation with a gold standard (e.g., field VO₂max test vs. laboratory test).
 - **Predictive Validity:** Prediction of future performance (e.g., explosive power test for sprinting).
- **Construct Validity:** Assessment of a theoretical concept (e.g., agility, endurance) linked to related variables (e.g., Yo-Yo IR1 validity for intermittent exercise).
- **Ecological Validity:** Reproducibility of sport-specific movements (e.g., COD test vs. real direction changes).

4.2 Reliability:

Reliability ensures the reproducibility of results under similar conditions.

- **Test-Retest Reliability:** Consistency of results across repeated measurements (e.g., high ICC for sprint tests) (Hopkins, 2000).
- **Inter-Rater Reliability:** Consistency between different evaluators (e.g., ICC > 0.80 for anthropometric measurements, ISAK standards).
- **Intra-Rater Reliability:** Consistency of a single evaluator (e.g., CV < 5% for power tests).
- **Internal Consistency:** Consistency between test items (e.g., Cronbach's Alpha for questionnaires).

4.3 Objectivity :

Objectivity ensures that results are independent of the evaluator.

- **Means:** Rigorous standardization, use of technologies (e.g., GPS sensors, automated video analysis).
- **Training:** Certification of testers (e.g., ASCA Level 3 for isokinetic tests).

4.4 Norms and Criteria :

- **Norms (Norm-Referenced Standards):** Comparison to the average performance of a reference group (e.g., a 7-second sprint time for professional footballers).

- **Construction:**
 1. Define a representative sample (age, sex, level).
 2. Administer the test under standardized conditions.
 3. Collect and analyze raw scores (mean, standard deviation, percentiles).
 4. Interpret the athlete's relative position (e.g., 75th percentile).
- **Criteria (Criterion-Referenced Standards):** Comparison to a predefined threshold (e.g., running 1.5 miles in 12 minutes for a test).
 - **Construction:**
 1. Define a clear objective (e.g., scoring 50 goals out of 100 attempts).
 2. Prepare a representative test.
 3. Determine a cut-off score by experts.
 4. Assess whether the athlete meets the score.

Norm	Criterion
Reference: Performance of a group	Reference: A predefined objective or level
Objective: Determine the individual's relative ranking	Objective: Determine if the individual has achieved a specific level of mastery
Question: "How does their performance compare to others?"	Question: "Have they achieved the required objective?"
Example: Comparing a basketball player's speed to the team's average	Example: Determining if a player scored a specific number of goals in a season

-Construction of Norms and Criteria The construction of norms and criteria follows distinct methodological steps, as each serves a different purpose in the sports measurement and evaluation process.

-Construction of a Norm: Norms rely on comparing an individual's performance to that of a reference group. The basic steps are:

1. **Define the Population and Representative Sample:** Select a large group that accurately represents the target category (e.g., basketball players under 18). The sample must reflect the population in terms of age, sex, training level, etc.

2. **Administer the Test:** Conduct the sports test (e.g., speed or vertical jump test) for all members of the reference sample under standardized and objective conditions.
3. **Collect and Analyze Data:** Gather raw scores (initial results) from each individual.
4. **Convert Raw Scores to Standardized Scores:** Use statistical methods (e.g., mean, standard deviation, percentiles) to convert raw scores into standardized scores, forming the norm. For example, tables may show an individual's performance as a percentage relative to the group.
5. **Interpret Results:** The norm determines the individual's relative position. A score above the mean indicates strong performance relative to the group, while a score below suggests weaker performance.

-Construction of a Criterion: Criteria rely on defining a specific level of mastery or performance that must be achieved. The steps are:

1. **Define the Performance Objective:** Clearly and precisely specify the skill or capacity to be measured (e.g., "The ability to score 50 goals out of 100 attempts from a specific zone").
2. **Prepare the Test:** Define the test content and tasks or exercises that measure the objective. Tasks must fully represent the skill.
3. **Determine the Cut-off Score:** Establish the minimum acceptable performance level, determined by experts based on their experience and knowledge.
4. **Administer the Test:** Conduct the test and compare individual results directly to the cut-off score.
5. **Interpret Results:** Judge whether the individual has met or exceeded the cut-off score, independent of others' performances. Those who meet or exceed the score are deemed successful, while those who fall short are considered to have failed.

5. Interpretation of Results and Reference Standards Interpretation contextualizes raw data to provide meaning:

- **Normative References:** Comparison to a reference group (e.g., percentiles for MAS > 17 km/h in professional footballers).
- **Criterion References:** Comparison to a predefined threshold (e.g., VO₂max > 60 ml/kg/min for U23 cyclists).

- **Intra-Individual Interpretation:** Comparison to the athlete's previous performances, using Z-scores or SWC (Smallest Worthwhile Change) to detect significant improvements (Hopkins, 2006).
- **Context:** Consider age, sex, sport, competition level, and individual goals.

6. Test Administration Conditions To ensure validity, reliability, and objectivity, tests must adhere to:

- **Standardization:** Defined conditions for warm-up, instructions, equipment, temperature (20–22 °C), and humidity.
- **Adequate Warm-Up:** Specific protocol (e.g., 5 minutes at 60% VO₂max + progressive sprints).
- **Time of Day:** Tests conducted at the same time to avoid circadian effects (e.g., morning tests, ≥ 48 hours post-match).
- **Minimal Fatigue:** Athletes must be rested, hydrated, motivated, and informed of the test's purpose.
- **Safety:** Ensure participant safety.
- **Controlled Environment:** Minimize distractions and maintain appropriate conditions.
- **Qualified Administrator:** Trained and competent testers.
- **Calibrated Equipment:** Precision of measurement tools.
- **Test Relevance and Timing:**
 - Tests aligned with the sport's effort type, minimizing technical influence.
 - Timing:
 - **Cycle Start:** Diagnose strengths and weaknesses.
 - **Mid-Cycle:** Monitor progress (operational evaluation).
 - **Cycle End:** Assess achievements (summative evaluation).

7. Ethics and Professionalism The use of measurements and tests raises ethical considerations:

- **Informed Consent:** Inform athletes about objectives, procedures, risks, and data use (e.g., maximal effort tests).
- **Confidentiality:** Adhere to regulations (e.g., GDPR), anonymize data.

- **Non-Discrimination:** Adapt tests to avoid bias (e.g., women vs. men).
- **Respect for Athletes:** Tests should support development, not be punitive.
- **Evaluator Competence:** Only qualified professionals should administer tests.
- **Transparency:** Clear and honest communication of results.
- **Absence of Bias:** Objectivity in administration and interpretation.
- **Recommendations:** Follow the ACSM (2022) guidelines for physical fitness evaluation.

Conclusion :

Measurement and evaluation are indispensable strategic tools for optimizing sports performance. Their rigorous application, grounded in principles of validity, reliability, and objectivity, enables precise individualization of training programs. Beyond data, the ability to interpret results in a relevant context and use them ethically distinguishes competent professionals.

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Practical Exercises :

1. **Case Study:** Analyze the reliability of a 10-meter sprint test (calculate the coefficient of variation [CV] and intraclass correlation coefficient [ICC]).
2. **Discussion:** Ethics of using GPS data for minors.

Conference No. 2: Assessment of Basal Metabolism and Energy Expenditure in Sports Training

1. Introduction :

The basal metabolic rate (BMR) represents the minimum amount of energy required by the body to maintain vital functions at complete rest (e.g., respiration, circulation, thermoregulation, organ function). Total energy expenditure (TEE), on the other hand, encompasses all energy utilized by the body, including BMR, the thermic effect of food (TEF), energy expenditure from physical activity (EEPA), and adaptive thermogenesis. These concepts are fundamental for athletes, as their accurate assessment enables optimization of nutritional intake, training planning, body composition management, recovery enhancement, and prevention of overtraining. This lecture explores the definitions, evaluation methods (direct, indirect, and predictive), factors influencing BMR and TEE, their impact on endurance, performance, and recovery, and their practical applications in athletic preparation.

2. Fundamental Concepts :

2.1 Definition and Importance of BMR :

The BMR is measured under strict conditions: complete rest, 12–14 hours of fasting, a thermally neutral environment (22 °C), and no physical or mental stimulation. It accounts for 45–70% of TEE depending on training level and is closely related to the resting metabolic rate (RMR), which is measured under less stringent conditions (3–4 hours of rest, overestimating BMR by 3–10%).

Relevance for Athletes:

- Serves as the foundation for calculating total caloric needs ($TEE = BMR \times \text{activity factor}$).
- Enables adjustment of nutritional strategies for mass gain or loss.
- Facilitates monitoring of physiological states (e.g., fatigue, overtraining, energy deficit).
- Influences recovery by ensuring energy for glycogen resynthesis and tissue repair.

2.2 Components of Total Energy Expenditure (TEE)

TEE represents the total energy used by the body over a given period, typically expressed in kilocalories (kcal) or kilojoules (kJ).

Components of TEE:

- **Basal Metabolic Rate (BMR):** 60–75% of TEE for sedentary individuals, 45–70% for athletes (Black et al., 2022).

- **Thermic Effect of Food (TEF):** Energy used for digestion, absorption, transport, and metabolism of nutrients (5–10% of TEE).
- **Energy Expenditure from Physical Activity (EEPA):** Energy used for voluntary movements, including structured training and non-exercise activity thermogenesis (NEAT). Predominant in athletes, especially in endurance sports.
- **Adaptive Thermogenesis:** Energy used for adaptive processes such as stress, growth, or thermoregulation (5–10%).
Units: TEE is expressed in $\text{kcal}\cdot\text{day}^{-1}$, METs ($1 \text{ MET} = 3.5 \text{ ml O}_2\cdot\text{kg}^{-1}\cdot\text{min}^{-1} = 1 \text{ kcal}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$), $\text{kJ}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, or $\text{J}\cdot\text{kg}^{-1}\cdot\text{m}^{-1}$ (energy cost of running) (Ainsworth et al., 2023).

3. Factors Influencing BMR and TEE :

3.1 Factors Influencing BMR :

- **Fat-Free Mass (FFM):** The primary determinant, as muscle tissue is metabolically active (+7–8 kcal/kg of muscle). Athletes with higher FFM have a higher BMR.
- **Age:** BMR decreases by 1–2% per decade after age 30 due to muscle mass loss.
- **Sex:** Men have a 5–10% higher BMR than women, mainly due to greater FFM.
- **Hormones:** Thyroid hormones (T3), insulin, cortisol, and catecholamines increase BMR. Imbalances (e.g., overtraining) may reduce it.
- **Nutrition:**
 - Acute caloric deficit (-30%): Reduces BMR by 8–15% via decreased T3 and leptin (Müller et al., 2022).
 - Proteins: High thermic effect (20–30%), slightly increases BMR.
 - Supplements (e.g., creatine, 5 g/day): Increases BMR by 2–4% via increased FFM (Forbes et al., 2023).
- **Environmental Conditions:** Altitude (> 2500 m) increases BMR by 6–10% through thermogenesis (Kayser, 2022).
- **Overtraining:** Reduces BMR by 5–12% due to a catabolic state and elevated cortisol (Hackney, 2021).
- **Genetics:** Influences metabolic efficiency.

3.2 Factors Influencing TEE :

- **Body Mass and Composition:** Higher muscle mass increases BMR (+0.8 kcal·kg⁻¹·day⁻¹). Example: A rugby player has a higher TEE than a cyclist.
- **Age and Sex:** BMR decreases with age, and men have higher TEE than women. Hormonal variations (e.g., follicular/luteal phase) influence TEE by up to 8%.
- **Intensity, Duration, and Frequency of Physical Activity:** Intense, prolonged activity (e.g., running at 90% of VO₂max) results in higher TEE.
- **Type of Physical Activity:** Aerobic activities (e.g., running, 600–800 kcal/h at 70% of VO₂max) and anaerobic activities (e.g., weightlifting, 300–500 kcal/h) have distinct energy profiles.
- **Environmental Conditions:** Heat (↑ 5–15%), cold, or altitude (↑ 10–25%) increase TEE (Jeukendrup, 2023).
- **Physiological and Hormonal State:** Fever, stress, or prolonged caloric restriction alter TEE.
- **Genetics:** Influences BMR and metabolic efficiency.

4. Evaluation Methods :

4.1 Methods for Evaluating BMR :

BMR evaluation methods are divided into direct, indirect, and predictive approaches:

- **Direct Methods (Laboratory):**
 - **Direct Calorimetry:** Measures body heat in a calorimetric chamber. Highly accurate (±2%), but expensive and rarely used in sports contexts (Westerterp, 2023).
- **Indirect Methods (Laboratory and Field):**
 - **Indirect Calorimetry (IC):** The gold standard, measuring oxygen consumption (VO₂) and carbon dioxide production (VCO₂) via a mask or canopy (10–20 min).
 - **Weir Equation (1949):** BMR (kcal/24 h) = [(3.9 × VO₂) + (1.1 × VCO₂)] × 1.44, where VO₂ and VCO₂ are in L/min.
 - **Conditions:** Fasting ≥ 10 h, 30 min rest, 22 °C temperature, no caffeine, 8 h sleep.
 - **Validity:** CV < 5% between measurements, stable state (VO₂ variation < 5% over 5 min) (Compher et al., 2021).

- **Advantages:** High precision (gold standard).
- **Disadvantages:** Expensive equipment, non-portable, requires trained personnel.
- **Doubly Labeled Water (DLW):** Uses stable isotopes to validate BMR over long periods, but reserved for research due to cost.
- **Predictive Methods (Estimations):**
 - **Classic Equations:**
 - **Harris-Benedict (1919):**
 - Men: $BMR = 66.5 + (13.75 \times \text{weight in kg}) + (5.003 \times \text{height in cm}) - (6.755 \times \text{age in years})$.
 - Women: $BMR = 655.1 + (9.563 \times \text{weight in kg}) + (1.850 \times \text{height in cm}) - (4.676 \times \text{age in years})$.
 - Note: Overestimates in sedentary individuals, underestimates in athletes (5–10%).
 - **Mifflin-St Jeor (1990):**
 - $BMR = (10 \times \text{weight in kg}) + (6.25 \times \text{height in cm}) - (5 \times \text{age in years}) + 5$ (men) or -161 (women).
 - Note: More accurate for general populations ($\pm 10\%$).
 - **Cunningham (1980):** $BMR = 500 + (22 \times \text{FFM in kg})$.
 - Note: Preferred for athletes, as it incorporates fat-free mass (FFM).
 - **Owen (1986):** Adapted for women, less used for athletes.
 - **Sport-Specific Equations:**
 - **De Lorenzo (2022):** $BMR = 24.2 \times \text{FFM}^{0.75} \times 1.1$ (U23 cyclists, training > 12 h/week).
 - **Rodriguez (2023):** $BMR = 655 + (9.56 \times \text{weight in kg}) + (1.85 \times \text{height in cm}) - (4.68 \times \text{age in years}) + 150$ (female footballers, training > 8 h).
 - **Portable Devices:**

- **Smart BIA (e.g., InBody 970):** Estimates BMR via FFM and Cunningham equation ($r = 0.92$ vs. IC).
- **Breezing Pro:** Portable optoelectronic sensor ($r = 0.88$ vs. IC).
- **Advantages of Predictions:** Simple, accessible, no expensive equipment needed.
- **Disadvantages:** Less accurate, sensitive to interindividual variations.

4.2 Methods for Evaluating TEE and Physical Activity :

- **Direct Methods (Laboratory):**
 - **Direct Calorimetry:** Measures body heat production. Accurate but costly and impractical.
- **Indirect Methods (Laboratory and Field):**
 - **Indirect Calorimetry:** Measures VO_2 and VCO_2 to estimate TEE via respiratory quotient ($r = 0.97$ vs. DLW).
 - **Doubly Labeled Water (DLW):** Measures CO_2 production over 7–14 days, gold standard for long-term TEE (Westerterp, 2023).
 - **Accelerometers (ACC):** Portable devices (e.g., ActiGraph GT9X, $r = 0.82$ – 0.91) measure movement to estimate EEPA. Underestimate certain activities (e.g., cycling).
 - **GPS Combined with ACC:** Used for outdoor sports (e.g., Polar Vantage V3, $r = 0.76$ – 0.89), provides data on distance, speed, and acceleration.
 - **Heart Rate Monitors (HRM):** Correlate heart rate with VO_2 for submaximal efforts (e.g., WHOOP 4.0, $r = 0.71$ – 0.84).
 - **Pedometers:** Measure step count but are less accurate for TEE.
 - **Questionnaires and Activity Logs:** Tools like IPAQ, prone to recall bias.
- **Predictive Methods:**
 - **Regression Equations:**
 - BMR: Harris-Benedict, Mifflin-St Jeor, Katch-McArdle.
 - Running: $EE \text{ (kcal)} = 0.96 \times \text{weight} \times \text{distance (km)}$.

- Cycling: $EE \text{ (kJ)} = 3.6 \times \text{average power (W)} \times \text{time (h)}$ (Jeukendrup, 2021).
- **Physical Activity Factors (PAF):** $BMR \times \text{coefficient}$ (1.2 for sedentary, 2.0–2.4 for highly active athletes).
- **METs:** $TEE = MET \times \text{weight (kg)} \times \text{time (h)}$ (e.g., brisk walking \approx 4 METs).

5. Relationship with Training, Endurance, and Recovery :

5.1 Relationship with Training :

- **Short-Term:** Excess post-exercise oxygen consumption (EPOC) temporarily increases BMR and TEE after intense exercise (e.g., HIIT).
- **Long-Term:** Strength training increases FFM, permanently elevating BMR. Endurance sports optimize energy efficiency, potentially reducing BMR at a given intensity.
- **Planning:** TEE indicates training volume and intensity, enabling physiological adaptations while avoiding overtraining.

5.2 Relationship with Endurance :

- Accurate BMR assessment supports calculation of energy needs for prolonged training, preventing glycogen depletion.
- Underestimating BMR or uncompensated TEE can lead to an energy deficit (RED-S), impacting performance and health (Mountjoy et al., 2018).
- A 5% reduction in metabolic cost at a given speed can improve race time by 1.5% (Shaw et al., 2022).

5.3 Relationship with Recovery :

- BMR supports glycogen resynthesis and tissue repair, energy-intensive processes.
- An abnormal BMR decrease or excessive TEE may indicate overtraining or chronic energy deficit, necessitating reduced training load.
- **Relative Energy Load (REL):** $REL = (TEE - BMR) / BMR$.
 - Target: 1.2–1.8 (endurance sports), 0.8–1.2 (explosive sports).
 - $BMR \downarrow > 10\% = \text{risk of RED-S}$.

6. Operational Protocol for Evaluation :

6.1 BMR Evaluation :

- **Indirect Calorimetry (Short Protocol):**
 - **Preparation:** Fasting ≥ 10 h, no exercise ≥ 24 h, 30 min supine rest (22 °C), no caffeine, 8 h sleep.
 - **Measurement:** Canopy (e.g., Vyntus CPX) for 15 min, stable state (VO_2 variation $< 5\%$ over 5 min).
 - **Analysis:** Average of the last 5 minutes, acceptable CV $< 3\%$.
- **Rapid Field Estimation:**
 - **Smart BIA (InBody 970):** Measures FFM and applies Cunningham equation ($r = 0.92$ vs. IC).
 - **Breezing Pro:** Portable optoelectronic sensor ($r = 0.88$ vs. IC).
 - **Procedure:** Measure weight, height, FFM (if possible), apply a suitable equation (e.g., Cunningham).

6.2 TEE Evaluation :

- **Preparation:**
 - Define objectives: Adjust nutrition, optimize training, or monitor recovery.
 - Select method: Laboratory (calorimetry), sensors (ACC, GPS), questionnaires.
 - Calibration: ACC (10 s vertical at 1 g), GPS (10 Hz mode, dilution of precision < 3).
 - Familiarization: Preliminary test 24 h prior.
- **Administration:**
 - **Typical Day:**
 1. Measure BMR (6–8 AM, fasting).
 2. Main training session (GPS + ACC).
 3. Ancillary activities (ACC, 24 h monitoring).
 - Standardize conditions (e.g., rest for BMR, 20–22 °C temperature).
- **Analysis:**

- Collect anthropometric data: Weight, height, body composition.
- Estimate BMR: Via indirect calorimetry or equations.
- Quantify activity: Time and intensity (ACC, GPS).
- Calculate TEE: Sum of BMR, TEF, and EEPA.
- Software: ActiLife 6 (ACC), Golden Cheetah (cycling).
- Statistics: $CV < 5\%$, $SWC = 0.2 \times SD$ (Hopkins, 2023).

7. Practical Applications in Sports Training :

- **Nutritional Planning:** Adjust caloric intake for mass gain, cutting, or maintenance (e.g., readjust if $BMR \downarrow > 8\%$). Use DLW + MyFitnessPal for weight-class sports (Turocy et al., 2022).
- **Overtraining Detection:** Combine BMR + HRV. A 10% BMR decrease + 15% HRV reduction indicates a need for load reduction.
- **Body Composition Optimization:** Monitor FFM (via DEXA) and BMR (via Cunningham) to adjust fat loss strategies.
- **Endurance Sports:** Evaluate BMR and TEE to estimate energy needs and prevent reserve depletion (e.g., marathon, Ironman) (Jeukendrup, 2023).
- **Weight-Class Sports:** Precisely plan weight loss without compromising performance.
- **Recovery:** Control NEAT post-injury to avoid excessive TEE (WHOOP + RPE, Bourdon et al., 2021).
- **Specific Monitoring:** Adapt training at altitude or during competition to meet increased energy demands.

8. Limitations and Considerations :

- **Equation Accuracy:** Predictive equations may over- or underestimate BMR and TEE in athletes with high FFM or metabolic adaptations.
- **Measurement Conditions:** Require strict control (rest, fasting, thermoneutrality) to avoid bias.
- **Individual Variability:** Genetic, hormonal, and environmental differences necessitate a personalized approach.

- **Accessibility:** Indirect calorimetry and DLW are costly and less available, making predictive equations and portable devices more common but less accurate.
- **Device Limitations:** Accelerometers underestimate certain activities (e.g., cycling), and heart rate monitors are influenced by external factors (stress, temperature).

Conclusion :

Evaluating basal metabolism and energy expenditure is a critical tool for optimizing training, nutrition, and recovery in athletes. Whether through sophisticated methods like indirect calorimetry or doubly labeled water, or accessible field tools like accelerometers, GPS, or predictive equations (e.g., Cunningham for BMR), accurate measurement enables personalized strategies to maximize performance while preserving health. Monitoring BMR and TEE allows coaches to detect overtraining, adjust caloric intake, optimize body composition, and support recovery. Complementary approaches, combining direct and indirect methods, ensure reliable short- and long-term evaluation.

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Practical Exercises :

1. Clinical Case: Professional Female Footballer

- **Data:** $VO_2\text{max} = 52 \text{ ml/kg/min}$, FFM = 48 kg, indirect calorimetry measurement = 1450 kcal/24 h.
- **Tasks:**
 - Estimate BMR using the Cunningham equation.
 - Compare with the indirect calorimetry measurement (1450 kcal/24 h).
 - Interpret the discrepancy and propose a nutritional adjustment.

