Data and Analytics in Sports Medicine

Is your data driving action?
Introduction and Disclaimers

Dr. Dave Hogarth PT, DPT
dhogarth@fusionetics.com
Senior Director of Clinical Services, Education and Research - Fusionetics

Content developed in collaboration with:

Dr. Barnett Frank PhD, ATC
Director of Performance Science
Utah Jazz

Dr. Darin Padua PhD, ATC
Chair Dept Exercise and Sport Science
UNC-Chapel Hill

Fusionetics is a Software as a Service platform which includes testing, analytics and programming for movement, performance, and recovery scenarios.
Session Objectives

• After participating in this lecture, the learner will:
  • Recall valid and reliable measures of movement quality and state how to use them for actionable corrective interventions.
  • Provide examples of valid and reliable measures of internal training load and describe their utility in the management of sport training programs.
  • Analyze and interpret movement quality, internal and external training load, and performance test data to aid program development, management, and modification.
Data Collection Types

- Movement Quality
  - Primary Movement Patterns
  - Local Range of Motion
- Load Monitoring
  - Training Load
    - External
    - Internal
- Readiness
  - Subjective / Internal
  - Objective / Internal
  - Objective / External

Data Digestion Methods

- Empirical
  - Pre-programmed periodization by calendar and time
  - They look tired.
- Technology Enabled
  - They are recovering slower
  - Their loads are not balanced
  - Their performance is down
The Guiding Questions...

Is this a piece of data that I can do something about?

How easy is this data to collect?

How quickly can it be interpreted?

How does it affect the plan?

Who is involved in the decision?
- Athlete
- Sport Medicine Staff
- S&C/Sport Science/Performance Staff
- Sport Coach
Movement Assessments

Screens
Scoring Models
Data Reporting
Actionable Analytics
Why measure movement quality?

Does movement quality really matter?

**Movement Quality:** LESS and Double / Single Leg Squat

**Performance:**
- Modified T-test – agility
- Seated Rotational Medicine Ball Throw – core power
- Single Leg Triple Hop – lower body power
- 40-yard Sprint – speed


Does movement quality really matter?

**Impacts Functional Performance**

- Poor movement efficiency & control
- Greater soft tissue stress / load
- Increased level of fatigue
- Increased risk of injury
- Decreased durability

**Impacts Recovery & Durability**

- Decreased regrowth & regeneration
- Negative energy balance
- Tissue break down

Gabbett et al, 2004
Movement Data: What is actionable for us?

**Basic Movement Patterns**
- Functional Movement Screen
- Movement Efficiency Test
- Landing Error Scoring System

**Sport Movement Patterns**
- Performance Test Battery
- “Combines”
- Sport Skill Tests
- Sport Statistics
Movement Assessments

- Functional Movement Screen
- Landing Error Scoring System
- Movement Efficiency Test
Functional Movement Screen

- Developed to bridge gap of PPE & performance tests

- 7 movement patterns
  - Squatting
  - Stepping
  - Lunging
  - Reaching
  - Leg raising
  - Push up
  - Rotary stability

### Scoring of the FMS

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
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<tbody>
<tr>
<td>3</td>
<td>Perform pattern as directed</td>
</tr>
<tr>
<td>2</td>
<td>Perform pattern with compensation / imperfection</td>
</tr>
<tr>
<td>1</td>
<td>Unable to perform pattern</td>
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<tr>
<td>0</td>
<td>Pain with pattern regardless of quality</td>
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</tbody>
</table>

Total Score = 21 to 0
Developed to identify high risk individuals for ACL injury

17 item checklist of movement impairments (yes/no)

**Initial Contact**
- Knee flexion
- Knee valgus
- Hip flexion
- Trunk flexion
- Lateral trunk flexion
- Toe in & Toe out
- Stance width
- Ankle plantarflexion

**Displacement**
- Knee flexion
- Knee valgus
- Hip flexion
- Trunk flexion
- Overall sagittal

**Overall impression**

**Total Score = 0 to 17**
Squat Components of Movement Efficiency Test

- Developed to identify movement impairments & underlying causes
- 7 Movement Patterns
- 60 point checklist of movement impairments (yes/no)