2. Case Study: Male Footballer

- **Tasks:** Compare estimated EE via accelerometer (Polar) vs. indirect calorimetry during a typical training session (5 vs. 5 + targets). Calculate the absolute error and discuss practical implications.

Conference No. 3: Assessment of Training Load and Technological Measurement Tools

1. Introduction :

The evaluation of training load is a cornerstone of athletic physical preparation, enabling performance optimization, injury prevention, and recovery management. By combining **objective measures** (external load) and **subjective measures** (internal load), coaches can adjust training programs to maximize physiological adaptations while minimizing the risk of overtraining.

2. Definitions and Key Concepts :

- **External Load:** Physical work performed, measured objectively (e.g., distance covered, speed, repetitions, power). It reflects the volume and intensity of training.
- **Internal Load:** Physiological and psychological response to external load, measured by indicators such as heart rate (HR), RPE, lactate, or heart rate variability (HRV). It varies based on the athlete's state (fatigue, stress, recovery).
- **Cumulative Load:** Accumulation of loads over a given period (day, week, month). Monitored via the Acute:Chronic Workload Ratio (ACWR) to assess long-term tolerance.
- **Biological Response:** Positive or negative adaptations of the body, including hormonal responses (e.g., cortisol), inflammatory responses (e.g., creatine kinase), and neuromuscular responses (e.g., CMJ jump height).

Load Type	Definition	Clinical Indications
External Load	Work performed (distance, power, accelerations).	Micro-cycle management.
Internal Load	Physiological/psychological response (HR, lactate, RPE).	Overtraining prevention.
Acute Load	Sum over 1 day.	Acute injury risk.
Chronic Load	Average over 28 days (ACWR).	Long-term tolerance.
Monotony	SD / mean.	Cumulative fatigue indicator.

3. Cumulative Load and Biological Response :

Cumulative load is essential for planning training cycles (micro-, meso-, and macro-cycles). Well-managed load promotes positive adaptations (strength, endurance, power), while overload can lead to maladaptations (chronic fatigue, injuries).

- **Stimulus-Response Model:** Describes how load induces physiological adaptations. Excessive load without adequate recovery can trigger:
 - **Hormonal Response:** Increased cortisol, decreased testosterone/cortisol ratio ($< 0.35 =$ fatigue threshold) (Peake et al., 2022).
 - **Inflammatory Response:** Creatine kinase (CK) > 1000 U/L, elevated interleukin-6 (IL-6) (Peake et al., 2022).
 - **Neuromuscular Response:** Drop in CMJ jump height $> 8\%$ (Halson, 2023).
- **Acute:Chronic Workload Ratio (ACWR):** Ratio of acute load (7 days) to chronic load (28 days). A value > 1.5 increases injury risk (Gabbett, 2016).

4. Global Load Indicators :

The following indicators quantify load:

- **Volume:** Total work performed (e.g., km covered, training hours).
- **Intensity:** Quality of effort (e.g., % HRmax, speed, power).
- **Density:** Effort/rest ratio within a session.
- **Frequency:** Number of sessions per period.

Indicator	Measurement	Critical Threshold	Tool
sRPE (session-RPE)	RPE \times duration (AU)	> 4000 AU/week = \uparrow injury risk	Foster Questionnaire
TRIMP	HR \times time \times intensity	> 300 AU/week (cycling)	Polar Team Pro
EPOC	Post-exercise $VO_2 > 7$ L	> 7 L = potential overtraining	Firstbeat
ACWR	7-day load / 28-day load	0.8–1.3 (safe zone)	Catapult AMS

5. RPE Method (Rating of Perceived Exertion) :

RPE, based on the Borg CR10 scale (0 = rest, 10 = maximal effort), subjectively quantifies internal load.

- **Protocol:**
 - Measured 30 minutes post-session to reflect overall effort (validity $r = 0.92$ vs. average HR).
 - **Calculation:** sRPE = RPE \times duration (min).

- **Example:** RPE = 7, duration = 90 min → sRPE = 630 AU.
- **Advantages:** Simple, cost-effective, captures physical and psychological stress.
- **Limitations:** Subjective, cultural biases, non-specific to certain efforts (e.g., short sprints).

6. Heart Rate (HR) and Derived Metrics :

- **Average HR and TRIMP:**
 - **TRIMP (Banister):** $TRIMP = \text{time (min)} \times \Delta HR \times e^{(1.92 \times \Delta HR)}$, where $\Delta HR = (HR_{\text{ex}} - HR_{\text{rest}}) / (HR_{\text{max}} - HR_{\text{rest}})$.
 - Measures intensity and duration across HR zones.
- **Recovery Heart Rate (HRR):**
 - **HRR60s:** Drop ≥ 25 bpm in 60 s = good recovery (Buchheit, 2021).
 - **HRR4min:** Correlated with $VO_{2\text{max}}$ ($r = -0.78$).
- **Heart Rate Variability (HRV):**
 - **Measurement:** RMSSD (Root Mean Square of Successive Differences) or lnRMSSD (reduces day-to-day variability).
 - **Interpretation:** Drop $> 10\%$ vs. baseline = overreaching risk (Plews et al., 2022).
 - **Advantages:** Indicator of autonomic nervous system balance and recovery.
 - **Limitations:** Sensitive to sleep, stress, hydration.

7. Modern Monitoring Technologies :

Technological tools enable precise, real-time measurement:

- **GPS (e.g., Catapult S7, 10 Hz):**
 - **Variables:** Distance, speed, accelerations ($> 3 \text{ m/s}^2$), High-Speed Running (HSR).
 - **Validity:** $r = 0.95$ (distance), $CV < 3\%$.
 - **Use:** Football, rugby, cycling.
- **Inertial Measurement Units (IMU):** Accelerometers and gyroscopes measure orientation and rotation ($r = 0.91$ for CMJ).

- **HRV (e.g., Kubios HRV Premium):** Measures RMSSD and LF/HF ($r = 0.96$ vs. 24-h Holter).
- **LIDAR Cameras:** 3D positioning < 2 cm ($r = 0.99$), used in labs or stadiums.
- **Wearable Sensors:** Watches (Garmin, Polar), vests (STATSports), smart insoles.

Technology	Variables	Validity vs. Gold Standard	Field Use
GPS 10 Hz (Catapult S7)	Distance, speed, accel > 3 m/s ²	$r = 0.95$ (distance), CV $< 3\%$	Football, rugby
IMU	Orientation, rotation	$r = 0.91$ (CMJ)	Acrobatic sports
Bluetooth HRV	RMSSD, LF/HF	$r = 0.96$ vs. 24-h Holter	Morning monitoring
LIDAR Cameras	3D position < 2 cm	$r = 0.99$	Lab & stadium

8. Operational Protocol for Data Collection and Analysis :

- **Weekly Load (Micro-Cycle):**
 - **Example:**

Day	External Load (GPS)	sRPE (AU)	HRV (lnRMSSD)	Decision
Monday	6 km, 15 accel > 3 m/s ²	350	3.85 ($\downarrow 8\%$)	\downarrow load Tuesday
Tuesday	4 km, 10 accel	250	4.10 ($\uparrow 6\%$)	Maintain
Wednesday	Active rest	100	4.25	—

- **ACWR and Monotony Analysis:**
 - **ACWR** = 7-day load / 28-day load (safe zone: 0.8–1.3).
 - **Monotony** = SD / mean (low if < 0.3).
 - **Strain** = ACWR \times monotony (low if < 0.5).
- **Visualization:**
 - **Tools:** PowerBI dashboards or Catapult AMS integrating GPS, RPE, and HRV.
 - **Alerts:** ACWR > 1.5 or HRV $\downarrow 15\%$ over 3 days = reduce load.

9. Practical Applications in Sports Training :

- **Planning:** Adjust micro-cycles to avoid load spikes (ACWR > 1.5).
- **Injury Prevention:** Monitor accelerations (GPS) and fatigue (HRV, RPE).

- **Individualization:** Adapt loads based on physiological responses (e.g., reduce intensity if HRV ↓).
- **Real-Time Monitoring:** Adjust during matches using GPS and HR.
- **Performance Optimization:** Combine sRPE, TRIMP, and GPS to maximize adaptations without overtraining.

10. Limitations and Future Directions :

- **Reliability:** Sensors (GPS, HRV) require regular calibration to avoid errors.
- **Cost:** Advanced systems (Catapult, LIDAR) are expensive, limiting accessibility.
- **Information Overload:** Excessive data can complicate decision-making without expert analysis.
- **Future Directions:** Artificial intelligence (e.g., LSTM models) leverages time-series data (HRV, GPS) to predict injury risk (Claudino et al., 2023).

Conclusion :

The evaluation of training load, combining **objective measures** (GPS, accelerometers) and **subjective measures** (RPE, HRV), is essential for modern physical preparation. These tools enable fine-tuned program individualization, injury prevention, and performance optimization. However, their use requires rigorous, contextualized interpretation to avoid bias.

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Practical Exercise :

- **Case Study:** Professional footballer – 14-day GPS (Catapult) and HRV (Kubios) data.
 - Calculate **ACWR**, **monotony**, and **strain**.
 - Propose load adjustments for the following week.

Conference No. 4 Physiological, Biomedical, and Cardiorespiratory Assessment of Athletes

1. Introduction :

The physiological, biomedical, and cardiorespiratory assessment of athletes is a strategic tool for optimizing performance, preventing injuries, monitoring health, and personalizing training programs. The cardiovascular and respiratory systems, the true engine of performance, play a key role—particularly in endurance sports where aerobic capacity ($VO_2\text{max}$), ventilatory efficiency, and rapid recovery are major determinants of success. Concurrently, biomedical assessment—through blood analyses, muscle fatigue markers, and functional tests—provides insight into the responses of the energetic, hormonal, immune, and neuromuscular systems to training. This approach enables early detection of overtraining, optimization of nutritional intake, and prevention of medical risks such as cardiomyopathies, exercise-induced bronchoconstriction (EIB), or rhabdomyolysis.

2. Objectives of Assessment :

Physiological, biomedical, and cardiorespiratory assessment aims to:

- **Early Detection:** Identify overtraining, inflammation, or nutritional deficiencies.
- **Nutritional Optimization:** Adjust intake of iron, vitamin D, amino acids, or other nutrients.
- **Risk Reduction:** Prevent injuries, infections, and silent pathologies (e.g., cardiomyopathies, rhabdomyolysis).
- **Personalization:** Tailor training loads to individual physiological status.
- **Performance:** Maximize aerobic capacity, energy efficiency, and recovery through precise evaluation.

3. Importance of Cardiorespiratory Indicators :

- **Endurance Performance:** Cardiorespiratory capacity (e.g., $VO_2\text{max}$) is a key predictor in aerobic sports (running, cycling, swimming).
- **Oxygen Transport and Utilization:** The cardiovascular system transports oxygen from the lungs to muscles, while the respiratory system ensures gas exchange, maximizing endurance.
- **Recovery:** Good cardiorespiratory function accelerates post-exercise recovery (e.g., rapid heart rate decline).

- **Health:** Tests detect abnormalities such as exercise-induced asthma (EIB) or cardiac pathologies (e.g., hypertrophic cardiomyopathy).

4. Main Systems Evaluated :

4.1 Energy System :

- **VO₂max:** Maximal oxygen uptake, measured via ergospirometry, indicator of aerobic capacity (reference value: $\geq 70 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ for elite male cyclists).
- **Ventilatory/Lactate Thresholds:**
 - **VT1:** Aerobic to aerobic-lactate transition ($\sim 2 \text{ mmol/L}$ lactate).
 - **VT2:** Significant lactate accumulation ($>4 \text{ mmol/L}$).
- **RER (Respiratory Exchange Ratio):** CO₂/O₂ ratio, indicating energy substrate (carbohydrates vs. lipids, ≥ 1.10 at maximal effort).

4.2 Hormonal System :

- **Testosterone, Cortisol, DHEA:** The testosterone/cortisol ratio (T/C) reflects anabolic/catabolic balance (critical threshold: T/C < 0.35, Urhausen & Kindermann, 1992).
- **IGF-1:** Supports tissue recovery.
- **Leptin:** Indicates energy availability.

4.3 Immune System :

- **Leukocytes, CRP, Immunoglobulins:** Detect inflammation or immunosuppression (CRP > 3 mg/L indicates acute inflammation, Peake et al., 2022).

4.4 Neuromuscular System :

- **Strength Tests:** Vertical jump (CMJ), isokinetic tests.
- **Electromyography (EMG):** Measures muscle activation and fatigue.

4.5 Cardiorespiratory System :

- **Key Variables:**

Variable	Definition	Reference Value (Elite Athletes)	Unit
VO₂max	Maximal O ₂ consumption	$\geq 70 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ (cycling)	$\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$
vVO₂max	Velocity at VO ₂ max	20–22 $\text{km}\cdot\text{h}^{-1}$ (1500 m)	$\text{km}\cdot\text{h}^{-1}$

		runners)	
FEV₁	Forced expiratory volume in 1 s	≥ 4.5 L (25-year-old male)	L
FVC	Forced vital capacity	≥ 5.5 L	L
FEV₁/FVC	Obstruction/restriction	> 80% normal	%
RER_{max}	Respiratory exchange ratio	≥ 1.10 (maximal effort)	—
VE/VCO₂ slope	Ventilatory efficiency	< 30 = excellent	—

5. Assessment Methods :

5.1 Standardized Blood Analyses :

Blood analyses provide objective data:

Panel	Markers	Recommended Frequency	Target Values (Athletes)
Complete Blood Count	Hb, Hct, Ferritin	1×/month (volume phase)	Hb 135–165 g/L (♂), Ferritin > 30 µg/L
Inflammation	CRP, IL-6, CK	2×/week (intense micro-cycle)	CK < 500 U/L, CRP < 3 mg/L
Oxidative Stress	GPx, SOD, MDA	1×/season	↑ 15% vs. rest = overload
Renal	Creatinine, eGFR	1×/month	eGFR > 90 mL/min/1.73 m ²
Cardiac	NT-proBNP, Troponin I	Post-marathon/ultra	NT-proBNP < 125 ng/L

5.2 Muscle Fatigue Markers :

- **Creatine Kinase (CK):**
 - Norms: 50–200 U/L.
 - **Post-Exercise:** Peak at 24–48 h, return to baseline < 72 h.
 - **Alert Threshold:** > 1000 U/L or ↑ 2× vs. baseline (Brancaccio et al., 2022).
- **Myoglobin, LDH:** Detect severe damage (e.g., rhabdomyolysis).
- **MyomiRs (miR-133a, miR-206):** Early markers of muscle damage, detectable at 6 h (r = 0.78 with CK) (Mouly et al., 2023).
- **Titin, Desmin:** Contractile proteins, measured via ELISA in research.

5.3 Hematological and Endocrine Markers :

Hormone	Role	Athletic Variation	Pathological Threshold
Testosterone	Anabolic recovery	↓ 15% = overload	< 10 nmol/L (♂)
Cortisol	Catabolic stress	↑ 30% = overtraining	> 600 nmol/L at 8 AM
T/C Ratio	Global indicator	< 0.35 = alert	—
IGF-1	Tissue recovery	↓ 20% = protein deficiency	< 115 ng/mL
Leptin	Energy availability	↓ 50% = RED-S	< 2 ng/mL (♀)

5.4 Measurement of Vital Capacity and Pulmonary Function :

- **Forced Vital Capacity (FVC):** Maximal air volume expired after maximal inspiration.
- **FEV₁:** Volume expired in 1 second, indicating airway patency.
- **FEV₁/FVC:** Detects obstruction (e.g., asthma, < 70%).
- **Maximal Voluntary Ventilation (MVV):** Maximal air volume ventilated in 1 minute.
- **Method:** Spirometry (e.g., Cosmed Pony FX), calibrated with 3 L syringe (\pm 2%). GLI-2012 z-scores ($>$ -1.64 = normal).

5.5 Specific Cardiorespiratory Tests :

- **Laboratory Tests:**
 - **Progressive Maximal Test (Ergospirometry):**
 - **Protocol:** Cycling (+25 W every 3 min) or running (+1 km·h⁻¹·min⁻¹, 0% slope).
 - **Measurements:** VO₂max, ventilatory thresholds (VT1, VT2), RER, HRmax.
 - **Stopping Criteria:** VO₂ plateau, RER \geq 1.1, HR \geq 90% theoretical, voluntary exhaustion.
 - **Reliability:** CV VO₂max < 3% (Bentley et al., 2022).
 - **Spirometry:** Measures FEV₁, FVC, bronchodilator test (\uparrow FEV₁ \geq 12% = asthma).
 - **Echocardiography:** Assesses cardiac structure and systolic ejection volume.
- **Field Tests:**
 - **Shuttle Run Test (Luc-Léger, 20 m):**

- **VO₂max Estimation:** $VO_{2\max} = 31.025 + 3.238 \times V - 3.248 \times \text{Age} + 0.1536 \times V \times \text{Age}$ (V = final speed in $\text{km}\cdot\text{h}^{-1}$).
- **Reliability:** $\text{ICC} = 0.90$ (Berthon et al., 2021).
- **Yo-Yo Intermittent Recovery Test (IR1/IR2):** Critical distance $\text{IR1} \geq 2400 \text{ m} \approx VO_{2\max} 60 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ (football) (Krustrup, 2023).
- **Cooper Test (12 min):** $VO_{2\max} = (\text{distance in m} - 504) / 45$. Less accurate for sprinters.
- **Heart Rate Recovery Test:** HR drop > 30 bpm in 1 min post-exercise indicates good cardiorespiratory fitness.

6. Relationship with Performance and Recovery :

- **Oxygen Supply:** Efficient ventilation reduces the energy cost of breathing.
- **CO₂ Elimination:** Prevents metabolic acidosis.
- **Respiratory Fatigue:** Respiratory muscles can fatigue, reducing performance in prolonged efforts. Inspiratory muscle training (e.g., PowerBreathe) improves respiratory endurance by 4–6% (Illi et al., 2023).
- **Ventilatory Limitation:** Rare ($< 10\% VO_{2\max}$), except in hypoxia or apnea (Dominelli, 2022).
- **Recovery:** Good cardiorespiratory function accelerates recovery (e.g., rapid HR decline).

7. Standardized Testing Conditions :

- **Timing:** 7–9 AM, fasting ≥ 10 h, rest ≥ 12 h post-exercise (blood tests); 8–11 AM, fasting ≥ 3 h (cardiorespiratory tests).
- **Position:** Seated 15 min before blood draw to avoid hemoconcentration.
- **Storage:** Tubes with gel separator, centrifugation (10 min, 3000 g), transport at 4 °C, analysis < 4 h (CK unstable > 6 h).
- **Temperature/Humidity:** 20–22 °C, 45–55% (ISO 8996 standard).
- **Warm-Up:** 5 min at 60% $VO_{2\max}$ + 3 min rest to stabilize metabolism.

8. Modern Tools and Technologies :

- **Portable Analyzers:**

- **Lactate Pro 2:** Lactate measurement (± 0.2 mmol, $r = 0.99$ vs. lab).
- **i-STAT Alinity:** CK, Hb, lactate, electrolytes (65 μ L capillary blood).
- **Spartan RX:** Genetic testing (ACTN3, ACE I/D).
- **Non-Invasive Sensors:**
 - **NIRS (Moxy):** SmO₂, HHb ($r = -0.82$ with lactate).
 - **Sweat Patch (Gatorade Gx):** Continuous [Na⁺], [K⁺].
- **Cardiorespiratory Technologies:**
 - **Portable VO₂ Mask (VO₂ Master Pro):** Field VO₂max ($r = 0.95$ vs. calorimetry).
 - **Tele-Spirometry (NuvoAir):** Home FEV₁ (± 50 mL vs. clinical spirometer).

9. Interpretation and Decision-Making :

- **Biomedical Decision Algorithm:**
 - **CK $\uparrow > 2\times$ baseline:**
 - **AND CRP $\uparrow > 5$ mg/L** \rightarrow 48 h rest + anti-inflammatory.
 - **AND Hb $\downarrow < 130$ g/L** \rightarrow Ferritin test + iron supplementation.
 - **Otherwise** \rightarrow \downarrow volume 30% + sleep + hydration.
- **Cardiorespiratory Interpretation:**

Parameter	Interpretation	Action
VO₂max \downarrow 8% vs. baseline	Overtraining or illness	Reduce load 30%
FEV₁ \downarrow 10% post-exercise	Exercise-induced asthma (EIB)	Scopolamine test
VE/VCO₂ \uparrow 35	Inefficient ventilation	Specific respiratory training
vVO₂max stagnant	Training plateau	30/30 intervals at 100% vVO ₂ max

10. Practical Applications by Sport :

Sport	Priority Panel	Frequency	Example
Triathlon	CK, Hb, ferritin, Na ⁺	2×/week	Hyponatremia monitoring
Strength Training	CK, myoglobin, creatinine	24 h & 48 h post-session	Rhabdomyolysis prevention
Combat Sports	CK, leptin, T/C	1×/week	Controlled weight loss
Endurance (Cycling, Running)	VO ₂ max, ventilatory thresholds	Seasonal	Training zones (VT1, VT2)
Rehabilitation	6-min walk test	Post-injury	Return-to-training planning

11. Strategy for Using Analyses :

- **Individualization:** Establish baseline values during low-intensity periods.
- **Contextualization:** Interpret results alongside training load, perceived fatigue, sleep, nutrition, and medical history.
- **Timing:** Tests at key moments (start of season, pre-competition, post-injury).
- **Frequency:** Seasonal monitoring or after intense loading periods; avoid over-testing.
- **Collaboration:** Cooperation between coaches, physicians, and nutritionists.

12. Limitations and Considerations :

- **Cost:** Advanced blood tests (e.g., cytokines, MyomiRs) and lab tests (ergospirometry, echocardiography) are expensive.
- **Individual Variability:** Markers vary by age, sex, training, and environmental conditions.
- **Interpretation:** Requires expertise to avoid bias (e.g., CK influenced by exercise type).
- **Ecological Validity:** Field tests are less accurate than lab tests.
- **Confounding Factors:** Fatigue, stress, or dehydration can skew results.
- **Safety:** Maximal tests require medical supervision.
- **Ethics:** Respect informed consent and confidentiality (e.g., GDPR).

Conclusion :

Physiological, biomedical, and cardiorespiratory assessment—through blood analyses (CK, ferritin, hormones), muscle fatigue markers (MyomiRs, titin), VO₂max tests, pulmonary function

(FEV₁, FVC), and cardiac recovery—is essential for optimal training management. By combining traditional methods (ergospirometry, spirometry) with modern technologies (portable masks, NIRS sensors, portable analyzers), professionals can personalize programs, prevent overtraining, and optimize health and performance.

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Practical Exercises :

1. Case Study: Swimmer, 20 years old

- **Data:** CK 1800 U/L (24 h post-exercise), CRP 4 mg/L, Hb 128 g/L, Ferritin 18 µg/L.
- **Questions:**
 - Interpret the results.
 - Plan rest, supplementation, and follow-up.
 - Estimate return-to-training timeline.

2. Case Study: U23 Cyclist, 21 years old, 68 kg

- **Data:** $\text{VO}_2\text{max} = 72 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, $\text{FEV}_1 = 4.8 \text{ L}$, $\text{FVC} = 5.9 \text{ L}$, $\text{FEV}_1/\text{FVC} = 0.81$.
- **Questions:**
 - Calculate FEV_1 z-score (GLI-2012).
 - Estimate vVO_2max (Lucia equation).
 - Propose a micro-cycle based on ventilatory thresholds.

Conference No. 5 Anthropometric, Morphological, and Biomechanical Assessment of Athletes

1. Introduction :

Anthropometric, morphological, and biomechanical assessment forms a foundational pillar in athlete monitoring, providing a comprehensive analysis of structural and mechanical characteristics to optimize performance, prevent injuries, and personalize training programs. Anthropometric evaluation measures height, weight, body composition, segmental proportions, and body symmetry, enabling precise morphological profiling, identification of training adaptations, and equipment customization (e.g., bicycles, wetsuits) to sport-specific demands. It is critical for talent identification, longitudinal monitoring, nutritional optimization, and early detection of disorders such as RED-S or asymmetries. Concurrently, biomechanical evaluation analyzes mechanical parameters of movement (kinematics, kinetics, electromyography) to assess technical gesture efficiency, identify imbalances, quantify joint stresses, and refine sport-specific techniques. By integrating these approaches with modern technologies (3D scanners, inertial sensors, video systems), these assessments deliver objective data for individualized, innovative athlete management.

2. Assessment Objectives :

2.1 Anthropometric and Morphological :

- **Morphological Profiling:** Align physical characteristics with biomechanical demands (e.g., sprinters vs. marathoners).
- **Adaptation Monitoring:** Measure muscle hypertrophy, fat mass loss, or segmental redistribution.
- **Early Screening:** Detect nutritional disorders (e.g., RED-S) or structural anomalies (e.g., asymmetries).
- **Equipment Sizing:** Optimize gear for aerodynamics/hydrodynamics.
- **Performance Optimization:** Tailor training and nutrition plans.
- **Injury Prevention:** Identify imbalances increasing injury risk.
- **Post-Injury Evaluation:** Monitor muscle/bone recovery for safe return to sport.

2.2 Biomechanical :

- **Decompose Sports Gestures:** Analyze movement efficiency.
- **Identify Motor Imbalances/Asymmetries:** Detect risk factors.
- **Quantify Joint Forces/Moments:** Assess mechanical stress.

- Evaluate Intersegmental Coordination: Understand energy transfer sequences.
- Optimize Techniques: Improve mechanical efficiency (\downarrow energy cost, \uparrow power).
- Guide Rehabilitation/Reconditioning: Ensure safe return to sport.
- Technical Individualization: Adapt to morphological and sport-specific constraints.
- Real-Time Feedback: Enable live coaching via sensors.

3. Analysis Methodology :

3.1 Anthropometric and Morphological :

Measured Parameters and Instruments:

- **Stature:** Stadiometer (e.g., SECA 213, ± 0.1 cm).
- **Body Mass:** Calibrated electronic scale (e.g., SECA 899, ± 0.05 kg).
- **Segmental Circumferences:** Arm (relaxed/contracted), thigh, calf, chest, waist, hip (Lufkin W606PM tape, ± 0.1 cm).
- **Skinfolds:** Triceps, biceps, subscapular, suprailiac (Harpenden caliper, ± 0.2 mm).
- **Segmental Lengths:** Arm, leg, wingspan (fingertip-to-fingertip).
- **Bone Breadths:** Bi-epicondylar femur/humerus for bone mass estimation.
- **Standardization (ISAK):** Repeated measures (TEM $< 5\%$ inter-tester), calibration (50 g weight, 10 mm block).

Body Composition Evaluation:

Method	Principle	Error (SEE)	Advantages	Disadvantages
DEXA	Dual-energy X-ray	$\pm 1.5\%$	Highly accurate, regional distribution	High cost, low radiation
BodPod	Air displacement	$\pm 1.8\%$ (Fields et al., 2022)	Non-invasive, fast	Specialized equipment
Hydrostatic Weighing	Archimedes' principle	$\pm 1.5\%$	Accurate (former gold standard)	Uncomfortable, bulky
BIA (8-electrode, InBody 970)	Bioelectrical impedance	$\pm 2.2\%$ vs. DEXA (Moon et al., 2023)	Portable, rapid	Hydration-sensitive
Skinfolds (4 or 7 sites)	Predictive equations (Durnin-Womersley, Jackson-Pollock)	$\pm 2.7-3.5\%$	Low cost, field use	Operator-dependent, subcutaneous fat only

Key Morphological Indices:

Index	Formula	Sport Thresholds	Application
BMI	Mass (kg) / height ² (m ²)	20–25 (endurance)	Mass screening, limited in athletes
FFMI	FFM (kg) / height ²	18–22 (natural)	Natural hypertrophy
WHR	Waist (cm) / hip (cm)	♂ < 0.90, ♀ < 0.85	Metabolic health
Rohrer Index	Mass / height ³ × 100	1.25–1.65	Morphotype
Conicity Index	Height / (0.109 × $\sqrt{\text{mass/height}}$)	↓ = cylindrical silhouette	Cycling aero

-BMI Limitations: Does not distinguish fat/lean mass, unsuitable for muscular athletes (e.g., rugby players, bodybuilders).

-Somatotype – Heath & Carter Model:

- **Endomorphy:** Relative adiposity (e.g., lugers: 7-1-3).
- **Mesomorphy:** Musculoskeletal development (e.g., sprinters: 1-6-1).
- **Ectomorphy:** Linearity, leanness (e.g., pole vaulters: 1-2-6).
- **Measurement:** Calculated from skinfolds, circumferences, bone breadths (TEM < 0.2 units, ISAK, 2021).
- **Applications:** Youth athlete orientation, training strategy adaptation.

-Segmentometry and Mass Distribution:

- **Bone Lengths:** Lower limb length (tragus → malleolus), wingspan (ratio > 1.05 advantageous for swimmers).
- **Functional Circumferences:**
 - **Arm Circumference (AC):** Relaxed vs. contracted difference = muscle index.
 - **Thigh Circumference (TC):** Correlated with squat power (r = 0.78).
 - **Calf Circumference (CC):** Sprint performance predictor (r = 0.65).

Discipline-Specific Measurements:

Sport	Key Measure	Technique	Normative Reference
Road Cycling	Reach & stack	3D Bike Fit	Reach 395 ± 10 mm (M)
Swimming	Span / stature	> 1.04 = arm advantage	Phelps 1.07
Rowing	Femur / tibia ratio	Optimal 0.92–0.97	Ingham et al., 2022
Powerlifting	Arm / stature	> 0.55 = bench advantage	—

3.2 Biomechanical :

Kinematic Analysis:

- Measures joint angles, velocities, accelerations of body segments.
- **Tools:** Optoelectronic systems (Vicon, OptiTrack), high-speed cameras.
- 2D/3D trajectory and movement pattern analysis (m, $m \cdot s^{-1}$, $m \cdot s^{-2}$).
- **Relevance:** Running, golf swing.

Kinetic Analysis:

- Measures ground reaction forces (GRF) and joint moments (N, N·m).
- **Tools:** Force platforms (Kistler), isokinetic dynamometers.
- **Relevance:** Boxing, judo, weightlifting.

Electromyography (EMG):

- Measures muscle electrical activity (μV , % MVC).
- Determines activation timing/intensity, correlated with gesture efficiency.

Inertial Measurement Units (IMUs):

- Accelerometers, gyroscopes, magnetometers for real-world recording.
- **Advantage:** Portability, real-time analysis.

Mechanical Energy:

- Work & power (J, W) for cycling, swimming.

4. Biomechanical Parameters by Sport Type :

Sport Type	Key Biomechanical Parameters
Running	Contact time, vertical oscillation, stride length, GRF, Peak Tibial Acceleration (PTA > 8 g = injury risk, Davis et al., 2022).
Jumping (height, triple)	Approach velocity, takeoff angle, ground impulse.
Throwing (javelin, shot put)	Segmental coordination, energy transfer sequence.
Racket Sports	Segment velocity, reaction time, strike posture.
Weightlifting	Segmental alignment, isokinetic force, lifting strategy.

5. Analysis Tools :

5.1 Anthropometric :

- **Non-Invasive & 3D Tools:**
 - **3D Body Scanning (Styku, SizeStream):** < 1% accuracy for segmental volumes, STL export for CFD modeling (swimming drag).
 - **Smartphone Photogrammetry (MyBodee, 2023):** %FM vs. DEXA $r = 0.91$ (SEE 2%).
 - **Segmental BIA (InBody 970):** Asymmetry tracking in arms/thighs for return from injury.

5.2 Biomechanical :

- **3D Video Systems:**
 - **High-Speed Cameras:** 240–1000 Hz (Photron, Basler).
 - **Calibration:** 500 mm L-frame wand, accuracy < 0.5 mm (ISO 18523).
 - **Software:** Dartfish 11 (semi-auto tracking), OpenCap (cloud-based, 7 mm accuracy vs. Vicon, $r = 0.94$, Uhlrich et al., 2023).
- **IMUs & Wearables:**
 - **Xsens DOT:** Quaternions, 16 g accel, $r = 0.96$ (RMSE 3°).
 - **MyoMotion:** 3D joint angles, $r = 0.91$ (knee).
 - **BlazePod / FitLight:** Reaction time, CV < 5%.
- **Force Platforms & Pressure Sensors:**
 - **Instrumented Track (Kistler 9287BA):** 10 kHz, vertical force noise < 0.1 N.
 - **F-Scan 7.0 Insoles:** 9600 sensors, plantar pressure 0–100 N·cm⁻².
 - **GymAware Power Bars:** Lift velocity < 0.5%.
- **Others:** Vicon, Qualisys, Kistler, wireless EMG (Noraxon, Delsys), Myotest, Catapult.

6. Operational Protocols :

6.1 Anthropometric – Standard Session :

- **Preparation:**

- **Timing:** 8–10 AM, empty bladder, 22 °C.
- **Labeling:** Anonymous code, double entry.
- **Execution:**
 1. Stature & mass → BMI, FFMI.
 2. 8-site skinfolds → %FM (Durnin).
 3. 6-site circumferences → FFMI.
 4. Segmental lengths → Heath-Carter somatotype.
 5. 3D scan → volumes & surfaces.
- **Analysis:**
 - Z-scores vs. sport-specific norms.
 - Excel/PowerBI dashboard: longitudinal tracking.

6.2 Biomechanical – Full Test :

- **Preparation:**
 - **Marker Placement:** 16-point Plug-in-Gait model.
 - **Dynamic Calibration:** 500 mm wand, 2 s T-pose.
 - **Warm-Up:** 5 min run + 5 sub-max jumps.
- **Acquisition:**
 - **Frequency:** 200 Hz video + 1000 Hz force plate.
 - **Sequence:** 3 CMJ trials + 3 × 10 m sprints.
 - **Synchronization:** TTL trigger (LED flash + force).
- **Processing:**
 - **Filtering:** 4th-order Butterworth, $f_c = 12$ Hz.
 - **Normalization:** Angles as % jump cycle.
 - **Statistics:** $CV < 5\%$, $SWC = 0.2 \times SD$.

7. Practical Applications :

7.1 Anthropometric :

Objective	Measure	Action	Follow-Up
Lean Mass Gain	FFMI + circumferences	Caloric adjustment	2 weeks
Fat Mass Loss	%FM (BodPod)	Nutrition strategy	4 weeks
Bike Optimization	Reach & stack	Post adjustment	1×/season
RED-S Screening	Leptin + %FM	Medical referral	1×/month

7.2 Biomechanical :

- **Technique Optimization:** Correct gesture errors, refine individual styles.
- **Injury Prevention:** Identify high-risk movements (valgus, asymmetries).
- **Longitudinal Monitoring:** Measure training/rehab effects.
- **Return to Sport:** Verify symmetry/performance post-injury.
- **Individualized Training:** Exercises tailored to biomechanical profile.

Context	Tool	Indicator	Feedback
Running Store	iPad + Dartfish	Knee valgus in slow-mo	Sound if angle > 8°
Weight Room	GymAware + screen	Lift velocity	Stop if V < -10%
Soccer Field	Xsens + tablet	Pelvis orientation	Tactile vibration
Rehab	MyoMotion	Joint ROM	AR gamification

8. Clinically Relevant Biomechanical Variables :

- **Running:**
 - **Braking Torque:** ↓ 10% via technical training (auditory feedback).
 - **Frontal Valgus Angle:** ↑ > 10° = ↑ ACL risk (Hewett, 2023).
- **Vertical Jump (CMJ):**
 - **Mean Power:** $P (W) = 60.7 \times \text{mass (kg)} + 45.3 \times \text{height (cm)} - 2055$ (Bosco).
 - **Asymmetry:** > 10% leg difference = injury factor (Meylan, 2021).
 - **RFD:** ↓ > 15% = neuromuscular fatigue.
- **Golf / Tennis:**
 - **Kinetic Sequence:** Pelvis-torso-arm-club (racket) order.

- **Angular Velocities:** Pelvis 500–600 °·s⁻¹, club 2200 °·s⁻¹.

9. Link to Injury Prevention – ACL Model :

- **Screening:** Drop Vertical Jump (DVJ) + 3D.
 - **Thresholds:** Valgus > 10°, internal rotation moment > 35 N·m.
- **Intervention Program:**
 - 6 weeks neuromuscular training ↓ valgus 25% (Hewett, 2023).
 - BlazePod follow-up: ↓ reaction time 12%.

10. Interpretation of Anthropometric Results :

- **Optimal Fat Mass:**
 - Sprinters/power sports: 6–12% (men), 12–18% (women).
 - Endurance: < 8% (men).
 - Weight-class sports: Strategic variation.
- **Lean Mass:** Indicator of strength potential.
- **Hydration Balance (TBW):** Essential for recovery/performance.
- **Somatotype:** Guides specialization (e.g., mesomorph for sprinters, ectomorph for marathoners).

11. Methodological Recommendations :

- **Anthropometric:**
 - Measure in morning, fasted, post-void.
 - Use same method for longitudinal tracking.
 - Correlate with strength, VO₂max, biomarkers.
- **Biomechanical:**
 - Standardize conditions (markers, calibration).
 - Analyze in real conditions for ecological validity.

12. Limitations and Considerations:

- **Cost:** DEXA, BodPod, 3D scanners, Vicon/Qualisys systems are expensive.
- **Individual Variability:** Predictive equations (skinfolds, BIA) vary by population.
- **Precision:** Requires trained operators (ISAK Level 1–3, biomechanical expertise).
- **Health:** Excessively low fat mass can cause hormonal disorders/RED-S, especially in females.
- **Environment/Fatigue:** Can skew biomechanical analyses.
- **Team Sports:** Difficulty analyzing in real-game conditions.

Conclusion :

Anthropometric, morphological, and biomechanical assessment—combining basic measurements (height, weight, circumferences), advanced analyses (body composition, somatotype, 3D scanning), and mechanical evaluations (kinematics, kinetics, EMG)—is essential for accurate diagnosis and individualized programming. Modern technologies such as photogrammetry, 3D scanners, inertial sensors, and 3D video systems enhance measurement reliability and accessibility, enabling optimization of training, nutrition, and injury prevention strategies. Integrated within a multidisciplinary approach, these evaluations provide an objective, scientific reading of movement and morphology, ensuring comprehensive and innovative management of elite athletes.

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Practical Exercises :

1. Case Study: Judoka, 23 years old

- **Data:** 1.72 m, 73 kg, %FM (7 skinfolds) = 8%, FFMI = 21.8, Somatotype = 1-5-3.
- **Questions:**
 - Comment on the morphological profile.
 - Propose a weight class goal (-81 kg).
 - Estimate necessary fat mass loss without FFM reduction.

2. Case Study: 100 m Sprinter – 240 Hz Video

- **Tasks:**

- Measure knee flexion angle at starting blocks.
- Calculate horizontal power via force platform.
- Discuss technical optimization if valgus $> 6^\circ$.

Conference No. 6 Nutritional Monitoring and Annual Dietary Intake Assessment of Athletes

1. Introduction :

Nutrition is a fundamental pillar of athletic performance, recovery, and overall health. Rigorous nutritional monitoring, based on precise dietary intake assessment, enables optimization of training adaptations, prevention of fatigue, reduction of injury risk, and support for long-term career sustainability.

2. Objectives of Annual Dietary Assessment :

- **Quantify Energy and Nutrient Intake:** Evaluate 12-month adequacy with sport-specific needs (energy, macronutrients, micronutrients).
- **Detect Chronic Deficits or Excesses:** Identify deficiencies (e.g., iron, vitamin D) or excesses detrimental to performance or health.
- **Correlate with Training:** Analyze intake evolution across training, competition, and recovery phases.
- **Adapt Nutritional Strategy:** Personalize dietary plans based on morphological, metabolic, and sporting goals.
- **Prevent Risks:** Early detection of disorders such as **RED-S (Relative Energy Deficiency in Sport)**.

3. Dietary Habit Assessment Methods :

Tool	Duration	Advantages	Limitations	Validity vs. DLW
Weighed 3-Day Food Record	3 days (2 weekdays + 1 weekend)	Academic standard, precise	High writing burden	r = 0.70
24-Hour Recall	3×/week	Fast, less long-term memory-dependent	Memory bias	r = 0.55
PhotoFood App	7 continuous days	AI automation, user-friendly	Imperfect recognition	r = 0.82
Wearable Mastication Sensor (Bite Counter)	7 continuous days	Automatic, non-invasive	Noise with liquids	r = 0.63

Recommendation: Combine **weighed 3-day record** with **AI app** (e.g., **PhotoFood**) for cross-validation.

4. Nutritional Component Analysis :

Macronutrients :

- **Carbohydrates:** Primary energy source
 - **5–12 g/kg/day** depending on intensity
 - **Endurance:** 8–12 g/kg/day
 - **Light training:** 3–5 g/kg/day
- **Proteins:** Muscle repair and growth
 - **1.2–2.2 g/kg/day**, evenly distributed
- **Lipids:** Long-term energy, fat-soluble vitamin absorption
 - **20–35% of total calories**, balanced ω -3/ ω -6 ratio

Micronutrients :

- **Iron:** 10–18 mg/day (♀), **Vitamin D:** 4000 IU (northern winter), **Calcium:** 1500 mg/day, magnesium, zinc
- **Common Deficiencies:**
 - Iron → ↓ VO₂max
 - Vitamin D → ↓ strength, ↑ infections
 - Calcium → ↑ fractures
- **Method:** Dietary analysis + blood tests to confirm deficiencies

Hydration :

- **Electrolyte monitoring:** Sodium 300–500 mg/h (sweat > 1.2 L/h)
- **Weight loss:** < 2% pre-/post-exercise

5. Technological Tools for Nutritional Assessment

Software	Database	Country	Sport-Specific Features
NutriNet-Santé	Ciqua 2023	France	3400 foods, fiber, added sugars
MyFitnessPal	USDA + crowdsourcing	US	> 11M references, barcode
NutriSport-Pro	CIQUAL + sport labels	FR	Pre-/post-effort intake integration
Food Processor	USDA 2022	US	Excel export, sport RDAs

Post-Entry Steps:

1. Energy vs. PAL coherence check
2. RDA calculation (ACSM, 2022)
3. AMDR analysis

6. Key Nutritional Indicators and Performance Criteria :

Nutrient	Sport RDA	Deficit Threshold	Performance Impact
Energy	EEE = BMR × PAL (1.8–2.6)	↓ > 15% = RED-S	↓ VO ₂ max 5%
Protein	1.2–2.2 g·kg ⁻¹ ·day ⁻¹	< 1.2 g = ↓ protein synthesis	↓ Strength 8%
Carbohydrates	5–12 g·kg ⁻¹ ·day ⁻¹	< 3 g = ↓ glycogen	↓ Endurance 10%
Iron	10–18 mg (♀)	Ferritin < 30 µg/L	↓ VO ₂ max 12%
Vitamin D	4000 IU (northern winter)	< 75 nmol/L	↓ Strength, ↑ infections
Calcium	1500 mg	< 1000 mg = ↑ fractures	Stress fractures

7. Nutritional Adaptation by Training Phase :

Phase	Goal	Energy	CHO	PROT	LIP	Examples
Preparation (volume)	↑ Lean mass	+10%	8 g/kg	1.6 g/kg	25%	Porridge + whey
Specific (intensity)	↑ Power	± 0%	6 g/kg	1.8 g/kg	30%	Rice + chicken
Competition	Maintenance	-5%	5 g/kg	1.4 g/kg	30%	Pasta party
Transition	Recovery	-10%	4 g/kg	1.2 g/kg	35%	Mediterranean

8. Sport-Specific Cases :

Endurance Sports (Marathon, Triathlon) :

- **Carbohydrate Loading:** 10–12 g·kg⁻¹·day⁻¹ 36 h pre-race
- **Sodium:** 300–500 mg·h⁻¹ (sweat > 1.2 L·h⁻¹)
- **Monitoring:** Pre-/post-race weight < 2%

Strength Sports (Weightlifting) :

- **Protein:** 2.0–2.2 g·kg⁻¹·day⁻¹, 4 meals
- **Creatine:** 5 g·day⁻¹ (monohydrate), ↑ 5–15% power

- **Calories:** +300–500 kcal·day⁻¹ (lean bulk)

Weight-Class Sports (Judo, Boxing) :

- **Moderate Deficit:** –300 kcal·day⁻¹ (↓ 0.5% mass/week)
- **High Protein:** 2.2 g·kg⁻¹ to preserve FFM
- **Strategies:** 16/8 intermittent fasting, glycogen manipulation, sauna

9. Link Between Nutrition and Physical Improvement :

- **Performance:** Carbohydrates optimize glycogen → ↑ endurance & power
- **Recovery:** Protein + antioxidants (e.g., vitamin C) → faster muscle repair, ↓ inflammation
- **Prevention:** Adequate iron, calcium, vitamin D → ↓ anemia, fractures, fatigue
- **Body Composition:** Tailored nutrition → optimal lean/fat ratio → ↑ relative power
- **Cognition:** Proper hydration & nutrition → ↑ concentration, coordination

10. Operational Protocol – 12-Month Nutritional Assessment :

1. **Data Collection:** Weighed record (3 days × 4 periods: base, prep, competition, transition)
2. **Analysis:** NutriNet-Santé + NutriSport-Pro, vs. RDA (ACSM 2022, ISSN 2023)
3. **Adjustment:** Quarterly meeting (coach + nutritionist)
4. **Re-evaluation:** Anthropometry, blood tests, performance tests

11. Visualization and Annual Report :

- **PowerBI Dashboards:** Energy vs. EEE trend, micronutrient radar vs. RDA, PAL vs. CHO correlation
- **PDF Export:** Summary for coach, nutritionist, physician

12. Limitations and Considerations :

- **Accuracy:** Reporting bias (underestimation, omission)
- **Cost:** Professional software and consultations expensive
- **Individual Variability:** Needs vary by metabolism, sport, goals
- **Ethics:** Respect cultural preferences and dietary restrictions

13. Integration into Practice :

- **Regular Monitoring:** Quarterly or biannual assessments
- **Multidisciplinary Collaboration:** Nutritionists, coaches, physicians
- **Education:** Athlete awareness to improve adherence

Conclusion :

Nutritional monitoring and annual dietary intake assessment are crucial for optimizing performance, recovery, and health. By combining questionnaires, digital tools, and phase-specific strategies, professionals can personalize nutrition plans, ensuring optimal results and a sustainable athletic career.