**Overhead Squat**
- Knee moves in
- Knee moves out
- Excessive trunk flexion
- Toe out
- Low back arches
- Arms fall forward
- Asymmetrical wt shift
- Foot flattens
- Heel lift

**Single Leg Squat**
- Hip hike
- Hip drop
- Knee moves in
- Trunk inward rotation
- Trunk outward rotation

**Identify underlying muscle Imbalance**

**Scoring:** less important as the checklist is linked to an intervention.
# Reliability

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Intra-rater</th>
<th>Inter-rater</th>
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</thead>
<tbody>
<tr>
<td>FMS (total score)</td>
<td>Good to Excellent</td>
<td>Good to Excellent</td>
</tr>
<tr>
<td>FMS (individual tests)</td>
<td>Poor to Good</td>
<td>Poor to Excellent</td>
</tr>
<tr>
<td>LESS (total score)</td>
<td>Good to Excellent</td>
<td>Good to Excellent</td>
</tr>
<tr>
<td>LESS (individual items)</td>
<td>Mod to Excellent</td>
<td>Mod to Excellent</td>
</tr>
<tr>
<td>Overhead &amp; Single Leg Squat (individual items)</td>
<td>Good to Excellent</td>
<td>Mod to Excellent</td>
</tr>
</tbody>
</table>

Hirth & Padua, 2007; Padua et al, 2009; Minick et al, 2010; Butler et al, 2011; Schneiders et al, 2011; Teyhen et al, 2012; Gribble et al, 2012; Onate et al, 2012; Smith et al, 2012; Cornell, 2018
Evolution of Movement Assessment

- Transition to full patho-kinesiologic model
  - Not just identifying “high risk”
  - Quality data must drive solutions

- Focus on specific movement impairments
  - Link movement impairments to underlying mechanism
    - Muscle imbalances
    - Joint restrictions

- Develop targeted interventions

  • Total scores can be used for identifying “high risk”
  • Specific movement impairments must also be identified

  • Movement assessment leads to mechanism identification
  • ROM, strength & joint restrictions contribute
Range of Motion Assessment

• Key joint metrics:
  • Ankle DF
    • Lack of sagittal plane ankle motion necessitates additional frontal and transverse plane motion to compensate
  • Hip Internal Rotation
    • Lack of Hip IR associated with higher incidence of knee injury
  • Hip Extension
    • Key Movement in Janda’s Lower Crossed Syndrome
  • Glenohumeral Internal Rotation / Shoulder Total Arc of Motion (ER-IR at 90)
    • Loss of total arc normally via dominant side IR associated with shoulder pathology

Gomes, 2008; Mills et al 2015; Malliaras et al 2006; Kibler et al 2012; Wilk et al 2011
Movement Data Reporting

• Individual
  • What movement patterns are most important to improve?
    • Ankle Mobility
    • Knee Stability
    • Hip Mobility
    • L-Spine Stability
    • Dynamic Scapular and Shoulder Control

• What is this person’s anticipated movement ceiling?
  • Structural limitations.
  • Injury History
## Biomechanical Analysis

### 2-Leg Squat: Side View

<table>
<thead>
<tr>
<th>Angle at Bottom of Squat</th>
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<tbody>
<tr>
<td>Shoulder Extension</td>
<td>138.5°</td>
</tr>
<tr>
<td>Hip Flexion</td>
<td>94.3°</td>
</tr>
<tr>
<td>Knee Flexion</td>
<td>114.4°</td>
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<tr>
<td>Ankle Flexion</td>
<td>43.2°</td>
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</tbody>
</table>

### Video Quality Rating

VQR = % of frames in video reporting high quality data.

Data quality is impacted by events such as joint occlusions (i.e. legs crossing over in front of each) or body outside of field of view.