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Practical Exercise:

Case Study: Triathlete, 28 years old, 70 kg, 10 h training/week

- **3-Day Intake:**
 - Energy: 2800 kcal vs. EEE 3500 kcal
 - Carbohydrates: 4 g/kg
 - Protein: 1.2 g/kg
 - Iron: 12 mg

Questions:

1. Calculate energy deficit and consequences
2. Adjust carbohydrates and protein
3. Plan iron supplementation

Conference No. 7: Assessment of Sports Fitness and Fundamental Physical Qualities

1. Introduction :

The assessment of sport form is a continuous and multifactorial process aimed at determining an athlete's physical, physiological, and psychological readiness at a given moment. It goes beyond mere performance measurement to encompass a holistic understanding of training adaptation and the ability to achieve specific goals. General Physical Preparation (GPP) forms the foundation of this form, developing fundamental athletic qualities before transitioning to specific preparation.

The evaluation of fundamental physical qualities – strength, speed, endurance, flexibility, and agility – is a core pillar of sports conditioning. These qualities underpin performance across all disciplines, and their precise measurement enables the creation of a detailed athletic profile, identification of individual strengths and weaknesses, design of targeted training programs, progress tracking, and performance potential prediction. Annual monitoring of form and training is an essential practice for improving health and physical performance. It allows tracking progress, detecting potential issues, and adapting accordingly.

2. Definitions and Scope of “Sport Form” :

Sport form is defined as the optimal state of preparation to perform at the highest level. It is the result of a delicate balance between training load (stimulus) and recovery (adaptation). It manifests through improvements in physical, technical, tactical, and psychological capacities.

Level	Term	Description	Associated Measures
Macro	Final Performance	Competition outcome	Time, distance, ranking
Meso	General Physical Preparation (GPP)	Set of biomotor qualities	Strength, Endurance, Speed, Flexibility
Micro	Neuromuscular & Recovery State	Acute or chronic fatigue	HRV, CMJ, RPE

“Sport form is the optimal conjunction between GPP, health status, and recovery” (Bourdon, 2023)

3. Conceptual Framework and Classification of Qualities :

Quality	Operational Definition	Primary Dimension
Strength	Ability to exert maximal tension	Max (1RM), RFD ($N \cdot s^{-1}$)
Speed	Maximal speed or reaction time	$m \cdot s^{-1}$, ms
Endurance	Resistance to local or global fatigue	$W \cdot kg^{-1}$, min, % VO_2max
Flexibility	Active/passive joint range of motion	$^{\circ}$, cm
Agility / Coordination	Rapid & precise direction change	s, errors

4. Modeling “Form”: From Historical Models to Modern Monitoring :

- **Banister Model (1975):** $Performance = Fitness - Fatigue \rightarrow \tau_1$ (fitness), τ_2 (fatigue) estimated via **TRIMP**
- **PPM Model (Skiba 2022):** Integrates **W'** (capacity), **CP** (threshold), **RPE**
- **Machine Learning:** Random-Forest on 250 variables (GPS, HRV, lactate) $\rightarrow r = 0.92$ vs. real-time (Claudino, 2023)

5. Indicators of General Physical Preparation (GPP) :

5.1 Biomotor Qualities – Reference Test Batteries :

Quality	Test	Elite Norm	Validity
Aerobic	Yo-Yo IR1	> 2400 m	$r = 0.92$ $VO_2\max$
Lactic Anaerobic	Wingate 30 s	12–14 $W \cdot kg^{-1}$	$CV < 5 \%$
Strength	1RM half-squat	$2.2 \times BM$	$ICC = 0.97$
Power	CMJ height	45–55 cm	$r = 0.83$ sprint 10 m
Flexibility	Sit-and-reach	+15 cm	$r = 0.65$ posture

5.2 Composite Scores :

- **Eurofit Adult:** 9 items \rightarrow global Z-score
- **ALPHA-FIT:** 5 items (plank, jump, endurance, flexibility, BMI)
- **FMS (Functional Movement Screen):** Score $< 14 = \uparrow$ injury risk (Cook, 2022)

6. Inter-Individual Variability and Individualization :

- **Genetic Typing:** ACTN3 RR vs. XX \rightarrow 8% CMJ differences
- **Maturation:** Adjustment for **PHV** (% adult prediction)
- **Sex:** Allometric correction $mass^{(-0.33)}$ for power

Training response is highly individual. Interpretation must be individualized and compared to personal baseline data, not general population norms.

7. Determining Preparation via Performance :

Sport form is most evident through **performance**. Assessment involves:

- **Sport-specific tests:** Increasingly representative of competition demands
 - *Distance runner:* 3000 m / 5000 m

- *Soccer player*: Repeated sprints + direction changes
- *Weightlifter*: Maximal loads / competition series
- **Comparison to MPP (Personal Best Performances)**: Improvement or maintenance + **perceived ease** = strong form
- **Subjective Markers**:
 - Well-being (fresh, motivated, rested)
 - RPE (perceived effort appropriate to load)
 - Restorative sleep
 - Emotional stability, no excessive irritability

8. Role of Tests in Training Load Adjustment :

Purpose	Application
Initial Diagnosis	Baseline profile, realistic goals
Progress Monitoring	Program effectiveness (micro/mesocycles)
Over/Undertraining Detection	↓ performance + ↑ fatigue = alert
Taper Optimization	↑ power + ↓ fatigue = peak form
Evidence-Based Decision Making	Replace instinct with data

Annual monitoring benefits: motivation, adaptation, self-awareness

9. Main Physical Fitness Tests :

- **Strength**: 1RM (squat, bench press)
- **Speed**: 10–40 m sprint (photoelectric cells)
- **Endurance**: Léger shuttle, 3000 m run
- **Coordination**: Illinois Agility Test
- **Anaerobic Power**: Wingate 30 s

Must be validated, reliable, and sport-specific

10. Specific Tests for Each Physical Quality :

10.1 Strength Tests :

Maximal Strength :

- **1RM:** Maximal load for 1 rep (squat, bench press, deadlift)
 - **Protocol:** Progressive warm-up → +5% increments
 - **Elite Norms:** Squat = $2.0 \times \text{BM}$ (endurance), $2.5 \times \text{BM}$ (sprint); Bench press = $1.3 \times \text{BM}$
 - **Reliability:** ICC = 0.97, CV = 2.8% (Suchomel, 2023)
- **Isometric:** Handgrip dynamometer, Mid-Thigh Pull ($> 3 \text{ N} \cdot \text{m} \cdot \text{kg}^{-1}$ at $60^\circ \cdot \text{s}^{-1}$)
- **H:Q Ratio:** > 0.6 (ACL injury prevention)

Explosive Strength / Power :

- **CMJ:** Jump height & power (force plate)
- **SJ, Standing Broad Jump, Medicine Ball Throw**
- **Norms:** CMJ = 45–55 cm; RFD $> 15,000 \text{ N} \cdot \text{s}^{-1}$ (sprint $< 11 \text{ s}$)

Strength-Endurance :

- Max reps at 60% 1RM
- Static hold (plank $> 120 \text{ s}$ = excellent)

10.2 Speed Tests :

- **Short Sprint:** 10, 20, 30, 40 m
 - **Elite Norms:** 10 m $< 1.65 \text{ s}$; 30 m $< 4.00 \text{ s}$
 - **CV = 1.5–1.8%** (Brower cells)
- **Reaction:** FitLight ($< 180 \text{ ms}$), BlazePod ($< 250 \text{ ms}$)

10.3 Endurance Tests :

Aerobic Endurance :

- **Lab:** Incremental VO_2max test
- **Field:**
 - Cooper 12-min ($> 3200 \text{ m} \approx 65 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$)
 - Léger / Yo-Yo IR1 (VMA $\geq 17.5 \text{ km} \cdot \text{h}^{-1}$ pro)

- 3000 m time trial

Anaerobic Endurance :

- **Wingate 30 s:** PP > 13 W·kg⁻¹, MP > 10 W·kg⁻¹, FI < 35%
- **Yo-Yo IR1 > 2400 m**

10.4 Flexibility Tests :

- **Sit-and-Reach:** > +15 cm
- **Goniometry**
- **FMS Deep Squat:** 3/3

Active/passive difference > 10° = injury risk

10.5 Agility Tests

- **505:** < 2.3 s
- **T-Test:** < 9.5 s
- **Illinois:** < 15 s

T-Test + CMJ → COD prediction (r = -0.78)

11. Construction of a Specific Battery :

11.1 Test Selection by Discipline :

Discipline	Required Tests	Complements
Football	Yo-Yo IR1, 1RM squat, CMJ, 505 10 m sprint, FMS	
Sprint Swimming	1RM pull-up, CMJ, 30 m swim	Loaded pull RFD
Athletics	30 m sprint, 1RM squat, Wingate	Hip flexibility

11.2 Calibration and Sport-Specific Norms :

- **Internal Database:** z-scores vs. team average
- **Re-evaluation:** Every 4–6 weeks

12. Documentation and Result Analysis :

- **Collection:** Individual sheets or software (TeamBuildr, Excel)
- **Analysis:**
 - Comparison to **sport-specific norms**
 - **Intra-individual trends**
 - **Variability:** TE, CV, SWC
 - **Graphs:** PPG radar, longitudinal trends
- **Interpretation:**
 - Identify **strengths/weaknesses**
 - Detect **over/undertraining**
 - **Alert Algorithm:** $\downarrow 1RM > 5\% + \uparrow CMJ > 8\% =$ neuromuscular overload

13. Applications in Sports Training :

- **Personalization:** Low CMJ \rightarrow plyometrics
- **Periodization:** Distribute loads based on results
- **Injury Prevention:** Imbalance \rightarrow corrective exercises
- **Longitudinal Monitoring:** Monthly tests

14. Protocols and Practical Considerations :

- **Standardization:** Same time, equipment
- **Calibration:** Precise tools
- **Supervision:** Avoid injury in max tests
- **Contextual Interpretation**

15. Validation and Reliability :

- **Reproducibility:** CMJ ICC = 0.92, CV = 3.8%
- **Sensitivity:** SWC: $VO_{2max} = 2\%$, CMJ = 1 cm
- **MDC95:** $1.5 \times SWC$

16. Use of Results – Micro-Cycle Adjustment :

Indicator	Immediate Action	Example
↓ CMJ > 8%	↓ explosive load, ↑ sleep	Remove jumps 48 h
↑ RPE > 1	↓ volume 30%	30 min run @ 65% HRmax
↓ HRR	Epsom salt bath + HRV	20 min biofeedback

17. Longitudinal Monitoring – Profile Construction :

17.1 PPG Radar :

- **Axes:** VO₂max, 1RM/BM, CMJ, COD, RFD, HRR60s
- **Target:** z-score ≥ 0.5 vs. elite specialty
- *U23 Cyclist Example:* VO₂max 72 (z = +1.2), CMJ 38 cm (z = -0.3) → **explosive priority**

17.2 PowerBI Dashboard :

- **Sources:** GPS, force plates, HRV, RPE
- **Auto-Alerts:** ↓ CMJ > 8% + ↑ RPE > 1 = recovery micro-cycle

18. Rapid Field Tests – “Form-5” Protocol :

Test	Duration	Equipment	Alert Threshold
CMJ	2 min	Force plate	↓ > 8%
HRR60s	2 min	HR wrist	< 25 bpm
Global RPE	30 s	Questionnaire	> 1 point vs. baseline
Grip Strength	1 min	JAMAR	↓ > 5%
Y-Balance Test	3 min	YBT kit	< 95 cm composite

19. Summary Table – “Form Sheet” :

Variable	Current Value	Elite Target	Gap	Priority
VO ₂ max (ml·kg ⁻¹ ·min ⁻¹)	58	65	-7	Endurance
CMJ (cm)	42	50	-8	Power
1RM squat (kg)	140	160	-20	Strength
HRR60s (bpm)	22	30	-8	Recovery

20. Perspectives – AI & Prediction :

- **LSTM Model:** Predicts 10 km time at +7 days (RMSE = 3.2 s)

- **Textile Sensors:** EMG + HRV + temperature → continuous fatigue alert

21. Limitations and Considerations :

- **Ecological Validity:** Lab ≠ real competition
- **Individual Variability:** Fatigue, stress, motivation
- **Cost:** Wingate, force plates
- **Expert Interpretation Required**
- **Learning Effect:** 2–3 familiarization sessions
- **Standardization:** 20–22 °C, same time ±1 h, ≥48 h post-match

22. Integration into Practice :

- **Periodization:** Structure cycles based on results
- **Longitudinal Monitoring:** Start/end of season, pre-competition
- **Multidisciplinary:** Combine with physiology, nutrition
- **Athlete Feedback:** Clear reports, radar charts
- **Modern Technologies:** GPS, wearables, video analysis
- **Visual Feedback:** PPG radar
- **Key Testing Moments:** Start of season, pre-competition

23. Holistic Assessment Approach :

Integrates:

- **Tactical:** Video analysis, simulation games
- **Cognitive:** Concentration, working memory training
- **Physical-Tactical Link:** Strength + speed → faster decisions
- **Technological Innovations:** Motion sensors, AI (LSTM, RMSE = 3.2 s)

Conclusion :

Sport form is a dynamic state quantifiable through biomotor, physiological, and perceptual indicators. Regular monitoring with individualized algorithms enables load adjustment and performance maximization. The assessment of physical form and GPP is a key tool for training

optimization. Standardized, individualized tests allow load adjustment, injury prevention, and progress tracking. A rigorous approach ensures reliable and actionable results. The evaluation of fundamental physical qualities is a scientific and methodical process to optimize performance and personalize training. By combining standardized tests, rigorous documentation, and contextual analysis, coaches gain a clear picture of athlete capabilities. This approach promotes targeted planning, injury prevention, and long-term progression. Upcoming lectures will explore fatigue management and overtraining prevention.

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Practical Exercises :

1. Case Study: Soccer Player, 24 y.o.

- **Data:** VO₂max: 58 ml·kg⁻¹·min⁻¹ (Yo-Yo IR1: 2100 m). CMJ: 40 cm (-8% vs. 4 weeks). Avg RPE: 7/10 (+1). HRR60s: 20 bpm (-6).
- **ACWR (7d/28d) = 1.45**
- **Questions:**
 1. Interpret table and propose adjusted micro-cycle
 2. Choose priority monitoring indicator

2. Case Study: Handball Player, 22 y.o.

- **Data:** BM = 77.3 kg. 1RM squat: 170 kg (2.2 × BM). CMJ: 42 cm (-10% vs. 4 weeks). 10 m sprint: 1.71 s. Yo-Yo IR1: 2000 m. Sit-and-reach: 8 cm
- **Questions:**
 1. Calculate z-scores vs. European norms
 2. Identify priority deficit
 3. Program specific micro-cycle

Conference No. 8 Assessment of Immediate and Chronic Fatigue and Prevention of Overtraining in Athletes

1. Introduction :

Fatigue is an inevitable component of sports training and competition. Acute fatigue, a normal response to intense effort, promotes physiological adaptations, but poor management can lead to chronic fatigue, or even Overtraining Syndrome (OTS) or Relative Energy Deficiency in Sport (RED-S).

Overtraining Syndrome (OTS) is a debilitating condition characterized by prolonged performance decline, physiological, psychological, and immune disturbances, resulting from a chronic imbalance between training load and recovery. Unlike acute fatigue, reversible within days, OTS may require months of rehabilitation.

Precise and early fatigue assessment, combined with continuous monitoring, is essential to optimize performance, prevent injuries, and preserve physical and mental health in athletes.

2. Fatigue: Definitions and Taxonomy :

Type	Delay	Dominant Mechanisms	Key Biomarkers
Acute (AF)	0–30 min post-effort	CP depletion, acidosis, extracellular K ⁺	↓ CMJ, ↑ lactate
Prolonged Acute	24–48 h	DOMS, micro-lesions, inflammation	↑ CK (> 500 U/L), ↑ IL-6
Chronic (CF)	> 2 weeks	Overtraining, RED-S, neuro-hormonal	↓ HRV, ↓ T/C, ↑ cortisol

3. Continuum of Excessive Load :

Term	Delay	Main Symptoms	Recovery
Functional Overreaching (FOR)	1–7 days	Transient fatigue, ↑ performance after	3–7 days
Non-Functional Overreaching (NFOR)	2–6 weeks	↓ performance, hormonal disturbances	2–8 weeks
Overtraining Syndrome (OTS)	> 6 weeks	Chronic ↓ performance, depression	6–12 months

4. Physiological Indicators of Fatigue :

4.1 Cardiorespiratory :

- **Heart Rate (HR):**

- **Resting HR:** Prolonged elevation (+5–10 bpm) = chronic stress
- **Submaximal HR:** Increase at same intensity (e.g., +10 bpm at 70% VO₂max)
- **HR Recovery (HRR):** HRR60s < 25 bpm (men) or < 30 bpm (women) = overtraining sign
- **Heart Rate Variability (HRV):**
 - **Measurement:** Morning, at rest (sitting/lying), via chest strap (e.g., Polar H10) and apps (Elite HRV, HRV4Training). Key parameters: **LnRMSSD, pNN50**
 - **Interpretation:** ↓ LnRMSSD > 10–15% vs. baseline = functional fatigue (Plews, 2022). **LnRMSSD < 3.5 = red alert**

4.2 Blood Biomarkers :

Marker	Fatigue Threshold	Overtraining Threshold	Sampling
CK	300–800 U/L	> 1000 U/L	24 h post-effort
Morning Cortisol	300–500 nmol/L	> 600 nmol/L	7–9 AM
Testosterone/Cortisol	0.35–0.50	< 0.25	—
CRP	3–10 mg/L	> 10 mg/L	—

4.3 Neuromuscular :

Test	Variable	Fatigue Threshold	Equipment
CMJ	Pmax, RFD, Flight Time	↓ > 8%	Force plate
TMS	↓ M-wave amplitude	↓ > 15%	Magstim 200 ²
EMG RMS	↓ VL activation	↓ > 10%	Delsys Trigno

5. Psychological and Sleep Indicators :

5.1 Validated Questionnaires :

- **RESTQ-Sport:** General score > 3.0 = fatigue (Kellmann, 2023)
- **POMS:** ↑ fatigue > 14, ↓ vigor < 50 = overtraining risk
- **DASS-21:** Depression > 9 = burnout risk
- **Hooper Index:** Daily monitoring of sleep, stress, fatigue, DOMS

5.2 Sleep Monitoring :

Tool	Variables	Alert Threshold	Validity
Oura Ring	HRV, sleep time, latency	↓ HRV > 15%	r = 0.85 vs. PSG
Portable PSG	Deep sleep < 15%	↓ 20%	r = 0.92
Sleep Diary	Subjective quality < 6/10	—	r = 0.65

6. Biological and Psychological Warning Signs :

6.1 Early Signs (FOR/NFOR) :

- **Performance:** ↓ 5–10% vs. baseline (e.g., CMJ, sprint)
- **HRV:** ↓ LnRMSSD > 10% over 3 consecutive days
- **Hormones:** ↑ morning cortisol > 600 nmol/L, ↓ T/C < 0.35
- **RPE:** ↑ 1 point on 0–10 scale for same external load

6.2 Late Signs (OTS) :

- **Performance:** ↓ > 15%, stagnation > 4 weeks
- **Psychological:** DASS-21 > 14 (depression)
- **Immune:** ↑ infections, OR = 2.4 (Meeusen, 2023)
- **Sleep:** ↓ deep sleep > 20% (Oura Ring)

7. Detection Models – Validated Algorithms :

7.1 ACWR + EWMA Model :

- **ACWR:** 7-day load / 28-day load. **Safe zone: 0.8–1.3. High risk: > 1.5** (Gabbett, 2016)
- **EWMA:** Exponentially Weighted Moving Average, **alert threshold > 1.2** (Williams, 2022)
- **Strain:** ACWR × monotony (SD/mean). **Alert > 2.0**

7.2 RPE-Based Model :

- **Cumulative sRPE:** > 4000 AU/week = ↑ injury risk (Rossi, 2023)
- **Monotony:** SD/mean > 1.5 = increased fatigue

8. Field Protocol “Fatigue-Panel” (30 min)

Step	Duration	Tool	Decision Threshold
1. Global RPE	30 s	0–10	> +1 vs. baseline
2. CMJ	2 min	Force plate	↓ > 8%
3. 1-min HRV	1 min	HRV4Training	↓ LnRMSSD > 10%
4. Salivary cortisol	2 min	Salimetrics	> 0.55 µg/dL
5. RESTQ-Sport	5 min	Mobile app	> 3.0

9. Multimodal Monitoring – Short Protocol (15 min) :

Variable	Tool	Alert Threshold	Frequency
CMJ	Force plate	↓ > 8%	3×/week
HRV	HRV4Training	LnRMSSD ↓ > 10%	Daily
RPE	Foster app	↑ > 1 point	Post-session
Sweat Na ⁺	Gx Sweat Patch	> 1800 mg/L	Hot competitions
Sleep	Oura Ring	Score < 70	Daily

10. “Traffic-Light” Decision Algorithm :

Color	Criteria	Action
Green	All indicators ↔ baseline or < threshold	Maintain load
Orange	1–2 indicators at threshold	↓ volume 20%, ↑ sleep
Red	≥ 3 thresholds or ↓ CMJ > 15%	Active rest 48 h, medical check

11. Immediate Preventive Measures :

Threshold	Action	Timing
Orange	↓ volume 20%, ↑ sleep 1 h	48 h
Red	Active rest, medical check	3–5 days
Prolonged Red	Refer to sports physician	1 week

12. Practical Applications by Sport :

Sport	Priority Monitoring	Frequency	Key Tool
Football	CMJ, HRV, RESTQ	2×/week	Force plate + Oura
Cycling	HRR, CK, T/C	1×/week	HRV EliteHRV
Swimming	HRV, sRPE, sleep	3×/week	WHOOP

13. Practical Applications – Monitoring Plan :

13.1 Typical Micro-Cycle (Professional Football) :

Day	External Load	sRPE	HRV	Action
Mon	Match	800 AU	3.8	—
Tue	Regen 30 min	150 AU	3.4 (↓ 12%)	↓ load 30%
Wed	Gym + bike	200 AU	3.6	Maintain
Thu	4v4 field	400 AU	3.9	Normal load
Fri	Rest	100 AU	4.0	—

13.2 PowerBI Dashboard :

- Widgets: ACWR, EWMA, HRV, CMJ, RPE

- **Algorithm:**
 - IF (ACWR > 1.3 AND HRV ↓ > 10%) THEN “orange”
 - IF (CMJ ↓ > 15%) THEN “red”

14. New Technologies :

- **Sweat cortisol patch:** Result in 10 min (Gao et al., 2023)
- **Muscle ultrasound:** Fascia thickness, echogenicity for DOMS ($r = 0.78$)
- **AI fatigue:** CNN model on CMJ video (RMSE = 1.8 cm)
- **Predictive AI:** Gradient Boosting on 300 variables, **AUC = 0.91** (Claudino, 2023)
- **Genetics:** COMT rs4680 polymorphism, ↑ OTS risk $\times 1.6$ (Papadopoulos, 2022)

15. Staff Role – Communication and Ethics:

- **Weekly meetings:** Data scientist + coach + physician for data analysis
- **GDPR consent:** Encrypted cloud storage for sensitive data
- **Transparency:** Dashboard accessible to athletes via smartphone

16. Limitations and Precautions :

- **Learning effect:** CMJ requires 2–3 familiarization sessions
- **Chronotype:** HRV measured at same time (± 30 min)
- **Questionnaire bias:** Double-blind responses by staff
- **Cost:** Blood tests and HRV devices expensive
- **Individual variability:** Fatigue threshold adapted per athlete
- **Subjectivity:** Questionnaires depend on response honesty
- **Interpretation:** Requires expertise to avoid analytical errors

17. Integration into Practice :

- **Regular monitoring:** Daily (HRV, RPE) and weekly (RESTQ, CK)
- **Multidisciplinary approach:** Collaboration between coaches, physicians, psychologists
- **Modern technologies:** Wearables (WHOOP, Garmin) for real-time data

- **Education:** Train athletes to report fatigue and stress

18. Clinical Case Example :

- **Athlete:** Triathlete, 28 y.o.
- **Data:** ACWR = 1.55, HRV ↓ 18%, CMJ ↓ 12%, RPE ↑ 2, DASS-21 = 16
- **Diagnosis: Non-Functional Overreaching (NFOR)**
- **Plan:** Active rest 10 days, ↑ nutrition 15% (calories/protein), sleep 9 h, psychologist follow-up

19. Conclusion :

The assessment of acute and chronic fatigue, and the prevention of overtraining, rely on a multimodal approach combining physiology (HRV, biomarkers), neuromuscular (CMJ, EMG), and psychology (RPE, RESTQ, sleep). A short protocol (15–30 min) enables rapid diagnosis, early detection of overload signs, and training load adjustment, thus preventing OTS. An integrated approach, supported by modern technologies (wearables, AI, cortisol patches) and transparent communication between staff and athletes, optimizes performance and preserves athlete health.

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Practical Exercises :

1. Case Study: Professional Soccer Player, Post-Match Data

- **Data:**
 - CMJ: –12% (vs. baseline)
 - HRV LnRMSSD: 3.2 (baseline 3.8)
 - Morning cortisol: 620 nmol/L
 - RESTQ general: 3.4
- **Questions:**
 1. Classify fatigue level (traffic-light)
 2. Propose 48 h plan (active rest, nutrition, sleep)
 3. Choose priority follow-up indicator

2. Case Study: U23 Cyclist, 4-Week Data

- **Data:**
 - ACWR = 1.47 (EWMA 1.31)
 - HRV LnRMSSD = 3.1 (baseline 3.7, ↓ 16.2%)

- CMJ = ↓ 10%
- RPE = +1.5
- **Questions:**
 1. Define threshold (green/orange/red)
 2. Program next week (volume, intensity)
 3. Choose priority follow-up indicator

Conference No. 9 Assessment of Energy Systems – Aerobic, Anaerobic Lactic, and Anaerobic Alactic

1. Introduction :

The aerobic energy system is essential for endurance sports and disciplines requiring rapid recovery between intense efforts, producing ATP via oxidation of carbohydrates and lipids in the presence of oxygen to sustain prolonged efforts.

In parallel, the anaerobic lactic (glycolytic) system is crucial for intense efforts lasting 30 seconds to 2 minutes, such as repeated sprints or explosive actions in team sports, generating ATP rapidly via glucose/glycogen breakdown, but producing lactate and H⁺ ions, leading to fatigue via acidosis.

Finally, the anaerobic alactic (phosphagen or ATP-PCr) system provides energy for ultra-intense, brief efforts (0–10 s), such as short sprints, jumps, or throws, relying on ATP and phosphocreatine (PCr) stores without lactate production.

Assessment of these energy pathways allows quantification of aerobic, anaerobic lactic, and alactic capacities, enabling training optimization, detection of fatigue or overtraining signs, and improvement of explosive performance.

2. Bioenergetics Review :

2.1 Aerobic Pathway :

- **Mechanism:** ATP production via substrate oxidation (carbohydrates, lipids) in mitochondria
- **Physiological Limitations:**
 - Oxygen transport (VO₂max)
 - Mitochondrial capacity
 - Capillarization and oxidative enzyme activity
- **Dominant Duration:** Efforts > 75 s (aerobic contribution > 90% ATP)
- **Role:** Predominant in endurance sports (marathon, cycling) and recovery in intermittent sports (football, rugby)

2.2 Anaerobic Lactic Pathway :

- **Mechanism:** Anaerobic glycolysis → 2 ATP per glucose molecule + lactate

- **Dominant Duration:** Intense efforts 30 s to 4 min
- **Limitations:**
 - Glycolytic capacity (ATP yield)
 - Lactate tolerance (H^+ buffering)
 - Muscle glycogen stores
- **Role:** Predominant in high-intensity sports (400 m, rugby) and repeated efforts in team sports

2.3 Anaerobic Alactic Pathway :

- **Substrate:** ATP + PCr (phosphocreatine)
- **Dominant Duration:** 0–10 s (ultra-rapid efforts)
- **Energy Capacity:** ≈ 20 mmol ATP \cdot kg $^{-1}$ dry muscle
- **Maximal Power:** $3\text{--}4 \times VO_2\text{max}$
- **Limiting Factors:** Initial [PCr], CK activity, type IIX fibers

3. Key Variables to Measure :

3.1 Aerobic System :

Variable	Definition	Unit	Elite Reference
VO₂max	Maximal oxygen uptake	ml \cdot kg $^{-1}\cdot$ min $^{-1}$	♂ 65–85 (sport-dependent)
vVO₂max	Velocity at VO ₂ max	km \cdot h $^{-1}$	18–22 km \cdot h $^{-1}$
LT1 / VT1	First ventilatory threshold	%VO ₂ max	50–65%
LT2 / VT2	Second threshold (MLSS)	%VO ₂ max	80–90%
PPO	Peak aerobic power	W	350–450 W (cycling)

3.2 Anaerobic Lactic System :

Variable	Definition	Unit	Elite Reference
Pmax	Maximal anaerobic power	W or W \cdot kg $^{-1}$	13–15 W \cdot kg $^{-1}$ (♂)
Pmean	Mean power (capacity)	W or W \cdot kg $^{-1}$	10–12 W \cdot kg $^{-1}$ (♂)
FI	Fatigue index	%	< 35%
[La$^-$]max	Post-effort lactate	mmol \cdot L $^{-1}$	12–18 mmol \cdot L $^{-1}$
MLSS	Maximal lactate steady state	mmol \cdot L $^{-1}$	4–7 mmol \cdot L $^{-1}$

3.3 Anaerobic Alactic System :

Variable	Definition	Unit	Elite Reference
Pmax alactic	Peak power 1 s	W·kg ⁻¹	25–35 W·kg ⁻¹ (♂)
W' (alactic)	Alactic anaerobic work	kJ	15–25 kJ (♂ 70 kg)
PCr recovery	T ^{1/2} PCr resynthesis	s	20–30 s
RFD	Rate of force development	N·s ⁻¹	> 10,000 N·s ⁻¹

4. Laboratory Tests :

4.1 Aerobic System – Incremental Maximal Test (Ergospirometry) :

- **Mode:** Treadmill (1% incline) or cycle ergometer (80–100 rpm)
- **Increment:**
 - Treadmill: +1 km·h⁻¹·min⁻¹ (modified Bruce)
 - Bike: +25 W·min⁻¹ (ramp)
- **Stop Criteria:** VO₂ plateau, RER ≥ 1.10, HR ≥ 90% theoretical (220 – age)
- **Reliability:** CV VO₂max < 3% (Bentley, 2022)
- **Indicators:** VO₂max, vVO₂max, ventilatory thresholds (VT1, VT2), running economy

4.2 Ventilatory Thresholds :

- **VT1 (LT1):**
 - ↑ VE/VO₂ without ↑ VE/VCO₂ (V-slope method)
 - Lactate confirmation: ~2 mmol·L⁻¹
- **VT2 (LT2):**
 - ↑ VE/VCO₂ + PETCO₂ drop
 - Lactate: ~4 mmol·L⁻¹ or Dmax method

4.3 Movement Economy Test:

- **Protocol:** O₂ consumption at fixed submaximal speed (e.g., 12 km·h⁻¹)
- **Indicator:** Less O₂ used at same intensity = better economy

4.4 Anaerobic Lactic System – Wingate Anaerobic Test (WAnT) – 30 s :

- **Protocol:** Maximal effort on cycle ergometer (Monark 894E, inertia 0.70 kg·m²), load = **0.075 kg·kg⁻¹ body mass** (standard) or **0.085 kg·kg⁻¹** (cyclists)
- **Indicators:**
 - **Pmax:** Peak over 5 s (anaerobic power)
 - **Pmean:** Average over 30 s (anaerobic capacity)
 - **FI:** (Pmax – Pmin)/Pmax × 100 (fatigue resistance)
- **Reliability:** ICC = 0.95, CV = 4% (Dorel, 2022)

4.5 Extended Tests :

- **Wingate 60 s:** Pmean reflects prolonged lactic capacity
- **Margaria-Kalamen Stair Test:**
 - Power = (m × g × h)/t (W·kg⁻¹)
 - Norm: 150–200 W (men)

4.6 Lactate Analysis :

- **Protocol:** Blood samples at 1, 3, 5, 7 min post-effort (Lactate Pro 2, ±0.1 mmol·L⁻¹ accuracy)
- **Indicators:**
 - [La⁻] slope (3–12 mmol·L⁻¹) = buffering capacity
 - Area under curve = lactic capacity

4.7 Anaerobic Alactic System – Inertial Cycle Ergometer (SRM Isoinertial) :

- **Protocol:** 6 s maximal effort, inertia 100–120 kg·m², brake 0.5 s
- **Indicators:** Pmax, RFD, W' (alactic work)
- **Reliability:** CV = 3% (Dorel, 2023)

4.8 Force Platform (CMJ 1 s) :

- **Protocol:** Countermovement jump (CMJ) or squat jump (SJ)
- **Calculations:**
 - Pmax = Fmax × vTOF / BM (vTOF = takeoff velocity)

- $F_{max} > 3 \times \text{body mass (BM)}$
- RFD: 0–200 ms slope $> 10,000 \text{ N}\cdot\text{s}^{-1}$

4.9 Magnetic Resonance Spectroscopy (^{31}P -MRS) :

- **Protocol:** Direct measurement of [PCr], [Pi], pH
- **Indicator:** $T_{1/2} \text{ PCr} \approx 20\text{--}25 \text{ s}$
- **Use:** Research (gold standard)

5. Field Tests :

5.1 Aerobic System :

Test	Distance / Duration	Estimation	Validity vs. Lab
Luc-Léger (20 m)	Until exhaustion	$\text{VO}_{2\text{max}} \& \text{VMA}$	$r = 0.92$
Cooper 12 min	Maximal distance	$\text{VO}_{2\text{max}} = (\text{dist} - 504)/45$	$r = 0.90$
5-min running field	5 min max pace	$v\text{VO}_{2\text{max}} = \text{dist} \times 12$	$r = 0.89$
MAV-test VMA	6 min bike	$\text{PPO} = W \times 1.1$	$r = 0.93$

5.2 Specific Intermittent Tests – Team Sports :

- **Yo-Yo IR1:**
 - Critical distance: $2400 \text{ m} \approx \text{VO}_{2\text{max}} 60 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$
 - Reliability: $\text{ICC} = 0.90, \text{CV} = 5\%$
- **30-15 IFT:**
 - Final speed (VIFT) correlated with $\text{VO}_{2\text{max}}$ ($r = 0.85$)
 - Adapted for intermittent sports (football, basketball)

5.3 Anaerobic Lactic System :

Test	Duration/Protocol	Estimation	Validity vs. WAnT
RAST	$6 \times 35 \text{ m (10 s rec)}$	$P_{\text{max}}, P_{\text{mean}}, \text{FI}$	$r = 0.87$
RSA	$6 \times 40 \text{ m (20 s rec)}$	Best time, mean time, %dec	$r = 0.82$
Yo-Yo IR2	Intermittent $2 \times 20 \text{ m}$	Lactic VMA	$r = 0.78$

5.4 Specific Tests – Team Sports :

- **RSA Football:**

- 6 × 40 m (20 s recovery)
- Total time < 34 s (elite), %dec < 3%
- **RSA Cycling:**
 - 5 × 6 s (24 s rec) on ergometer
 - Pmax > 12 W·kg⁻¹, FI < 25%

5.5 Anaerobic Alactic System :

Test	Duration/Protocol	Estimation	Validity vs. Lab
10 m Sprint	10 m	Pmax = $\frac{1}{2} m v^2 / t$	r = 0.88 vs. SRM
Margaria Stair	2–3 s	Pmax = (mgh)/t	r = 0.85
CMJ with Bar	1 s	Pmax (Wingate 1 s)	r = 0.91
5 m Radar Sprint	5 m	V max 1 s	CV = 2%

6. New Technologies :

Aerobic System :

- **Portable VO₂ mask (VO₂ Master Pro):** 150 g, Bluetooth 5.0, validated vs. lab (r = 0.95)
- **Muscle NIRS (PortaMon):** SmO₂ plateau = LT1 threshold (r = 0.83)
- **AI VO₂max prediction:** XGBoost model on GPS + HR data (RMSE = 2.1 ml·kg⁻¹·min⁻¹)

Anaerobic Lactic System :

- **Inertial ergometer (SRM):** RFD and per-pedal power (r = 0.95 vs. lab)
- **Quadriceps NIRS:** [HHb] plateau = lactate threshold (r = 0.83)
- **IMU sensor:** Power during running sprints (validated vs. radar, r = 0.91)

Anaerobic Alactic System :

- **SRM inertial ergometer:** Precision 0.001 s
- **IMU + radar:** Instantaneous speed < 0.01 m·s⁻¹
- **EMG sensor:** Type IIx fiber activity vs. RFD (r = 0.78)

7. Operational Protocols :

7.1 Typical Week – Aerobic System :

Day	Test	Objective	Equipment
Mon	Rest	—	—
Tue	Luc-Léger	VMA, VO ₂ max	20 m track
Wed	Lab VO ₂ max	VO ₂ max, thresholds	Ergospirometer
Thu	30-15 IFT	VIFT	Football field
Fri	Recovery	—	—

7.2 Typical Week – Anaerobic Lactic System :

Day	Test	Objective	Equipment
Mon	Rest	—	—
Tue	Wingate 30 s	Pmax, Pmean, FI	Cycle ergometer
Wed	RSA 6 × 40 m	Lactic endurance	Field + photocells
Thu	4 × 1000 m @ 110% VMA	Lactate 1,3,5 min post	Treadmill + lactate analyzer
Fri	Recovery	—	—

7.3 Typical Day – Anaerobic Alactic System :

Step	Duration	Tool	Criteria
Warm-up	5 min	Bike + mobility	HR < 60% HRmax
6 s Sprint	6 s	SRM inertial	Pmax > 30 W·kg ⁻¹
Recovery	3 min	Passive	PCr > 90%
Repetitions	5 × 6 s (1 min rec)	—	Decline < 5%

8. Interpretation and Training Guidance :

8.1 Aerobic System :

Variable	Interpretation	Action
VO ₂ max ↓ 5%	Suboptimal aerobic base	↑ volume zone 3 (60–70% VO ₂ max)
LT2 ↑ 5%	↑ endurance	↑ threshold work (80–90% VO ₂ max)
vVO ₂ max stagnant	Aerobic plateau	30/30 intervals at 95–100% vVO ₂ max

8.2 Anaerobic Lactic System :

Variable	Interpretation	Action
Pmax ↓ 5%	Suboptimal power	↑ 10–30 s sprint sessions
FI > 40%	Poor fatigue resistance	↑ 30–60 s lactic work
[La ⁻] _{max} < 10 mmol	Low glycolytic capacity	↑ 2–4 min @ 110–120% vVO ₂ max

8.3 Anaerobic Alactic System :

Variable	Interpretation	Action
P_{max} ↓ 5%	Low alactic capacity	↑ 6–10 s sprints
RFD ↓ 10%	Poor neural activation	↑ plyometrics
PCr T_{1/2} ↑ 35 s	Slow recovery	↑ rest between sets

9. Specific Applications – Anaerobic Alactic System :

Sport	Test	Norm	Use
100 m Athletics	10 m split	< 1.65 s	Selection
Football	CMJ 1 s	> 35 W·kg ⁻¹	Explosivity monitoring
Basketball	5 m Sprint	< 1.00 s	Fast defense

10. Key Indicators and Interpretation – Anaerobic Alactic System :

- **Peak Power:** Indicates ability to produce energy rapidly for explosive efforts
- **Rate of Force Development (RFD):** Measures speed to reach maximal force, critical for rapid-response sports
- **Fatigue Index in very short efforts:** Rapid power drop in repeated efforts indicates limited PCr capacity
- **Effort Recovery Capacity:** Reflects PCr resynthesis rate, assessed via repeated efforts with varying rest

11. Using Results for Training – Anaerobic Alactic System :

- **Identify strengths/weaknesses:** Determine if athlete needs to improve explosive power or power maintenance
- **Personalize training:** Design strength (Olympic lifting, max strength), plyometric (jumps, throws), and short sprint sessions targeting ATP-PCr system
- **Track adaptations:** Compare results to evaluate program efficacy and explosive power gains
- **Guide planning:** Adjust volume and intensity based on instantaneous energy production capacity

12. Limitations and Precautions :

- **Cost:** Lab tests expensive (e.g., ergospirometer ~€50,000)

- **Ecological validity:** Field tests more specific but less precise
- **Individual variability:** Motivation, fatigue, weather affect results
- **Interpretation:** Requires expertise to define training zones
- **Learning effect:** 2 familiarization sessions for Wingate and CMJ (reduce motivational variability)
- **Motivation:** Standardized verbal encouragement ($\pm 5\%$ on Pmax)
- **Hydration:** Control euhydration (USG < 1.020)
- **Surface:** Synthetic track (stable friction)
- **Temperature:** 20–22 °C (avoid variations)
- **Standardization:** Identical conditions (same surface, equipment)
- **Calibration:** Verify equipment (force plates, photocells)
- **Preparation:** Athletes rested, specific warm-up (10–15 min with progressive sprints)
- **Safety:** Supervision for maximal tests to prevent muscle injury

13. Integration into Practice :

- **Planning:** Structure cycles around intensity zones (fundamental endurance, threshold, high-intensity intervals, explosive exercises)
- **Longitudinal monitoring:** Repeat tests every 2–3 months to assess progress
- **Modern technologies:** GPS watches (Garmin, Polar), GPS (Catapult, STATSports), optoelectronic sensors (Optojump), apps (MyJump) for field measures
- **Multidisciplinary approach:** Combine aerobic, anaerobic, nutritional, and biomechanical testing

Conclusion :

The assessment of aerobic, anaerobic lactic, and alactic energy systems, via laboratory tests (VO₂max, thresholds, Wingate, CMJ) and field tests (Léger, Cooper, RSA, sprints, jumps), provides essential data to personalize training, optimize performance in endurance, high-intensity, and explosive sports, and maximize energy efficiency. A standardized approach, integrating modern technologies (portable masks, NIRS, IMU sensors), enhances precision and personalization of training while promoting athlete longevity.

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Practical Exercises :

1. Case Study: Soccer Player, 24 y.o., 75 kg

- **Data:**

- Luc-Léger: 2400 m (VMA 17 km·h⁻¹)
- Lab VO₂max: 62 ml·kg⁻¹·min⁻¹, LT2 82% VO₂max

- **Questions:**

1. Calculate vVO₂max and compare with VMA
2. Program session: 4 × 4 min @ 95% vVO₂max
3. Estimate distance covered and internal load (TRIMP)

2. Case Study: Rugby Player, 25 y.o., 95 kg

- **Data:**

- Wingate 30 s: Pmax = 12 W·kg⁻¹, FI = 38%, [La⁻]max = 14 mmol·L⁻¹
- RSA 6 × 40 m: Total time = 36 s, %dec = 4%

- **Questions:**

1. Comment on lactic profile
2. Program session: 5 × 30 s @ 120% Pmax (30 s rec)
3. Estimate internal load (RPE × time)

3. Case Study: Tennis Player, 24 y.o., 80 kg

- **Data:**

- 10 m Sprint: 1.70 s
- CMJ 1 s: 33 W·kg⁻¹
- PCr recovery: 28 s

- **Questions:**

1. Calculate Pmax and compare to norms
2. Program session: 8 × 6 s sprint (60 s rec)
3. Estimate internal load (RPE × time)

Conference No. 10 Assessment of Recovery and Regeneration

1. Introduction :

Recovery and regeneration are fundamental pillars of sports performance, enabling the body to adapt to training stress, repair tissues, replenish energy stores, and restore physiological balance.

Inadequate recovery can lead to chronic fatigue, performance decline, increased injury risk, and overtraining syndrome (OTS).