### Arms Forward Index

<table>
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% of time subject demonstrates Arms Forward compensation during test

### Forward Lean Index

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% of time subject demonstrates Forward Lean compensation during test

### Trunk vs. Shin Ratio

-31.9°

Greatest angular difference between shin and trunk angles

<table>
<thead>
<tr>
<th>Greatest angular difference between shin and trunk angles</th>
<th>Trunk Upright</th>
<th>Trunk : Shin Parallel</th>
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### Biomechanical Analysis

#### 1-Leg Squat: Front

<table>
<thead>
<tr>
<th>1-Leg Squat: Front View</th>
<th>RIGHT</th>
<th>LEFT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knee: Frontal Plane Projection Angle</td>
<td>14.6°</td>
<td>-11.0°</td>
</tr>
</tbody>
</table>

**Frontal Plane Projection Angle** = acute angle between thigh and extension of the tibia.
- The most valgus position is reported.
- It's optimal to have ranges near zero (0)

**Positive Value = Knee Out**
**Negative Value = Knee In**

**RIGHT**

**Knee Stability Index**

<table>
<thead>
<tr>
<th>% of Time</th>
<th>Knee Out</th>
<th>Neutral</th>
<th>Knee In</th>
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**LEFT**

**Knee Stability Index**

<table>
<thead>
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<th>% of Time</th>
<th>Knee In</th>
<th>Neutral</th>
<th>Knee Out</th>
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<tbody>
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**RIGHT**

**Trunk Stability Index**

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**LEFT**

**Trunk Stability Index**

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**Video Quality Rating**

- **RIGHT**: 88%
- **LEFT**: 86%

VQR = % of frames in video reporting high quality data.
Data quality is impacted by events such as joint occlusions (i.e., legs crossing over in front of each) or body outside of field of view.
Actionable Analytics

• Individual
  • Map Movement and Motion data directly to the corrective intervention:
    • Exercise
      • Daily Key Stretches
    • Behavior
      • Posture / Positions
    • Manual Therapy
      • What is their personal “keystone” joint
    • Modality
Actionable Analytics

• Group/Team
  • Are there common movement inefficiencies across the whole team?
    • Typical Patterns present by position?
  
• Can we program in groups to optimize coach to athlete efficiency?
Actionable Analytics

Movement Compensation Incidence Ratio
1-Leg Squat

- Loss of Balance:L
- Loss of Balance:R
- Uncontrolled Trunk:L
- Uncontrolled Trunk:R
- Knee:Moves Out:L
- Knee:Moves Out:R
- Knee:Moves In:L
- Knee:Moves In:R
- Foot Flattens:L
- Foot Flattens:R

Movement Compensation Incidence Ratio
2-Leg Squat

- Arms Fall Fwd:L
- Weight Shift:L
- Weight Shift:R
- Back Rnd:L
- Back Arch:L
- Fwd Lean:L
- Knee:Moves Out:L
- Knee:Moves Out:R
- Knee:Moves In:L
- Knee:Moves In:R
- Heel Lifts:L
- Heel Lifts:R
- Foot Flattens:L
- Foot Flattens:R
- Foot Turns Out:L
- Foot Turns Out:R

Legend:
- Std Dev
- Average Rate of Incidence
Why link movement quality and training load?

• “Individuals with poor movement profiles experience greater mechanical loads compared to individuals with excellent movement profiles.”

• “A poor movement profile is associated with greater overall concentrations of circulating cortisol, representative of greater systemic stress”

Frank et al, J Sci Med Sport, 2018
Training Load

Monitoring Tools
Exposure Types
Response Model
Recovery Behaviors
Training Load Basics

• What
  • Measuring the demand of the training on the body
    • Micro: Single Session / Single Day
    • Macro: Weekly → Monthly
    • Meso: Annual → Quadrennial → Long Term Athlete Development

• Why
  • Physiologic Availability
  • Social-Emotional Tolerance

• How
  • Internal Load – How do they feel?
  • External Load – What did they do?
Fatigue and Performance

Muscle Performance
- Muscle strength
- Muscle power
- Muscle contractile velocity

Exercise Performance
- Speed
- Power output
- Balance / Stability
- Movement
- Distance Covered

Competition Performance
- Work rate during competition
- Decision making
- Anticipation
Dynamic Load Response Model

ANALYTICS
Optimize response to loading.
Understand influence of modifiers on response to loading
- Track Load
- Monitor Response
- Modulate Load and Modifiers to Achieve Optimal Response