2. Objectives and Recovery Model :

Phase	Duration	Objective	Key Indicators
Immediate	0–30 min	↓ HR, muscle re-oxygenation	HRR60s, SmO ₂
Rapid	30 min–24 h	↓ DOMS, ↓ CK	CK 24 h, RPE
Intermediate	24–72 h	Glycogen & PCr restoration	[La ⁻] < 2 mmol/L
Delayed	3–7 days	Super-compensation	Performance ≥ baseline

3. Recovery Indicators :

3.1 Cardiovascular Indicators :

- **Heart Rate Recovery (HRR):**
 - **HRR60s** ≥ 25 bpm (♂) / 30 bpm (♀) = good recovery (Buchheit, 2022)
 - **HRR4min**: ↓ 50 bpm = endurance threshold
- **Heart Rate Variability (HRV):**
 - Return ≥ 90% baseline in 24 h
 - **Traffic-light algorithm** (Plews, 2023)
 - **Measurement**: Morning, at rest (sitting/lying), via chest strap (e.g., **Polar H10**) and apps (**HRV4Training**, **Elite HRV**)
 - **Key Parameters**: LnRMSSD, pNN50
 - **Interpretation**: ↓ LnRMSSD > 10–15% vs. baseline = functional fatigue.
LnRMSSD < 3.5 = red alert

3.2 Neuromuscular Indicators :

- **CMJ Recovery**: Return ≥ 95% Pmax in 24 h (SWC = 1 cm, CV 3%)
- **EMG RMS**: Return VL activation ≥ 95%

3.3 Biological Markers :

Marker	Sampling	Recovery Threshold	Reference
CK	24 h	< 500 U/L	Brancaccio, 2022
Myoglobin	3 h	< 100 µg/L	—
Cortisol	9 AM	< 500 nmol/L	Meeusen, 2023
CRP	24 h	< 3 mg/L	—

3.4 Psychometric Tests :

- **RESTQ-Sport:**
 - **Protocol:** 76-item questionnaire assessing **stress-recovery balance** (general fatigue, sleep, social conflicts)
 - **Indicators:** General score ****< 2.0 = recovery OK****. High recovery (>4) & low stress (<2) = **optimal state**
- **Hooper Index:**
 - **Protocol:** Daily assessment of **fatigue, stress, sleep, DOMS** (1–7 scale)
 - **Indicators:** Scores **< 3 = good recovery****; ****> 5 = chronic fatigue**
- **POMS:** ↑ fatigue > 14, ↓ vigor < 50 = overtraining risk
- **DASS-21:** Depression > 9 = burnout risk

3.5 Reaction and Reflex Tests :

- **Protocol:** Simple (SRT) or choice (CRT) reaction time via **BlazePod/Fitlight**
- **Indicators:** **SRT < 160 ms, **CRT < 220 ms**** (elite). Increase > 10% = neuromuscular fatigue
- **Application:** Reactive sports (judo, tennis)

3.6 Sleep Monitoring :

- **Tools:** **Oura Ring, Whoop, portable PSG, sleep diary**
- **Variables:** Deep sleep > 15%, duration 7–9 h, HRV, latency
- **Alert Thresholds:**
 - **Oura Ring:** ↓ HRV > 15%, score < 70

- **Portable PSG:** Deep sleep < 15%, ↓ 20%
- **Sleep diary:** Subjective quality < 6/10
- **Validity:**
 - **Oura Ring:** $r = 0.85$ vs. **PSG**
 - **Portable PSG:** $r = 0.92$
 - **Sleep diary:** $r = 0.65$

4. Tests to Assess Recovery :

4.1 Subjective Tests :

- **Perceived Fatigue Scale (RPE):** 1–10 scale (1 = not fatigued, 10 = maximally fatigued)
- **Training Log:** Notation of sensations, sleep, mood
- **Sleep Quality Tests:** Questionnaires or wearable devices
- **Subjective Recovery Assessment:** Questionnaires for mental fatigue and recovery

4.2 Objective Tests :

- **Heart Rate Variability (HRV):** High HRV = better recovery
- **Resting Heart Rate:** Morning measure, low value = good recovery
- **Ruffier-Dickson Test:** HR after exercise, rapid recovery = low HR
- **Performance Tests:** Time/distance tests to assess effort reproducibility
- **Biomarkers:** CK, lactate, cortisol for recovery state
- **Muscle Fatigue Assessment:** Voluntary activation test (VAT), electromyography (EMG)

5. Field Technologies :

Technology	Variable	Validity vs. Gold	Price
Oura Ring Gen3	HRV, sleep	$r = 0.85$ vs. PSG	€300
HRV4Training	LnRMSSD	ICC = 0.92	€10
NIRS PortaMon	SmO ₂ recovery	$r = 0.83$ vs. ³¹ P-MRS	€4,000
Grip Dynamometer	Hand strength	CV < 5%	€200

6. Use of Wearable Devices :

- **Features:**
 - Continuous heart rate (rest, sleep, effort)
 - HRV during sleep or upon waking
 - Sleep quality/duration (phases, awakenings)
 - Physical activity (steps, calories)
 - Some include stress estimators or recovery scores
- **Protocol:** 24/7 wear, app synchronization
- **Indicators:** Stable HRV, quality sleep, **ACWR 0.8–1.3 = optimal recovery**
- **Advantages:** Continuous, non-invasive, real-time feedback
- **Limitations:**
 - Variable accuracy by device
 - Proprietary algorithms sometimes lack scientific validation
 - Requires contextual analysis by staff

7. “Recovery-Scan 20 min” Protocol :

Step	Duration	Tool	Criterion
HRR60s	2 min	Polar H10	≥ 25 bpm
CMJ	3 min	Force plate	≥ 95% baseline
HRV	2 min	HRV4Training	≥ 90% baseline
RESTQ	5 min	Mobile app	< 2.0
Salivary cortisol	5 min	ELISA	< 500 nmol/L

8. Restoration Strategies :

Intervention	Duration	Effectiveness	Evidence
Whole-body cryotherapy	3 min (-110 °C)	↓ CK 20%	Bleakley, 2022
Pneumatic compression	30 min	↓ DOMS 25%	Hill, 2023
Contrast hydrotherapy	15 min (10 °C/38 °C)	↑ HRV 8%	Stanley, 2021
Mindfulness HRV	10 min	↓ cortisol 15%	Jha, 2023

9. Nutritional Strategies and Supplements :

- **Key Nutrients:**
 - **Protein:** 1.6–2.2 g/kg/day for muscle repair
 - **Carbohydrates:** 4–6 g/kg post-effort for glycogen
 - **BCAA, L-glutamine:** Reduce DOMS, accelerate recovery
 - **Dextrose, maltodextrin:** Rapid glycogen restoration
- **Hydration:** 500–1000 mL water + electrolytes post-effort
- **Timing:** Consumption within **30 min post-training (metabolic window)**

10. Sport-Specific Applications :

Sport	Priority Monitoring	Frequency	Tool
Football	CMJ + HRV	3×/week	Force plate + Oura
Cycling	HRV + CK	2×/week	HRV4Training + i-STAT
MMA	RESTQ + cortisol	4×/week	Mobile app
Esports	Sleep + HRV	Daily	Whoop

11. “Recovery-Score” Decision Algorithm :

Score	Interpretation	Action
> 80%	Excellent	Maintain load
60–79%	Average	↓ intensity 10%
< 60%	Poor	Active rest 24 h

12. New Trends :

- **AI Prediction:** XGBoost model on HRV + CMJ + sleep (**RMSE = 2%**)
- **Lactate Patch:** Continuous monitoring (Gao, 2023)
- **EEG Neurofeedback:** ↓ recovery time 12%

13. Super-Compensation :

- **Definition:** Physiological adaptation post-recovery **exceeding initial level**
- **Conditions:** Work/recovery alternation, optimized nutrition, **7–9 h sleep**
- **Tests:**

- **Physiological:** HRV, lactate
- **Performance:** Vertical jump, sprint
- **Psychological:** RESTQ, Hooper
- **Strategies:** Reduce volume (**41–60%**) during taper, maintain intensity

14. Integration into Practice :

- **Multimodal monitoring:** Combine HRV, CMJ, biomarkers, questionnaires
- **Technologies:** Wearables (**Oura, Whoop**) for continuous tracking
- **Education:** Train athletes on sleep and nutrition importance
- **Planning:** Integrate recovery weeks (3–4 weeks intense training : 1 regeneration week)
- **Individualization:** Tailor strategies by athlete profile (strength, sleep, stress)

15. Limitations and Considerations :

- **Cost:** Wearables/NIRS expensive (€300–€4,000)
- **Subjectivity:** Questionnaires depend on honesty
- **Individual variability:** HRV/sleep thresholds vary
- **Interpretation:** Requires expertise for contextualization
- **Wearable accuracy:** Varies by device
- **Proprietary algorithms:** Sometimes lack scientific validation

16. Signs of Overtraining :

- Persistent fatigue, performance decline, loss of appetite, sleep disturbances, increased injury susceptibility
- **Action:** Reduce training volume, increase rest

Conclusion :

The assessment of recovery through physiological (HRR, HRV, CK, lactate), neuromuscular (CMJ, EMG), psychometric (RESTQ, Hooper, POMS, DASS-21), and technological (Oura, Whoop, HRV4Training) tests enables performance optimization, overtraining prevention, and super-compensation promotion. A holistic approach, combining active recovery, nutrition, sleep, and multimodal monitoring, is essential to maximize athlete longevity and effectiveness.

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Practical Exercise :

Case Study: Professional Soccer Player, Post-Match

- **Data:**

- **HRR60s = 22 bpm**
- **CMJ = –8% (vs. baseline)**
- **HRV = 85% baseline**
- **RESTQ = 2.3**
- **CK 24 h = 750 U/L**

- **Questions:**

1. Calculate **Recovery-Score**
2. Program 48 h plan (active rest, nutrition, sleep)
3. Choose priority follow-up indicator

Conference No. 11 Assessment of Neuromuscular Adaptations Resulting from Training

1. Introduction :

Neuromuscular adaptations, encompassing changes in neural activation and muscular performance, are essential for improving strength, power, speed, coordination, and movement efficiency in sport.

Evaluating these adaptations enables quantification of training progress, program optimization, and prevention of imbalances that may lead to injuries.

2. Concepts of Neuromuscular Adaptations :

Neuromuscular adaptations occur in response to strength, power, or endurance training:

- **Neural Adaptations:**
 - ↑ **motor unit recruitment** (↑ firing frequency, ↓ recruitment threshold)
 - Improved **motor fiber synchronization**
 - ↓ **neural inhibition**, enabling more powerful contractions
- **Muscular Adaptations:**
 - **Hypertrophy** (increased muscle volume)
 - Shifts in **fiber type composition** (e.g., toward fast-twitch for explosive sports)
 - ↑ **contractile efficiency** (↑ mitochondrial density, ↑ capillarization)
- **Impact:** These adaptations enhance maximal strength, explosive power, and fatigue resistance, critical for sports performance
- **Reversibility:** 0.5–1% strength loss per week after training cessation (Aagaard, 2023)

3. Key Neuromuscular Variables ;

Variable	Instrument	Performance Threshold	Unit
EMG RMS	Surface EMG	↑ 20–40% vs. baseline	μV
RFD (Rate of Force Development)	Force plate	> 10,000 N·s ⁻¹	N·s ⁻¹
Twitch potentiation	TMS	↑ 15% torque	N·m
Voluntary Activation (VA%)	Twitch interpolation	> 95%	%
Myotonometry	MyotonPro	± 5%	N·m ⁻¹

4. Tools for Measuring Neuromuscular Activation :

- **Electromyography (EMG):**
 - **Protocol:** Measures muscle electrical activity via surface or intramuscular electrodes
 - **Indicators:** **EMG amplitude (mV)** = activation intensity; impulse frequency = fatigue
 - **Example:** Quadriceps EMG during squat to assess recruitment (normalized to %MVC)

- **Transcranial Magnetic Stimulation (TMS):**
 - **Protocol:** Non-invasive cortical stimulation (120% MEP) to assess neuronal excitability
 - **Indicators:** **Latency & amplitude of MEPs**, reflecting neural transmission efficiency

- **Isokinetic Dynamometry:**
 - **Protocol:** Force measurement at constant velocity (e.g., Biodex for quadriceps)
 - **Indicators:** **Peak torque (Nm)**, power, limb asymmetries

- **Force Platforms:**
 - **Use:** Measure vertical/horizontal forces during jumps, landings, accelerations
 - **Data:** Peak force, RFD, impulse, balance

- **Inertial Measurement Units (IMUs):**
 - **Use:** Sensors (accelerometers, gyroscopes) for 3D joint angles, velocities, accelerations
 - **Data:** Mechanical load estimation, fatigue (e.g., running biomechanics changes)

- **3D Motion Analysis:**
 - **Use:** Cameras tracking body markers
 - **Data:** Joint angles, velocities, biomechanical efficiency

- **MyotonPro:**

- **Protocol:** Measures tissue stiffness pre/post session
- **Indicator: Myotonic stiffness ($\pm 5\% \text{ N}\cdot\text{m}^{-1}$)**

5. Rapid Field Tests :

- **CMJ + EMG:** Assesses gastrocnemius/soleus activation ratio
- **Tendon stiffness ultrasound (SWE):** Shear-wave elastography for tendon stiffness
- **Single-leg hop:** Detects asymmetries ($>10\%$ = injury risk)

6. Relationship with Sports Performance :

- **Strength & Power:** Neural gains (recruitment, synchronization) improve **explosive performance** (e.g., sprint, jump)
- **Muscular Endurance:** \uparrow contractile efficiency reduces fatigue in **endurance sports** (e.g., cycling)
- **Coordination:** Neural adaptations enhance precision in **technical sports** (e.g., gymnastics)
- **Example:** A weightlifter with \uparrow **quadriceps EMG amplitude (+20% after 8 weeks)** shows better activation, correlated with **increased lifted load** (Suchomel et al., 2020)

7. Assessment of Neuromuscular Imbalances and Injury Prevention :

- **Muscular Imbalances:**
 - **Example: Quadriceps/hamstrings ratio < 0.6** (dynamometry) \uparrow **hamstring tear risk**
 - **Solution:** Eccentric exercises (e.g., **Nordic Hamstring**) to rebalance
- **Limb Asymmetries:**
 - Measured via **Y-Balance Test** or **single-leg hop ($>10\%$ = knee sprain risk)**
- **Neuromuscular Fatigue:**
 - \downarrow EMG amplitude or \uparrow reaction time (TMS) indicates fatigue, \uparrow **injury risk**
- **Application:** EMG/dynamometry data guide **prevention programs** (e.g., targeted strengthening, biomechanical correction)
- **Impact:** Correcting imbalances reduces **injury incidence by 30–40%** (Hewett et al., 2019)

8. Applications in Sports Training :

- **Personalization:** Tailor exercises based on results (e.g., **eccentric work** for low agonist/antagonist ratio)
- **Progress Tracking:** Compare EMG/dynamometry **pre/post cycle** to assess gains
- **Injury Prevention:** Corrective exercises based on identified imbalances
- **Optimization:** Target **neural adaptations** for power/endurance per sport

9. Protocols and Practical Considerations :

- **Standardization:** Tests under **identical conditions** (e.g., same electrodes, protocol)
- **Calibration:** Verify equipment (**EMG**, dynamometers) before testing
- **Supervision:** **TMS requires trained experts** for safety
- **Frequency:** Assessment **every 4–8 weeks** for monitoring

10. Interpretation and Planning :

- **VA% < 90%** → Prioritize **neuromuscular activation** (e.g., high-intensity training)
- **RFD ↓ 10%** → **Plyometrics + overspeed**
- **Myoton ↑ 15%** → **Fascial mobility work**

11. Data Integration and Decision-Making :

- **Holistic Analysis:** Combine strength, velocity, fatigue, and coordination data for full picture
- **Trends vs. Absolute Values:** **Longitudinal tracking** more meaningful (e.g., gradual ↓ strength = adjustment)
- **Individualization:** Tailored programs (e.g., **plyometrics** for explosive weakness)
- **Communication:** Explain results to athletes for **adherence/motivation**
- **Flexibility:** Plans adjustable based on **athlete state (fatigue data)**

12. Limitations and Considerations :

- **Cost:** **EMG/TMS equipment expensive**, low accessibility
- **Complexity:** Interpretation requires expertise in physiology/biomechanics

- **Individual Variability:** Responses vary by **age, sex, experience**
- **Reliability:** **EMG measures** affected by **electrode placement, external conditions**

Conclusion :

Assessment of neuromuscular adaptations is a vital component of sports training science. Tools (EMG, TMS, force plates, IMUs, dynamometers) provide precise data on muscle activation, imbalances, and fatigue. A multidisciplinary approach, combining these measures with rigorous analysis, enables performance optimization, injury prevention, and program personalization. The ability to translate complex data into actionable decisions is the key to success in elite sport.

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Practical Exercise :

- **Duration:** 20 min | **Group:** 6 athletes | **Equipment:** Force plate, EMG, portable TMS
- **Scenario:** U23 Judo athlete, 73 kg, **4 weeks into “explosive strength” cycle**
- **Raw Data:**
 - **1RM squat = 150 kg** ($2.06 \times \text{BM}$)
 - **CMJ RFD = 8,900 N·s⁻¹** (baseline 7,800)
 - **VA% (TMS) = 88%** (baseline 82%)
 - **EMG gastrocnemius = 68% MVC** (baseline 55%)
- **Questions:**
 1. Calculate relative change (%) for each variable
 2. Interpret: Predominant neural or muscular adaptation?
 3. Program 1 micro-cycle (3 sessions) to reach VA% > 95%

Conference No. 12 **Psycho-pedagogical Assessment and Competitive Stress in the Development of Sports Performance**

1. Introduction :

Psychological and pedagogical aspects play a key role in optimizing sports performance, influencing motivation, resilience, discipline, decision-making, reactivity, and precision under pressure. Psychopedagogical assessment enables coaches to adapt their methods, strengthen mental preparation, and promote holistic athlete development. At the same time, competitive stress—whether cognitive (worries, fear of failure) or somatic (physiological symptoms)—can impair concentration, motor execution, and increase injury risk. Psychomotor abilities, such as reaction time and attention, are essential in sports requiring speed and precision (judo, tennis, team sports).

2. Theoretical Framework :

2.1 Self-Determination Theory (SDT) and Self-Regulation :

- **Self-Determination Theory (SDT):**
 - Based on **three fundamental needs**:
 - **Autonomy**: Sense of control over actions
 - **Competence**: Perception of ability to succeed
 - **Relatedness**: Need for belonging and social connections
 - **Motivation types**: Continuum from **amotivation** to **intrinsic motivation** (pleasure) via **extrinsic forms** (rewards, external pressure)
- **Self-Regulation**: Ability to **plan, self-observe, and adjust behaviors/emotions** (e.g., stress management under pressure)
- **Validity and Reliability**: Psychometric tools must **measure accurately (validity)** and **reproducibly (reliability, e.g., $\alpha > 0.8$)** psychological states/traits

2.2 Sports Stress and Performance :

Dimension	Operational Definition	Typical Measure
Perceived stress	Cognitive appraisal of demand vs. resources	SCAT, CSAI-2R
Somatic anxiety	Bodily symptoms (HR, sweating)	CSAI-2R somatic
Cognitive anxiety	Negative thoughts, worry	CSAI-2R cognitive
Psychomotor	Reaction time, selective attention	FitLight, CPT-3

- **Competitive Anxiety:**
 - **Cognitive:** Negative thoughts, fear of failure, concentration difficulties
 - **Somatic:** ↑ HR, muscle tension, excessive sweating
 - **State anxiety:** Temporary reaction to competition
 - **Trait anxiety:** Stable predisposition to perceive competitions as threatening
 - **Impact: Moderate anxiety** can facilitate performance; **high levels** impair **concentration, decision-making,** and ↑ **injury risk** (Hanton et al., 2019)

3. Concepts of Psychological Measurement in Sports Training :

- **Motivation: Intrinsic** (pleasure, mastery) vs. **extrinsic** (rewards, recognition)
- **Self-control:** Emotion regulation, focus under pressure, perseverance
- **Personality:** Traits like **self-confidence, resilience, anxiety** impact performance
- **Pedagogical dynamics:** Teaching methods (e.g., **positive feedback, observational learning**) influence engagement
- **Subjectivity:** Self-reports require **validation** via **behavioral observations** and **interviews** for context (Weinberg & Gould, 2019)

4. Validated Measurement Tools :

Tool	Items	Score / Interpretation	Validity
SIMS	16 items	4 scales 1–7 ($\alpha = 0.83$)	Standage, 2022
SRQ-Sport	32 items	Autonomy vs. control ($\alpha = 0.91$)	Standage, 2022
BRSQ	36 items	6 factors (amotivation → integrated, $\alpha = 0.89$)	Standage, 2022
POMS	65 items	Tension, depression, vigor (>20 = optimal)	Lochbaum et al., 2020
CSAI-2	27 items	Cognitive/somatic anxiety, confidence (10–20 = optimal)	Lochbaum et al., 2020
ABQ	15 items	Exhaustion, devaluation (>3 = burnout risk)	Lochbaum et al., 2020
SCAT	15 items	Likert 1–4, 10–30 (≥ 20 = high anxiety)	Martens, 2022
CSAI-2R	17 items	Cognitive ($\alpha = 0.90$), Somatic ($\alpha = 0.88$), Self-confidence ($\alpha = 0.91$)	Martens, 2022
TAI-S	20 items	20–80 (≥ 45 = performance anxiety)	—

4.1 Psychological Tools :

- **Profile of Mood States (POMS):** Assesses emotional states (**vigor >20 = optimal**)

- **Competitive State Anxiety Inventory-2 (CSAI-2):** Measures **cognitive/somatic anxiety** and **confidence** pre-competition (>**20** or <**15** = intervention needed)
- **Athlete Burnout Questionnaire (ABQ):** Detects **burnout risk** (score >**3**)
- **Sport Competition Anxiety Test (SCAT):** 15 items, Likert 1–4, **score ≥ 20 = high competitive anxiety**, reliability $\alpha = 0.87$, validated in Arabic/French (Aït-Mehdi, 2023)
- **CSAI-2R (Revised):** Administered **20 min pre-competition**, subscales: **cognitive, somatic, confidence**
- **Test Anxiety Inventory – Sport (TAI-S):** Pre-selection/exam, **score ≥ 45 = performance anxiety**
- **Structured/semi-structured interviews:** Explore thoughts/emotions
- **Behavioral observation grids:** Analyze **body language, interactions, reactivity under pressure**
- **Training logs/EVA:** Daily self-reporting (stress, confidence) via apps (**PDA, 5×/day**)
- **Chatbot coach:** Adaptive questions, **NLP analysis** for motivational tracking

4.2 Self-Regulation and Metacognition :

- **SRSS (Self-Regulation in Sport Scale):** Assesses **planning, self-observation, self-reaction**
- **EMBU:** Measures **environment-sport link** (e.g., parental influence)
- **Applications:** Digital journal for self-observation; **choice-oriented coaching** if autonomy < 4/7

5. Psychomotor Tests :

Test	Variable	Elite Norm	Equipment
Simple Reaction Time (SRT)	< 160 ms	< 160 ms	FitLight
Choice Reaction Time (CRT)	< 220 ms	< 220 ms	BlazePod
Go/No-Go	Error rate < 3%	< 3%	CPT-3
Selective attention	RT < 450 ms (Flanker Test)	< 450 ms	Inquisit 6
3D Tracking	Precision < 1°	< 1°	Oculus + EMG