Load
- Magnitude / Intensity
- Duration
- Frequency

Adaptation

Response
- Perceptual
- Physiological
- Performance
- Movement
- Injury

Modifiers
- Movement
- Rest
- Re-Fuel
- Recovery Behaviors

Repeat Participation
+ve
neutral
-ve

Padua et al 2017
Over-Training vs. Under-Recovery

Over-training is a misnomer

- Suggests strenuous exercise is a primary cause of fatigue resulting in progressive decreased performance and increased injury risk

Strenuous exercise is the stimulus for positive physiologic responses (anabolic → growth / gains)

- Anabolic responses do not occur during exercise
- Anabolic responses occur during rest with appropriate fuel

Strenuous Exercise + Under-Recovery = 

↑Fatigue  
↓Performance  
↑Injury

YOU CAN DO SOMETHING ABOUT THIS PART  
TO PREVENT THIS PART
Training Load and Recovery Behaviors

Strenuous Exercise + Optimum Recovery = Positive Physiologic Response “Super-compensation”

Catabolic Response

Anabolic Response
Monitoring for Under-Recovery

**Surveys / Questionnaires**

- **Rating of Perceived Exertion (RPE)**
  - Quantify training load and intensity
  - Indicator of adaption to training load
  - One single question

- **Profile of Mood States**
  - 65-item questionnaire to quantify mood disturbances

- **Recovery-Stress Questionnaire for Athletes (RESTQ-Sport)**
  - 77-item questionnaire to assess recovery-stress
  - Indicates extent of physical/mental stress and whether or not person is capable of using recovery strategies
Monitoring for Under-Recovery

Performance

• Decreased maximal strength
• Decreased performance during stress tests
  • Speed-endurance or repeated sprint ability (e.g. Yo-yo intermittent recovery test)
• Need 48 hours of rest between last training session / game for performance testing
  • Separate drop in muscle glycogen stores post-training from over-reaching/over-training
• May not be practical to assess for maximal effort in-season
Monitoring for Under-Recovery

**Behavioral and Psycho-Social**

- Sleep Quality
- Sleep Length
- Stress Level
- Soreness Location and Intensity
- Overall feeling of “Readiness”
- Altered mood state
- Reports of lethargy (“tired” “heavy legs”)
- Sleep disturbances
Monitoring for Under-Recovery

• Need individual assessment

• Main goal is to identify athletes whose recovery-stress states are out of balance with the training/game demands
  • Training Load > Recovery Behavior

• Over-reaching occurs over a longer period of time due to imbalances in recovery-stress
  • Thus, key is to identifying people at risk for over-reaching/fatigue due to poor recovery practices (under-recovery)
  • Then target these individuals for appropriate recovery interventions based on their current recovery behaviors
Internal Load Monitoring

- Record the following information: (training, practices & games)
  - RPE within 30 minutes of training
    - Focus on feeling of exertion (not pain or shortness of breath)
  - Total minutes of exercise

RPE $\times$ Minutes of Exercise = Training Load

**Internal Training load strongly correlated to injury rates**

Ultimately there are mechanical loading factors that contribute to the overall physiological load an athlete experiences – which may further impact work rate & capacity.
External Load: What tools do we have?

- **Player motion assessment** –
  - GPS
  - Accelerometry
  - Video data

- **Physiological variables**
  - Heart rate characteristics / tracking
# Data Collection Devices

## TABLE I Analytic Devices and Their Application

<table>
<thead>
<tr>
<th>Device</th>
<th>Application</th>
<th>In-Market Devices</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wearable devices</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accelerometer</td>
<td>Measures acceleration of an individual or body part during a specific movement. It also assesses energy expenditure and sleep patterns</td>
<td>FitBit (Fitbit), Nike + FuelBand (Nike), Misfit Ray (Misfit Wearables), and Microsoft Band (Microsoft)</td>
</tr>
<tr>
<td>Global positioning system (GPS) device</td>
<td>Locates the athlete on the field and measures changes in acceleration</td>
<td>Vivotif and Forerunner (Garmin), Surge (Fitbit), and Polar M200 (Polar Electro)</td>
</tr>
<tr>
<td>Radio-frequency identification (RFID) tracking system</td>
<td>Measures speed, acceleration, deceleration, distance traveled, and alignment for a specific athlete</td>
<td>Zebra Technologies</td>
</tr>
<tr>
<td>Heart rate (HR) monitoring device</td>
<td>Measures an athlete’s heart rate and variability in heart rate during specific movements in training and competition</td>
<td>Zoom HRV (Salutron), Polar H7 (Polar Electro), Suunto Ambit3 (Suunto Oy), and WHOOP Tracker (WHOOP)</td>
</tr>
<tr>
<td>Integrated platform</td>
<td>Measures multiple movements and physiological biomarkers at the same time</td>
<td>AMS by Catapult (Catapult Sports), Zephyr Performance Systems (Zephyr Technology), and Viper Software (STATSports)</td>
</tr>
<tr>
<td><strong>Nonwearable devices</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Camera-based monitoring system</td>
<td>Captures player movements on the field including acceleration, distance traveled, and ball position in real time</td>
<td>SportVU (STATS)</td>
</tr>
</tbody>
</table>

Sikka et al, J Bone Joint Surg, 2019
A Note on Heart Rate Variability

What is it?

Measure of beat-to-beat timing variation
- Commonly R-R interval

Marker of autonomic nervous system function
- Relative activity of parasympathetic vs. sympathetic system function

Higher variability represents increased “health status” / function

APPLICATION

- Throughout a season
- High risk athletes
- Field Sport & Endurance athletes
- Morning upon waking

Buchheit 2014
External Load Measures

• **What they can tell us?**
  • How much time spent in a specific activity type
  • Level of work rate / intensity
  • Total percentage of activity
  • Mechanical load exposure estimation

• **Actionable Items for Staff**
  • Managing mechanical load exposure during **return to play**
  • Determining if athlete can achieve and sustain certain load variables
  • Training specificity based on observed loads
## External Load Measures

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Utility</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Absolute/Total Distance</strong></td>
<td>Total length of path of travel during activity session</td>
<td>• Total motion in activity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Basic cumulative load</td>
</tr>
<tr>
<td><strong>Relative Distance</strong></td>
<td>Absolute distance per unit of time for entire activity session</td>
<td>• Measure of intensity for a practice, game, advanced rehab</td>
</tr>
<tr>
<td><strong>Speed</strong></td>
<td>Instantaneous rate of travel</td>
<td>• Measure of intensity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Can be used to track time spent in specific intensity level &amp; activity type</td>
</tr>
</tbody>
</table>
## External Load Measures: Accels-Decels

<table>
<thead>
<tr>
<th>Acceleration</th>
<th>Description</th>
<th>Utility</th>
</tr>
</thead>
</table>
| **Linear**   | Rapid changes in direction of travel: | • Manage number of exposures to high magnitude forces  
               • Determine asymmetrical loading patterns during sport activity |
| Force = Mass*Acceleration | • Cutting  
                        • Starting / stopping  
                        • Side-to-side loading | |
| \(\uparrow\) Acceleration = \(\uparrow\) Force / Mass | | 

**Valid Estimation of Force Exposure**

| Collision / Impact | Systems use algorithms / calculations to determine: | • Manage number of athlete exposures to impacts during activity session  
                   • Track magnitude of athlete impacts |
|--------------------|---------------------------------------------------|---------------------------------------------|
|                    | • Player-to-player  
                        • Player-to-ground | |

Force = Mass*Acceleration

\[\uparrow \text{ Acceleration} = \uparrow \text{ Force} / \text{ Mass}\]
Optimal Times to Apply

Relatively High Internal Load
- Deconditioned
  - Reconditioning
- High intensity
- Training congestion
- Environmental factors

Moderate & Consistent Internal Load
- Planned training & competition schedule
- Low intensity training
- Conditioning maintenance

Relatively High Internal Load
- Unplanned training & competition congestion
- Cumulative load
- Travel

Pre-Season Training Conditioning
- Direct gradual load exposure
- Returning to play*
- Load disparity
- Trend analysis

Mid-Season Competition
- Returning to play
  - Able to meet sport demands
  - “Pitch count mentality”
- Load disparity

Post-Season Competition
- Minimal actionable items
- Simple monitoring
- May direct recovery behaviors based on mechanical loads

*Returning to play
Load Balance

External Training Load (ETL)

- **LOW**
  - LOW INTERNAL LOAD
  - LOW EXTERNAL LOAD
  - Low load periods – off-season / recovery
  - Potential for under-training stimulus – periodization