5.1 Psychomotor Qualities Assessed :

- Coordination
- Balance
- Reactivity
- Strength
- Flexibility

6. Impact of Physical Effort and Stress on Psychomotor Abilities :

- **Muscle fatigue:** Slows reaction time (RT +10–20%) (Smith et al., 2021)
- **Physiological stress:** Low HRV or high cortisol impairs **concentration**
- **Cognitive load:** Prolonged efforts (e.g., football match) reduce **attention**

7. Modern Technologies :

Technology	Variable	Validity	Cost
BlazePod	RT, coordination	$r = 0.93$ vs. lab	€300
FitLight	RT, peripheral vision	CV < 3%	€800
NeuroTrackerX	Divided attention	$r = 0.85$ vs. CPT-3	SaaS €50/month
Portable EEG (Muse S)	Alpha/beta ratio	$r = 0.78$ vs. lab	€250

7.1 Emerging Trends :

- **VR stress testing:** Anxiety-inducing immersion ($r = 0.90$ vs. real)
- **AI choking prediction:** Random Forest on HR + RT (AUC = 0.88)
- **COMT Val158Met genetics:** Modulates RT under stress

8. Stress–Performance Correlation :

Indicator	Performance Impact	Critical Threshold
SCAT ≥ 22	↓ 5–8% reaction time	Competition
CSAI-2 somatic ≥ 24	↑ HR > 8 bpm	Pre-match
Alpha/beta ↑ 20%	↓ attention 10%	EEG

9. Role of Psychological Questionnaires in Training Plan Guidance :

- **Need identification:** SMS-II/CSAI-2 detect **motivational support** or **stress management** needs
- **Personalization:** **Positive feedback** for low confidence; **visualization** for high anxiety
- **Planning:** Integrate **mindfulness/relaxation** sessions based on scores
- **Burnout prevention:** Adjust **load/rest** via **ABQ**
- **Impact:** **Psychology-based interventions** improve **performance under pressure** by **10–15%** (Brown et al., 2021)

10. Injury Prevention and Psychomotor Qualities :

- **Statistics:** Sports injuries represent a **significant portion** of accidents (departmental physical activity council)
- **Importance:** Reducing **anxiety** and improving **psychomotor qualities (coordination, balance, reactivity)** ↓ **injury risk** from poor technique or stress-induced decisions
- **Strategies:**
 - Biomechanical assessment to identify imbalances
 - Functional tests (Y-Balance Test, FMS) for coordination/stability
 - Training load analysis to avoid overload
 - Technique and warm-up education

11. Operational Protocol – Psycho-Scan 15 min :

Step	Duration	Tool	Alert Threshold
CSAI-2R	5 min	Mobile app	Somatic ≥ 24
SRT + CRT	4 min	FitLight	RT $\uparrow 10\%$
Flanker Test	3 min	Inquisit	Error $\uparrow 5\%$
Salivary α -amylase	3 min	ELISA	> 50 U/mL

12. Immediate Interventions :

Threshold	Intervention	Evidence
Somatic ≥ 24	HRV breathing 0.1 Hz (6 breaths/min)	↓ 15% HR (Plews, 2022)
RT $\uparrow 10\%$	Mindfulness 10 min	↓ RT 8% (Jha, 2023)
Alpha/beta \uparrow	Neurofeedback 5 min	↓ 12% (Thompson, 2023)

13. Sport-Specific Applications :

Sport	Focus	Key Test	Use
Basketball	Defensive RT	FitLight 5 m	Mental warm-up
Tennis	Visual attention	Flanker	Service
Esports	Go/No-Go	CPT-3	Team selection
Volleyball	Autonomy, competence	SRQ-Sport	Individual coaching

14. Integration of Physical Performance and Mental Preparation :

- **Holistic approach:** Combine **psychological data** (e.g., **CSAI-2**) and physiological data (e.g., **HRV**) for full picture
 - **Example:** High anxiety + low HRV → **relaxation techniques**
- **Pedagogical feedback:** Constructive feedback strengthens **confidence/motivation**
- **Integrated mental training:** **Visualization** in physical sessions (e.g., imagine perfect sprint)
- **Longitudinal monitoring:** Regular assessments to adjust strategies

15. Integration into Practice :

- **Multidisciplinary collaboration:** **Psychologists, coaches, physiologists** share data
- **Modern technologies:** Apps (**Headspace, BlazePod, Fitlight, portable EEG**) for **mindfulness** and **field measures**
- **Athlete education:** Awareness of **psychological assessment importance**
- **Planning:** Integrate **reaction exercises** and **stress management** into training
- **Continuous monitoring:** **Monthly/quarterly** evaluations for adjustments

16. Limitations and Considerations :

- **Subjectivity:** Dependent on **athlete honesty/self-awareness**
- **Cost:** Tools require **trained psychologists/paid software** (€250–€800)
- **Individual variability:** Responses vary by **culture, sex, experience**
- **Interpretation:** **Expertise required** to avoid erroneous conclusions

Conclusion :

Psychopedagogical assessment (POMS, CSAI-2, ABQ, SRQ-Sport) and competitive stress evaluation (SCAT, CSAI-2R) combined with psychomotor tests (SRT, CRT, Flanker) are essential to optimize performance, prevent injuries, and promote well-being.

Modern technologies (BlazePod, Fitlight, EEG, VR) provide objective data to personalize mental preparation.

A multidisciplinary approach, integrating psychology, biomechanics, physiology, and training, enhances resilience, reactivity, and athlete longevity.

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Practical Exercises :

1. Case Study: U18 Women's Volleyball, 2 Weeks Before National Championship

- **Duration:** 20 min | **Group:** 8 athletes | **Tool:** Smartphone + Google Forms
- **SRQ-Sport Results** (scale 1–7):

Subscale	Team Average	High-Quality Threshold
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Autonomy	4.2	≥ 5.0
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Competence	5.1	≥ 5.5
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Relatedness	6.0	≥ 5.5
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- **Questions:**
 1. Identify need to strengthen
 2. Propose 2 concrete strategies (coaching + activity)
 3. Plan follow-up evaluation (tool + timeline)

2. Case Study: Judoka, 22 y.o., Day Before Competition

- **Data:**
 - **CSAI-2R:** Cognitive = 28, Somatic = 26, Self-confidence = 15
 - **Simple RT:** 185 ms (\uparrow 12%)
 - **Salivary α -amylase:** 55 U/mL
- **Questions:**
 1. Interpret scores
 2. Program 10-min HRV breathing protocol
 3. Choose 1-h pre-fight follow-up indicator

Conference No. 13 Design of Field Test Batteries According to Sports Specialty

Introduction :

Sports performance assessment is essential for effective training planning. While laboratory tests offer optimal precision, their cost, logistical complexity, and lack of ecological validity limit their use. Field test batteries, on the other hand, allow evaluation under conditions close to competitive reality, provided they are rigorously designed. A test battery is a series of standardized tests targeting physical, technical, and cognitive qualities specific to a sports discipline.

1-1- Deterministic Analysis of Performance (The "What" to Evaluate) :

The first step involves deconstructing the demands of the discipline to identify performance-determining qualities.

1. Activity Modeling:

- **Quantitative Analysis:** Use technologies (**GPS, accelerometers, video analysis**) to quantify competitive demands.
 - **Example (Football):** Distance covered (**10–12 km**), sprints (**>19.8 km/h**), accelerations/decelerations, changes of direction.
 - **Example (Judo):** Effort/pause duration (**tachi-waza/mate**), effort/recovery ratio, types of grips/projections.
- **Qualitative Analysis:** Identify motor patterns, muscle groups, and predominant energy systems.
 - **Example (Volleyball):** Vertical jump (**attack/block**), short-distance speed, upper limb power (**serve/smash**).

2. Hierarchy of Physical Qualities:

- **Determining Qualities:** Direct impact on performance (e.g., **maximal aerobic power** for marathon runners).
- **Contributory Qualities:** Support primary qualities (e.g., **maximal strength** for power/speed).
- **Secondary Qualities:** Lesser importance but necessary (e.g., **flexibility** for injury prevention).

1-2- Rational Selection of Measurement Tools (The "How" to Evaluate) :

Select scientifically validated tests adapted to practical context.

1. Test Selection Criteria:

- **Validity:** Does it accurately measure the targeted quality?
 - **Content Validity:** Covers all aspects of the theoretical construct (**expert opinion**)?
 - **Criterion Validity:** Correlation with "**gold standard**" tests (e.g., **VAMEVAL vs. lab VO₂max**).
 - **Construct Validity:** Discriminates performance levels (**experts vs. novices**)?
- **Reliability:** Consistent results (**ICC > 0.80**, ideally **> 0.90**; low standard error of measurement).
- **Objectivity:** Independent of evaluator (**clear instructions, unambiguous criteria**).
- **Sensitivity:** Detects small, significant post-training changes.
- **Specificity:** Represents **metabolic/biomechanical demands** of the sport.
- **Feasibility:** Cost, time, equipment, ease of administration.

2. Selection Examples:

- **Lower limb power: Countermovement Jump (CMJ)** preferred over **Squat Jump** (includes stretch-shortening cycle, more specific).
- **Intermittent aerobic endurance: Yo-Yo Intermittent Recovery Test** (more specific for team sports than **continuous Léger-Boucher**).

1-3- Standardization of Test Administration Protocol :

Standardization ensures data comparability.

1. Test Conditions:

- **Environment:** Same surface, time, conditions (**temperature, humidity**).
- **Athlete:** Comparable freshness (**no training/competition 48h prior**), standardized **hydration/nutrition**.
- **Warm-up:** General + specific, **identical each session**.

2. Test Order: Minimize fatigue impact.

1. **Anthropometry** (non-fatiguing).
 2. **Flexibility/mobility**.
 3. **Power/speed** (e.g., sprints, jumps).
 4. **Lactic anaerobic capacity** (e.g., **RSA, 300m**).
 5. **Aerobic endurance** (e.g., **Yo-Yo, VAMEVAL**).
3. **Instructions and Motivation:** Clear verbal instructions, standardized encouragement.

1-4- Data Processing and Interpretation :

Give meaning to data to guide decision-making.

1. Statistical Analysis:

- Descriptive calculations (mean, standard deviation) for group.
- Individual vs. group or prior results comparison.

2. Development of Norms (Calibration):

- **Population-based norms:** Comparison with similar athletes (**age, sex, level**).
- **Team-based norms:** Intra-team comparison for team sports.
- **Intrapersonal norms:** Longitudinal tracking of individual progress.
- **Methods:**
 - **Percentiles:** Score ranking (e.g., **75th percentile = better than 75% of group**).
 - **Z-Scores:** $\text{Score} = (\text{Result} - \text{Mean}) / \text{SD}$, allows comparison of different units.

3. Profiling and Decision-Making:

- Visualization via radar chart (Z-scores) to identify strengths ($> +0.5$) and weaknesses (< -0.5).
- Guide planning (e.g., low speed \rightarrow sprint cycle).

2- Quality Criteria and Validation of a Test Battery :

- **Content Validity:** Covers all **important sport qualities (expert opinion)?**

- **Construct Validity:** Results consistent with **performance levels (higher scores for elite)**.
- **Concurrent Validity:** Correlation with lab "**gold standard**" tests.
- **Predictive Validity:** Predicts **competitive performance**.
- **Test-Retest Reliability:** **ICC > 0.80, low SEM**.
- **Inter-Rater Reliability:** Results **independent of operator**.
- **Update:** **Annual reevaluation** to integrate **sport/technology evolutions**.

2-1- Practical Examples of Batteries by Specialty :

1. Football:

- **Demands:** Intermittent endurance, speed, agility, lower limb power, repeated high-intensity efforts.
- **Tests (6 items):**
 1. **Yo-Yo IR1 (VMA 17 km·h⁻¹).**
 2. **CMJ (45 cm elite).**
 3. **1RM squat.**
 4. **505 Agility Test.**
 5. **Functional Movement Screen (FMS).**
 6. **RPE post-test.**
- **Duration:** **35 min.**
- **Equipment:** 20 m mat, force plate, cones.

2. 50 m Sprint Swimming:

- **Demands:** Propulsion power, start/turn technique, upper body strength, specific endurance.
- **Tests (6 items):**
 1. **15 m start (< 5.5 s elite).**
 2. **30 m timed swim.**

3. **1RM pull-up.**
 4. **HRV (rest).**
 5. **Y-Balance Test.**
 6. **RPE post-test.**
- **Duration: 25 min.**
 - **Equipment:** Optical timing, dynamometer.
3. **Basketball:**
- **Demands:** Power, agility, speed, intermittent endurance.
 - **Tests (6 items):**
 1. **RSA 6×20 m (< 25 s total elite).**
 2. **CMJ (45 cm).**
 3. **¾ court sprint.**
 4. **Y-Balance Test.**
 5. **RPE post-test.**
 6. **FitLight reaction.**
 - **Duration: 30 min.**
 - **Equipment:** Photocells, FitLight.
4. **Judo:**
- **Demands:** Anaerobic power, grip strength, strength endurance, agility.
 - **Tests (6 items):**
 1. **1RM squat.**
 2. **Grip dynamometer (> 55 kg elite).**
 3. **COD 5 m.**
 4. **Special Judo Fitness Test (SJFT).**
 5. **RPE post-test.**

6. Grappling Dummy Test.

- **Duration: 20 min.**
- **Equipment:** JAMAR dynamometer, cones.

3- Digitalization Tools:

- **Google Forms + QR code:** Instant result entry on tablet.
- **PowerBI Template:** Automatic radar chart for performance profiling.

4- Time and Logistics Management :

- **Flow:** Rotation **8 athletes/station, 5 min/test.**
- **Staff: 1 staff/4 athletes** for safety/standardization.
- **Total duration: 20–35 min** depending on sport.

Conclusion :

The design of a field test battery transforms assessment into a strategic training tool. By following a rigorous methodology (demand analysis, validated test selection, standardization, calibration), coaches obtain objective data to individualize programs, track progress, and prevent injuries. Tailored to the specificities of individual and team sports, these batteries, enhanced by digital tools (Google Forms, PowerBI), maximize performance and athlete development.

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Practical Exercise :

Scenario: U20 handball team (**16 players**).

Duration: 30 min | **Tool:** Google Forms, PowerBI.

Questions:

1. Identify 4 key capacities.
2. Choose 5 tests + norms.
3. Plan 30-min logistics.
4. Build PowerBI dashboard.

Conference No. 14 Measurement and Evaluation in Specific Training Environments

Introduction :

Athletic performance optimization relies on leveraging innovative training strategies, particularly in specific environments such as altitude (hypobaric hypoxia), heat, high humidity, or cold. These conditions impose unique physiological stresses that, when well-managed, induce beneficial adaptations for performance—even in normal conditions. However, evaluation in these environments is complex, as classic physiological markers (heart rate, VO_2max , perceived exertion) are altered, making comparisons with standard norms inadequate.

1- Influence of Specific Environments on Sports Performance :

Each environment imposes distinct physiological constraints affecting performance.

1. Altitude (Hypobaric Hypoxia):

- **Main Stress:** ↓ partial pressure of oxygen (PO_2) → tissue hypoxia
- **Impact:** ↓ oxygen saturation (SpO_2), ↓ VO_2max (~1%/100 m above 1500 m), sleep disturbance, risk of acute mountain sickness
- **Performance Consequences:**
 - Severe reduction in aerobic performance (e.g., long-distance running, cycling)
 - Anaerobic performance (short sprints) less affected, sometimes improved (↓ air resistance)

2. Heat (Thermal Stress):

- **Main Stress:** Hyperthermia ($T_{\text{core}} > 39^\circ\text{C}$), dehydration, cardiovascular overload (cutaneous vasodilation)
- **Impact:** ↑ HR, cardiovascular drift, fluid loss, ↑ perceived effort
- **Performance Consequences:** ↓ endurance, impaired strength/power if severe dehydration (>2% body weight)

3. Extreme Humidity:

- **Main Stress:** ↓ sweat evaporation → ↑ thermal stress
- **Impact:** Risk of hyperthermia, HR > 180 bpm, ↑ fluid loss (low humidity)

- **Performance Consequences:** Similar to heat, exacerbated by high humidity

4. Cold (Cold Stress):

- **Main Stress: Hypothermia ($T_{core} < 35\text{ }^{\circ}\text{C}$), vasoconstriction, shivering (thermogenesis)**
- **Impact:** ↓ muscle temperature, ↓ nerve conduction
- **Performance Consequences:** ↓ strength, power, coordination, risk of frostbite/hypothermia

2- Evaluation of Physiological Indicators in Specific Environments :

Precise monitoring is essential to assess adaptation and minimize risks.

1. At Altitude:

- **Oxygen Saturation (SpO_2):** Measured via **pulse oximetry** (e.g., Masimo MightySat). $SpO_2 < 90\%$ = hypoxemia
- **Hemoglobin/Hematocrit:** Blood samples to track **hematological adaptations** (↑ red blood cells)
- **Heart Rate (HR)/HRV:** ↑ resting HR, altered HRV reflect **hypoxic stress**
- **Blood Lactate:** ↑ production at same **relative intensity**
- **Specific Performance:** Tracking **$VO_2\text{max}$, race time, power** to assess acclimatization

2. In Heat/Humidity:

- **Core Temperature (T_{core}):** Measured via ingestible capsule/rectal probe. $T_{core} > 39\text{ }^{\circ}\text{C}$ = hyperthermia
- **Sweat Rate:** Calculated by pre/post-effort weight difference + fluids ingested
- **Hydration:** Body weight, urine density, urine color
- **Heart Rate (HR):** ↑ due to cardiovascular drift
- **RPE/Thermal Comfort:** Subjective scales for tolerance
- **Blood Markers:** Electrolytes (sodium, potassium) for severe dehydration

3. In Cold:

- **Core/Skin Temperature (T_{skin}):** Monitoring to prevent **hypothermia (T_{skin} < 10 °C critical)**
- **Shivering:** Visual indicator of **thermogenesis**
- **Dexterity/Strength:** Neuromuscular tests to assess **cold impact**

3- Evaluation Protocols in Specific Environments :

1. At Altitude:

- **Challenge:** ↓ VO₂max, ↑ HR/RPE at same effort → invalid comparisons with sea level
- **Protocol:**
 - **Pre-Stage (Normoxia):** VMA tests (e.g., VAMEVAL), 5 km time trial, submaximal HR/RPE, hemoglobin/hematocrit
 - **During Stage (Hypoxia):**
 - **Daily Monitoring:** SpO₂ at rest (morning), resting HR, sleep (Hooper Index)
 - **Weekly Test:** 3 stages (4 min at 60%, 70%, 80% of sea-level VMA). Variables: HR, SpO₂ effort, RPE
 - **Interpretation:** ↑ SpO₂ (e.g., 90% → 94%), ↓ HR/RPE = positive acclimatization
 - **Post-Stage (Normoxia):** Repeat pre-stage tests (2–3 weeks post) to quantify gains (e.g., ↑ VO₂max 3%)

2. In Heat/Humidity:

- **Challenge:** Cardiovascular drift, dehydration (>2% weight) impair performance
- **Protocol:**
 - **Pre-Exposure (Temperate):** Performance tests (VMA, PMA), submaximal HR
 - **During Acclimatation:**
 - **Daily Monitoring:** Morning weight, urine color, resting HR

- **Control Test (2–3 days): 30–45 min at 65% VMA/PMA in heat.**
Variables: **HR, Tcore, sweat rate, RPE, thermal stress**
- **Interpretation: ↓ HR/Tcore, ↑ sweat rate, ↓ RPE = acclimatation (7–14 days)**
- **Hydration Strategy: Personalized plan based on sweat rate**

3. In Cold:

- **Protocol: Tests of Tcore/Tskin, dexterity (e.g., grip tests), muscular performance (e.g., jumps)**
- **Interpretation: Tcore stabilization, rapid post-exposure recovery = adaptation**

4- Environmental Simulation Techniques :

Environmental chambers allow precise control of conditions.

1. Hypoxic Chambers (Altitude):

- **Function: Normobaric hypoxia (↓ FiO₂, normal pressure). E.g., Hypoxico Altitude Tent (3000–5500 m, ± 0.1%)**
- **Strategies:**
 - **Live High, Train High (LHTH):** Training/life in hypoxia
 - **Live High, Train Low (LHTL):** Life in hypoxia, training in normoxia (effective)
 - **Intermittent Hypoxic Exposure/Training (IHE/IHT):** Short exposures
- **Advantages: Control, reproducibility, safety, no real-altitude logistics**

2. Climatic Chambers (Heat/Cold):

- **Function: Temperature control (20–45 °C, ± 0.5 °C), humidity (10–90% RH). E.g., ClimaCab Heat, Portable Heat Chamber**
- **Use:**
 - **Heat acclimatation:** Progressive training for **thermoregulation**
 - **Heat Tolerance Tests (HTT):** Evaluate **physiological limits**
 - **Cold training:** Test **equipment/adaptation**

- **Advantages: Safety, reproducibility, variable control**
3. **Others (e.g., Wind Tunnel):** Simulates wind (0–40 km/h, ± 1 km/h) for cycling aerodynamics

5- Acclimatation Strategies and Effectiveness Measurement :

1. **Strategies:**

- **Altitude:** Progressive exposure, **LHTL, iron supplementation**, adapted nutrition
- **Heat:** Progressive exposure, **strict rehydration, pre-cooling** (ice vests, cold baths)
- **Cold:** Gradual exposure, **adapted clothing, extended warm-up**

2. **Effectiveness Measurement:**

- **Performance Tests:** Repeat specific tests (e.g., **time trial, VO₂max**)
- **Physiological Indicators:**
 - **Altitude:** ↑ SpO₂ (2–3% in 7 days), ↓ HR effort, ↑ hemoglobin
 - **Heat:** ↓ Tcore/HR, ↑ sweat rate (15%), ↓ [Na⁺] sweat (10%)
 - **Cold:** Tcore stabilization, rapid recovery
- **Subjective Feedback:** ↓ RPE, ↑ comfort (scales)
- **Competitive Performance:** Results in **extreme conditions**

6- Safety and Monitoring :

- **Automatic Alerts:** SpO₂ < 88%, Tcore > 39.5 °C → SMS to staff
- **Emergency Kit:** Portable O₂, ice vests, electrolytes
- **Cloud Dashboard:** Real-time tracking (Tcore, SpO₂, HRV)

7- Synthesis of Tests and Indicators :

Environment	Major Stress	Critical Indicator	Reference
Altitude	Hypoxia, ↓ SpO ₂	SpO₂ < 90% = hypoxemia	Gore, 2022
Heat	Tcore > 39 °C	PSI > 7.5 = hyperthermia	Racinais, 2023
Humidity	↓ Sweat evaporation	HR > 180 bpm	Periard, 2022
Cold	Tcore < 35 °C	Tskin < 10 °C	Castellani, 2021

Test	Conditions	Variables	Adaptation Criteria
SpO ₂ Test	2500 m simulated	SpO ₂ rest/effort	↑ 2–3% in 7 days
HTT (Heat Tolerance)	40 °C / 40% RH	T _{core} , HR, PSI	PSI < 7.5
HST (Heat Stress)	35 °C / 70% RH	Sweat rate, [Na ⁺]	↑ Sweat 15%, ↓ [Na ⁺] 10%
Cold-Water Immersion	14 °C	T _{core} recovery	T ^{1/2} < 15 min
Indicator	Tool	Adaptation Threshold	Frequency
SpO ₂ rest	Masimo MightySat	↑ 2%	Daily
Salivary HSP70	ELISA	↑ 20%	2×/week
Nocturnal HRV	Oura	↑ 5%	Daily
[Na ⁺] sweat	Gx Sweat Patch	↓ 10%	2×/week

Conclusion :

Evaluation in specific environments (altitude, heat, humidity, cold) requires a rigorous methodological approach, focused on longitudinal monitoring of physiological responses (SpO₂, T_{core}, HR, sweat rate) and adaptation of test protocols.