- **HIGH**
  - LOW INTERNAL LOAD
  - HIGH EXTERNAL LOAD
  - Super-compensated athlete
  - However; potential for under-training stimulus – plateau

- **HIGH**
  - HIGH INTERNAL LOAD
  - LOW EXTERNAL LOAD
  - Warning sign - Detailed monitoring
  - Recovery behavior promotion

- **LOW**
  - HIGH INTERNAL LOAD
  - HIGH EXTERNAL LOAD
  - Detailed monitoring
  - Potential for super-compensation stimulus
Training Load and Injury Risk

- High training loads are strongly associated with increased lower extremity injury rates \( (r=0.86) \) *Gabbett, J Sports Sci, 2004*
  - Contact \( (r=0.82) \) & non-contact \( (r=0.82) \) injuries
  - \( \downarrow \) Training loads \( \Rightarrow \) \( \downarrow \) Injury rates *Gabbett, Br J Sports Med, 2004*
    - No compromise in performance improvements

---

**Supporting Evidence**

**Training Load and Injury Risk**

![Graph showing the relationship between training load and injury rate across different training phases.](image)

*Gabbett & Jenkins, J Sci Med Sport, 2011*
Post Activity: Monitor Training Load

- Record the following information: (training, practices & games)
  - RPE within 30 minutes of training/game
    - Focus on feeling of **exertion** (not pain or shortness of breath)
  - Total minutes of exercise

\[
\text{RPE} \times \text{Minutes of Exercise} = \text{Training Load}
\]

Training load strongly correlated to injury rates (r=0.86)

Acute to Chronic Training Load Concept

↑Internal Load →
↑ Injury Rates
(r = 0.86)

↑ Injury risk if acute to chronic load ratio ≥ 1.5

Also ↑ risk if < 0.5

Figure 6  Guide to interpreting and applying acute:chronic workload ratio data. The green-shaded area ('sweet spot') represents acute:chronic workload ratios where injury risk is low. The red-shaded area ('danger zone') represents acute:chronic workload ratios where injury risk is high. To minimise injury risk, practitioners should aim to maintain the acute:chronic workload ratio within a range of approximately 0.8–1.3. Redrawn from Blanch and Gabbett.46

Data Digestion

• What are the performance goals?
  • Short term for the session and long term for the training cycle

• Does the data point relate directly to a decision?
  • When does that decision need to be made?

• Is it nice to know or do you need to know?

• Is the athlete in a rehab phase or training phase?
How Sports Medicine Professionals can Leverage Load Information

• **Seasonal considerations**
  • Gradual objective load exposure

• **Rehab & reconditioning**
  • Training specificity
    • Match demand of sport

• **Return to play**
  • Load exposure management
  • Load achieved

• **Optimally paired with internal load**
Recovery and Readiness Questions

• What are some easy questions we can ask our athletes?

• Sleep: Quality is the easiest answer.
• Stress: Creates opportunity to be introspective.
• Readiness: In relation to “game time”
• Soreness: Links to sport medicine interventions and cross reference with movement quality.
REST / Sleep Quality

TEST

Question:
How well did you sleep last night?

Scale:
1. Very Good
2. Fairly Good
3. Average
4. Fairly Bad
5. Very Bad

ANALYZE

Answer : Points : Status
1 : 5 : Green
2 : 4 : Green
3 : 3 : Yellow
4 : 2 : Yellow
5 : 1 : Red

Report Output:
➢ R, Y, G = Points/Status (Icon)
  ➢ G = 5, 4
  ➢ Y = 3, 2
  ➢ R = 1
➢ Show Sleep Quality
  5-1 with happy to sad face

PROGRAM

Intervention:
Provide sleep quality status and recommend action (with image) based on calculation (Y, R only).
✓ You should get a quality sleep

Education:
• What’s wrong?
• Why is it important?
• How to make change?

Application:
Assign intervention to training calendar. Provide messages for that next day and 4 days out.
Stress Index

TEST

Question:
How would you rate your stress level today?

Scale:
1. Feeling great, stress free
2. A little stress, but pretty normal
3. Moderately stressed
4. Stress is starting to build up and getting pretty bad
5. Super Stressed

ANALYZE

Answer : Points : Status
1 : 5 : Green
2 : 4 : Green
3 : 3 : Yellow
4 : 2 : Red
5 : 1 : Red

Report Output:
➢ R, Y, G Status (Icon)
  ➢ G = 5, 4
  ➢ Y = 3
  ➢ R = 2, 1
➢ Show Stress level
  5-1 with Happy to sad face

PROGRAM

Intervention:
Provide stress level status and recommend action (with image) based on calculation (Y,R only).
✓ You should try to eliminate stress from your life

Education:
• What’s wrong?
• Why is it important?
• How to make change?

Application:
Assign intervention to training calendar.
Encouraging messages for next day and 3 days out. Refer appropriately.
Readiness to Perform

**TEST**

**Question:**
How ready your body feel today?

**Scale:**
1. Feels awesome, I can do anything
2. Better than normal
3. Average
4. Sore and tired, wish I could rest
5. Terrible, very fatigued and/or in pain.

Answer : Points : Status

1 : 5
2 : 4
3 : 3
4 : 2
5 : 1

![Scale emoticons: Happy, Neutral, Sad]

**ANALYZE**

**Report Output:**
- R, Y, G Status (Icon)
  - G = 4, 5, 3
  - Y = 2
  - R = 1
- Show Function Level
  - 1-5 with happy to sad face

**PROGRAM**

**Intervention:**
Provide Function status and recommend action (with image) based on calculation (Y,R only).
- Make sure you are preparing your body for activity and doing things to improve your recovery.

**Education:**
- What’s wrong?
- Why is it important?
- How to make change?

**Application:**
Assign intervention to training calendar & message center for today and next day.
**Soreness**

**TEST**

**Question:**
How would you rate your stress level today?

**Scale:**
1. Feeling great, stress free
2. A little stress, but pretty normal
3. Moderately stressed
4. Stress is starting to build up and getting pretty bad
5. Super Stressed

1 3 5

**ANALYZE**

**Answer : Points : Status**
1 : 5 : Green
2 : 4 : Green
3 : 3 : Yellow
4 : 2 : Red
5 : 1 : Red

**Report Output:**
- R, Y, G Status (Icon)
  - G = 5, 4
  - Y = 3
  - R = 2, 1
- Show Stress level
  5-1 with Happy to sad face

**PROGRAM**

**Intervention:**
Provide stress level status and recommend action (with image) based on calculation (Y,R only).
✓ How can we help with your stress?

**Education:**
- What’s wrong?
- Why is it important?
- How to make change?

**Application:**
Assign intervention to training calendar.
Encouraging messages for next day and 3 days out.
Refer appropriately.
Case Example – Individual Sport

Tennis Player
- 18 yrs old
- Top 5 Junior
- ITF Professional tour (Emerging elite)
- Timeframe: Dec-Jan snapshot
- December: preseason training
- January: Long travel and two tournaments

Available Data:
- Sleep
- Stress
- Readiness
- Soreness
- Training Load
- Movement and ROM
Case Example – Individual Sport

Daily Questions - December

Sleep:
One night event. Recovered well. Adjusted training following day.

Stress:
School Exams and Relationship troubles ;)

Daily Questions - January

Sleep:
Early month: New Years Eve and immediate overseas travel. Late month: During Tournament

Stress:
Pre and Early in Tournaments
Case Example – Individual Sport

Soreness Dip Detail - December

<table>
<thead>
<tr>
<th>Date</th>
<th>Value</th>
<th>Date</th>
<th>Value</th>
<th>Date</th>
<th>Value</th>
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<td>12/07/18</td>
<td>90.00</td>
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<td>70.00</td>
<td>100.00</td>
<td>100.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Soreness: 95.71  ▲ 11.11%

No Concern: Hard Training Day

Soreness Dip Detail - January

<table>
<thead>
<tr>
<th>Date</th>
<th>Value</th>
<th>Date</th>
<th>Value</th>
<th>Date</th>
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<tbody>
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<td>01/30/19</td>
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<td>01/31/19</td>
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<td>90.00</td>
<td>93.30</td>
<td>90.00</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