Hypoxic and climatic chambers provide precise control, facilitating safe acclimatation and evaluation.

By correctly interpreting data (e.g., ↓ HR = acclimatation, not detraining), coaches transform constraints into competitive advantages.

Continuous monitoring, supported by technologies (Masimo, Oura, PowerBI), ensures safety and optimization.

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Practical Exercise :

Scenario: Marathon preparation in Doha (35 °C / 70% RH).

Questions:

1. Plan HTT 7 days before departure.
2. Choose 4 daily monitoring indicators.
3. Establish thermal load adjustment algorithm.

Conference No. 15 Analysis of Test Results and Decision-Making in Training

1. Introduction :

Analysis of test results is a crucial step in the sports training process, enabling the transformation of raw data into concrete decisions to optimize performance. This analysis involves data processing, use of specialized software, and adaptation of training programs based on collected data.

This lecture explores data processing methods, digital tools for analysis, and strategies to guide training based on results, while considering individual athlete needs.

Data collection via tests and monitoring tools (covered in previous lectures) is only the first step in an essential process in sports science. The true value lies in the ability to analyze these results meaningfully and transform them into informed training decisions.

Rigorous analysis enables understanding of athlete strengths and weaknesses, evaluation of intervention effectiveness, detection of fatigue or overtraining signs, and adjustment of periodization to optimize performance and prevent injuries.

2. Decision-Making Chain – From Sensor to Action :

Step	Objective	Tools	Quality Criteria
Acquisition	Raw collection	GPS, force plate, HRV	Precision < 5%
Cleaning	Artifact removal	Kalman filters, outliers	< 2% data rejected
Analysis	Statistics & AI	Python, R, PowerBI	95% CI
Interpretation	Practical significance	SWC, Z-score, ES	Cohen d ≥ 0.2
Decision	Load adjustment	Dashboard, alerts	< 24 h

3. Processing and Organization of Results :

Before any analysis, raw data must be processed and logically organized.

- **Data Cleaning:**
 - **Integrity check:** Remove input errors, outliers, or inconsistent measurements (e.g., impossibly fast sprint time or abnormally low HRmax for effort).
 - **Missing data management:** Decide how to handle absent data points (interpolation, exclusion from analysis, etc.).
- **Standardization and Normalization:**
 - Convert units if needed (e.g., **m/s to km/h**).
 - Normalize certain data relative to body weight (e.g., VO₂max in mL/kg/min) for fairer comparisons between athletes.

- **Data Structuring:**

- Use spreadsheets (Excel, Google Sheets) or databases to organize results consistently, with unique identifiers for each athlete, test, and date.
- Ensure longitudinal tracking per athlete, enabling temporal comparisons.

4. Statistics Applied to Sports Data :

Concept	Formula / Threshold	Use
SWC (Smallest Worthwhile Change)	$0.2 \times SD$	Detecting real improvement
MDC (Minimal Detectable Change)	$1.96 \times \sqrt{2} \times SEM$	Test-retest reliability
ES (Effect Size)	$Cohen\ d = (M_2 - M_1) / SD$	Effect magnitude
CI 95%	$M \pm 1.96 \times (SD / \sqrt{n})$	Uncertainty
Individual Z-score	$(X_i - \mu) / \sigma$	Profiling

5. Data Visualization and Storytelling :

Graph	Use	Example
Radar PPG	Athlete profile vs. norm	Force, Endurance, Speed
Load-performance curve	Banister cycle	TRIMP vs. CMJ
Season heatmap	Injuries per week	GPS + RPE
Forest plot	Meta-analysis of interventions	Cryotherapy

6. Embedded Dashboards – Concrete Examples :

6.1 PowerBI – Football Team :

- **KPIs:** ACWR, HRV, CMJ, RPE, injuries
- **Alerts:** Red if ACWR > 1.3 & HRV ↓ > 10%
- **Export:** Automatic PDF every Monday 6 AM

6.2 Shiny App – University Laboratory :

- **Inputs:** 1RM, VO₂max, CMJ
- **Outputs:** Z-score vs. 500-athlete database
- **Open-source code:** GitHub MIT license

7. Predictive Models – ML Pipeline :

Graph	Algorithm	Input	Output	Performance
Injury prediction	Gradient Boosting	GPS + HRV + RPE	Yes/No	AUC = 0.91
Load optimization	LSTM time series	365 days data	1 km performance	RMSE = 2.1 s
VO₂max estimation	Random Forest	CMJ + HR + age	—	r = 0.94
Local fatigue	CNN visual	240 Hz CMJ video	—	RMSE 1.8 cm

8. Algorithmic Decision-Making – Example :

IF HRV ↓ > 10% AND CMJ ↓ > 8% AND RPE ↑ > 1

THEN micro-cycle = volume –30% + HRV biofeedback 10 min

ELSE maintain load

9. Inter-Staff Communication :

Stakeholder	Format	Frequency	Language
Coach	Radar PPG + alerts	2×/week	Simple visual
Physician	Biomarker table	Weekly	Clinical
Player	Score 0–100 + emoji	Daily	Gamified
Management	Injury ROI	Monthly	Business

10. Case Studies – Real Decisions :

- **Case A: Footballer – Overtraining Detected :**
 - Data: ACWR 1.45, CMJ –12%, CK 980 U/L
 - Decision: Active rest 48 h, re-test CMJ
 - Result: Return to baseline 72 h, injury avoided
- **Case B: Cyclist – Load Optimization**
 - LSTM Model: Predicts ↑ 3% power in 4 weeks
 - Action: ↑ zone 3 volume by 15%
 - Result: 2.8% gain in 20 km TT

11. GDPR & Data Ethics :

Obligation	Concrete Action
Consent	Dynamic checkbox on app
Anonymization	Hash ID, IP deletion
Portability	CSV / JSON export
AI Explainability	SHAP values dashboard

12. Perspectives :

- **Digital Twin:** Athlete's **digital avatar** (pre-simulation testing)
- **LLM Coach:** **ChatGPT fine-tuned** on team database
- **Blockchain:** **Data integrity traceability** for anti-doping

13. Limitations and Considerations :

- High cost and technical expertise required
- Interpretation requires deep knowledge of human mechanics
- Influence of environmental conditions or fatigue
- Difficulty analyzing team sports in real conditions

14. Integration into Practice

- **Multidisciplinary approach:** Collaboration between coaches, data analysts, and psychologists
- **Modern technologies:** Integrate GPS, HRV, and AI for a holistic view
- **Athlete education:** Explain data importance to strengthen engagement
- **Continuous monitoring:** Implement regular assessments for real-time program adjustment

Conclusion :

Analysis of test results is the bridge between data collection and sports performance optimization. By using appropriate software tools for data processing and organization, and relying on quantitative interpretation of progress, fatigue, and specificity indicators, coaches can make informed decisions.

This scientific approach, combined with a multidisciplinary strategy and open communication with the athlete, is essential to individualize training programs, prevent risks, and enable each athlete to reach full potential at the right time.

The ability to turn numbers into concrete actions is the hallmark of elite coaching.

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Practical Exercise :

- **Case Study:** U23 handball team, **50-athlete database, 6 months of GPS, HRV, CMJ data**
 - **Objective:** ↓ injuries by 20% in 3 months
 - **Questions:**
 1. Select 3 key indicators and thresholds
 2. Design simple decision algorithm (pseudo-code)
 3. Present coach visualization (wireframe)

Conference No. 16 Measurement Tools and Digital Tracking with Wearable Technologies

1. Introduction :

Technological advancements have revolutionized the evaluation and monitoring of sports performance, providing precise digital tools to measure physiological, biomechanical, and psychological parameters. These tools—including applications, wearables, simulation systems, and artificial intelligence (AI)—enable real-time data collection and in-depth analysis. In the context of modern sports training, performance evaluation relies on accurate, rapid, and contextualized data collection. While field tests are practical and sport-specific, they often suffer from limited frequency and delayed analysis. Wearable technologies, such as smartwatches, GPS sensors, heart rate belts, and biometric sensors, offer a complementary solution by enabling real-time monitoring of physiological and biomechanical parameters. The integration of this data with field test results creates a powerful synergy, transforming static evaluation into a dynamic and individualized process.

2. Strategic Positioning of Technologies :

Family	Objective	Key Data	Ecosystem
Consumer Wearables	24/7 continuous monitoring	HRV, sleep, temperature	WHOOP 4.0, Oura Gen3
Validated Sports Sensors	Lab-grade measurement in field	VO ₂ , force, lactate	VO ₂ Master, Lactate Plus
AI & Machine Learning	Prediction & prescription	Fatigue, injury	Athletica, Catapult Vector
Immersive Environments	Simulation & feedback	Thermal load, altitude	Hypoxico, ClimaCab

3. Wearables – Performance and Validity :

Device	Variables	Validity vs. Gold Standard	Field Use
WHOOP 4.0	HRV (r = 0.93 vs. ECG), Sleep (r = 0.85 vs. PSG)	HRV-guided training	24/7 wristband
Oura Gen3	Skin temperature (± 0.1 °C), SpO ₂ (± 2 %)	Fever & altitude monitoring	Ring
Polar Vantage V3	Wrist-based VO ₂ (r = 0.95 vs. CPET)	Cycling & running without mask	Wrist
Catapult Vector S7	GPS 10 Hz, accel 1000 Hz	Force plate & radar	Back / harness

4. Artificial Intelligence – Pipelines and Models :

AI Task	Algorithm	Input	RMSE / AUC	Platform
Injury Prediction	Gradient Boosting	GPS + HRV + RPE	AUC = 0.91	Athletica
Load Optimization	LSTM time series	365 days of data	RMSE 2.3 %	Catapult AMS
VO ₂ max Estimation	Random Forest	CMJ + HR + age	r = 0.94	VO ₂ Master Cloud
Local Fatigue	Visual CNN	240 Hz CMJ video	RMSE 1.8 cm	Dartfish AI

5. Patch Sensors and Microfluidics :

Technology	Variable	Precision	Application
Gatorade Gx Sweat Patch	[Na ⁺], [K ⁺]	± 5 mmol/L	Real-time hydration
Lactate Plus Patch	Capillary lactate	± 0.1 mmol/L	Lactate training
Corti-Patch	Salivary cortisol	± 1 nmol/L	Competition stress
Temp-Patch (Blue Spark)	Core temperature	± 0.05 °C	Hyperthermia

6. Simulation Environments

System	Controlled Parameters	Precision	Use
Hypoxico Altitude Tent	FiO ₂ 10–21 %	± 0.1 %	3000 m acclimatization
ClimaCab Heat Chamber	20–45 °C, 20–90 % RH	± 0.5 °C	Thermal testing
VR Choking Lab	Immersive anxiety stress	r = 0.90 vs. real	Mental preparation
Oculus + Kinect	Real-time 3D feedback	Latency < 20 ms	Sports technique

7. Cloud Integration and Dashboards

Platform	Features	API	Indicative Price
Catapult AMS	GPS + HRV + AI injury	Yes	10,000 €/team/year
Athletica	AI load prescription	Yes	50 €/month/athlete
TrainingPeaks WKO5	PPM, mFTP models	Yes	20 €/month
PowerBI Dashboard	Custom reports	Yes	Free + MS license

8. Data Chain – 2024 Workflow :

1. **Collection:** GPS + IMU + HRV + lactate patch → BLE → Smartphone.
2. **Transmission:** 4G/5G → AWS / Azure Cloud.
3. **Cleaning:** Kalman algorithm + outlier detection.
4. **Modeling:** ML model retrained every 24 h.
5. **Feedback:** Coach dashboard + SMS alert if threshold exceeded.

9. Validation and Regulatory Compliance :

Criterion	Standard	Tools
GPS Accuracy	FIFA Quality Pro < 0.5 m	Catapult Vector
GDPR	AES-256 encryption, dynamic consent	AWS KMS
CE / FDA	Class IIa medical sensors	VO ₂ Master Pro

10. Field Implementation Example – Pro Team :

Equipment	Variable	Frequency	Action
WHOOP 4.0	HRV, sleep	24/7	HRV-guided load
Catapult Vector	GPS 10 Hz	Training	ACWR & AI injury
Lactate Patch	[La ⁻]	2×/week	Lactate adjustment
VR Mental	Pre-match stress	1×/week	Neurofeedback

11. Limitations and Perspectives :

- **AI Freshness:** Models retrained every 3 months.
- **Cost:** ROI achieved if ↓ injuries > 5 % (FC Barcelona, 2023).
- **Ethics:** Explainable AI (XAI) transparency required by federations.

12. New Trends and Technological Innovations :

- **Sports Performance Analysis:** Sensors, cameras, AI for real-time data (sophisticated algorithms for insights). Wireless synchronization via connected devices (watches, bands) for clear recovery visibility.
- **Tailored Training:** Dedicated platforms for personalized tracking (precise progress). Algorithms predict tactics (optimal preparation).
- **Injury Prevention:** Biometric monitoring, training load, recovery (risk alerts).
- **Future Innovations:** VR for realistic virtual environments. Wearables, AI, GPS evolve (performance improvement).
- **Fan Experience:** AI enhances with stats, insights (game understanding).
- **Ethics and Transparency:** Ethical standards, data protection (sport authenticity, privacy).
- **AI Technology and Evaluation:** Smartwatches/trackers (HR, steps, distance, calories, sleep, stress). Smart clothing (shirts for HR, breathing). Smart shoes (gait, stride length, foot strike). Portable ECG monitors (cardiac activity, patches/straps). Portable blood pressure monitors (continuous BP). Smart glasses (posture, movements). Smart helmets (head impact force,

rotational acceleration, concussions). These technologies collect data during training, analyzed for insights (performance, progress, improvement areas, injury risks).

13. Integration into Practice :

- **Planning:** Use wearable/simulation data for training cycles (pre-competition tapering).
- **Real-Time Monitoring:** Session adjustments via GPS/HR.
- **Injury Prevention:** Overload detection via AI (ACWR >1.5 alert).
- **Tactical Optimization:** Video/VR analysis for team sports decisions.
- **Personalization:** AI-adapted programs (genetic, biometric profiles).

14. Context and Importance of Integration :

Traditional evaluation via field tests (e.g., Yo-Yo Test, CMJ) provides valuable snapshots but punctual of athlete capacities. Wearable technologies, in contrast, collect continuous data during training and competition, offering a longitudinal view.

1. Limitations of Field Tests :

- o Frequency: Conducted monthly or quarterly, they miss daily variations.
- o Context: Less representative of real match conditions.
- o Delayed Analysis: Results often processed post-session, limiting reactivity.

2. Advantages of Wearable Technologies :

- o Real-Time: Instant monitoring (HR, GPS, accelerometry).
- o Ecology: Measurements in real conditions (training, match).
- o Personalization: Individualized data per athlete.

3. Integration Objective: Combine field test precision (e.g., VMA, power) with wearable continuity for holistic monitoring, enabling immediate load adjustment and detection of overtraining or injury risks.

15. Available Wearable Technologies :

Technology	Measured Parameters	Examples	Precision
GPS Watches	Distance, speed, HR, HRV	Garmin Forerunner, Polar Vantage	± 1 m (GPS), ± 2 bpm (HR)
Heart Rate Belts	HR, HRV	Polar H10, Whoop Strap	± 1 bpm
Inertial Sensors	Acceleration, external load	Catapult One, STATSports Apex	± 0.1 g
Pulse Oximeters	SpO ₂ , HR	Masimo MightySat	± 2 % (SpO ₂)
Biometric Patches	Sweat, [Na ⁺], Tcore	Gx Sweat Patch, Core Body Temp	± 0.5 °C (Tcore)

• **Applications :**

- o GPS/Accelerometers: Quantify external load (distance, sprints, accelerations).
- o HR Belts/HRV: Assess internal load (physiological stress, recovery).
- o Patches: Monitor hydration and thermoregulation in extreme conditions.

16. Data Integration Methodology :

1. Step 1: Establish Baseline via Field Tests :

- o Tests: VMA (Yo-Yo IR1, VAMEVAL), CMJ, 20 m sprint, 1RM squat, RPE.
- o Objective: Define individual thresholds (e.g., VMA 17 km·h⁻¹, CMJ 45 cm).
- o Example (Football): Yo-Yo IR1 provides VMA to calibrate GPS intensity zones.

2. Step 2: Continuous Collection via Wearables :

- o Protocol: Continuous wear (training, match, recovery).
- o Key Data
 - o External Load: High-intensity distance (>19.8 km/h), PlayerLoad (Catapult).
 - o Internal Load: Avg/max HR, nocturnal HRV, post-session RPE.
 - o Tools: Google Forms (RPE), wearable apps (Garmin Connect, Polar Flow).

3. Step 3: Data Fusion :

- o Analysis Tools: PowerBI, Tableau for visualizations (radars, curves).
- o Method: Compare wearable data to field test thresholds.
 - o Example: If VMA = 17 km·h⁻¹, program alerts if distance >80 % VMA exceeds 20 min/session.
 - o Statistics: Z-scores to compare individual %-performance to team norms.

4. Step 4: Longitudinal Monitoring and Adjustments :

- o Frequency: Daily analysis (wearables), monthly (field tests).
- o Adjustments: Modify volume/intensity if HRV ↓ 5 % or RPE > 7/10.
- o Example: Footballer with low HRV → reduce external load (sprints).

17. Practical Applications by Discipline :

1. Football (Team Sport) :

- o Field Tests: Yo-Yo IR1 (VMA), CMJ (power), 505 Agility, RPE.
- o Wearables: GPS Catapult (distance, sprints), Polar H10 (HR, HRV).
- o Integration
 - o Baseline: VMA 17 km·h⁻¹, CMJ 45 cm.
 - o Real-Time Monitoring: Alert if high-intensity distance >25 % total session.

- PowerBI Dashboard: Z-score radar (VMA, CMJ, sprint) vs GPS data.
- Impact: Load adjustment by position (e.g., winger vs defender).

2. Cycling (Endurance) :

- Field Tests: VAMEVAL (VMA), PMA test (home-trainer).
- Wearables: Garmin Edge (power, HR), Core Body Temp (Tcore).
- Integration
 - Baseline: PMA 350 W, VMA 18 km·h⁻¹.
 - Monitoring: Alert if Tcore > 39 °C in heat camp.
 - Analysis: Correlate GPS power vs PMA test for planning.

3. Judo (Combat Sport) :

- Field Tests: 1RM squat, grip dynamometer, Special Judo Fitness Test (SJFT).
- Wearables: Whoop (HRV, sleep), Gx Sweat Patch ([Na⁺]).
- Integration
 - Baseline: Grip 55 kg, SJFT index < 12.
 - Monitoring: Reduce intensity if HRV ↓ 5 % or [Na⁺] sweat ↑ 20 %.
 - Visualization: PowerBI table (strength, endurance, recovery).

18. Safety Protocols and Risk Management :

• Automatic Alerts

- HR > 90 % max, HRV ↓ 5 %, Tcore > 39.5 °C → SMS to staff.
- Example: Polar Flow notifies if HR >180 bpm for >10 min.
- Monitoring: Cloud dashboard (PowerBI) for real-time tracking (HR, SpO₂, PlayerLoad).
- Emergency Kit: Portable O₂ (altitude), ice vests (heat), electrolytes.

19. Validation and Reliability of Integrated Data :

• Validity

- Content: Wearables measure parameters aligned with field tests (e.g., HR vs VMA).
- Criterion: Correlation between GPS speed and 20 m sprint (r > 0.85).
- Predictive: Low HRV predicts overtraining risk (80 % sensitivity).

• Reliability

- Test-retest: ICC > 0.90 for HR (Polar H10), ± 1 m for GPS (Catapult).
- Inter-operator: Standardization via apps (e.g., Garmin Connect).
- Update: Annual wearable recalibration, synchronization with field tests.

20. Digitalization Tools :

- Google Forms + QR Code: Post-session RPE entry.

- PowerBI/Tableau: Z-score radars, longitudinal curves (e.g., HRV, PlayerLoad).
- Wearable Apps: Polar Flow, Whoop, Garmin Connect for CSV export.
- Example Dashboard
 - o Axes: VMA, CMJ, sprint, HRV, RPE.
 - o Visualization: Strengths ($Z > +0.5$), weaknesses ($Z < -0.5$).

21. Summary of Indicators and Protocols :

Technology	Parameters	Precision	Use
GPS Catapult	Distance, speed, PlayerLoad	± 1 m	External load
Polar H10	HR, HRV	± 1 bpm	Internal load
Gx Sweat Patch	[Na ⁺], sweat	± 10 %	Hydration
Core Body Temp	Tcore	± 0.5 °C	Thermoregulation

Field Test	Wearable	Integration	Alert Threshold
Yo-Yo IR1	GPS Catapult	High-intensity distance vs VMA	>25 % session
CMJ	Catapult One	Jump power vs PlayerLoad	↓ 10 %
20 m Sprint	Garmin Edge	Max speed vs GPS	± 5 %

Conclusion :

The 2025 digital ecosystem combines wearables, AI, and simulations for ultra-precise and predictive monitoring. The key lies in seamless data integration and continuous validation. These tools revolutionize sports evaluation, offering accurate, objective, and personalized methods. AI transforms performance analysis, injury prevention, strategy improvement, and fan experience enhancement. The integration of field tests with wearable technologies enables individualized training plans, early risk detection (overtraining, dehydration), and performance optimization. Digital tools (PowerBI, Google Forms) and wearables (Garmin, Polar, Catapult) facilitate real-time analysis, turning raw data into strategic decisions. Navigating this digital era requires caution, ensuring fairness and data protection.

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Practical Exercises :

- **Case Study:** U23 Cycling Team

- o **Budget:** 15 k€/season.

- o **Objectives:** ↓ injuries 10 %, ↑ performance 3 %.

- o **Questions**

1. Select trio of sensors (budget, ROI).
2. Design cloud workflow.
3. Define success KPIs.

- **Case Study:** U20 Rugby Team (20 players)

- o **Duration:** 30 min | **Tools:** Google Forms, PowerBI, Catapult One, Polar H10.

- o **Questions :**

1. Identify 4 field tests for baseline.
2. Choose 3 wearable indicators for daily monitoring.
3. Plan data integration (protocol).
4. Build PowerBI dashboard.