Soreness: 95.83  ▲ 10.00%

Concern: Tennis Player, Hx of Shoulder Injury, Trigger for ROM test
## Case Example – Individual Sport

### ROM Detail following the Soreness Report

<table>
<thead>
<tr>
<th>JOINT / MOTION</th>
<th>OPTIMAL ROM</th>
<th>RIGHT ROM</th>
<th>% OPTIMAL</th>
<th>LEFT ROM</th>
<th>% OPTIMAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st MTP Toe Extension</td>
<td>70°</td>
<td>68</td>
<td>97.14%</td>
<td>75</td>
<td>100%</td>
</tr>
<tr>
<td>Ankle Dorsiflexion</td>
<td>20°</td>
<td>9</td>
<td>45%</td>
<td>14</td>
<td>70%</td>
</tr>
<tr>
<td>Knee Extension - 90/90</td>
<td>20°</td>
<td>61</td>
<td>0%</td>
<td>58</td>
<td>0%</td>
</tr>
<tr>
<td>Hip Abduction</td>
<td>45°</td>
<td>34</td>
<td>75.55%</td>
<td>32</td>
<td>71.11%</td>
</tr>
<tr>
<td>Hip Internal Rotation</td>
<td>45°</td>
<td>20</td>
<td>44.44%</td>
<td>23</td>
<td>51.11%</td>
</tr>
<tr>
<td>Hip External Rotation</td>
<td>45°</td>
<td>29</td>
<td>64.44%</td>
<td>28</td>
<td>62.22%</td>
</tr>
<tr>
<td>Hip Extension (Supine) w/ Knee Flexion</td>
<td>-5°</td>
<td>1</td>
<td>86%</td>
<td>4</td>
<td>77.5%</td>
</tr>
<tr>
<td>Shoulder Flexion</td>
<td>160°</td>
<td>134</td>
<td>83.75%</td>
<td>140</td>
<td>87.5%</td>
</tr>
<tr>
<td>Shoulder Internal Rotation</td>
<td>70°</td>
<td>38</td>
<td>54.28%</td>
<td>56</td>
<td>80%</td>
</tr>
<tr>
<td>Shoulder External Rotation</td>
<td>90°</td>
<td>103</td>
<td>100%</td>
<td>106</td>
<td>100%</td>
</tr>
</tbody>
</table>

**Action needed here**
Two groups within one team
4 outside hitters and 2 setters
Relatively close match in load for most of the month ….

…. Except for the recent spike in the setters.

ACTION: seek reason in the individual data

Acute to Chronic Snapshot:
Both groups have exceeded the top end of the “green zone” 0.8-1.3.

ACTION: Reconcile with expected training load and upcoming plan.
Summary

Focus on easily collected, quickly digested, and actionable data.
Monitor

• Movement efficiency
  • Continual re-assessment
  • Guide corrective exercise

• Training load
  • Minutes x RPE
    • Within 30 minutes
  • Age and injury history may impact the relative training load

• Recovery Behaviors and Readiness Status
  • Behavior modifications
  • Education
Guiding Questions...

Is this a piece of data that I can do something about?

How easy is this data to collect?

How quickly can it be interpreted?

How does it affect the plan?

Who is involved in the decision?

- Athlete
- Sport Medicine Staff
- S&C/Sport Science/Performance Staff
- Sport Coach
Thank-you

Dr. Dave Hogarth PT, DPT
dhogarth@fusionetics.com
Senior Director of Clinical Services, Education and Research - Fusionetics

Content developed in collaboration with:

Dr. Barnett Frank PhD, ATC
Director of Performance Science
Utah Jazz

Dr. Darin Padua PhD, ATC
Chair Dept Exercise and Sport Science
UNC-Chapel Hill

Fusionetics is a Software as a Service platform which includes testing, analytics and programming for movement, performance, and recovery scenarios.
References


• Blanch & Gabbett (2016) Br J Sports Med. Has the athlete trained enough to return to play safely? The acute:chronic workload ration permits clinicians to quantify a player’s risk of subsequent injury.

• Buchheit M (2014) Frontiers in Physiology Monitoring training status with HE measures: do all roads lead to Rome?

• Drew, Purdam (2016) Br J Sports Med. Time to bin the term “overuse injury”: is “training load error” a more accurate term?


References


