Effective Prevention: Identifying Those at Greatest Risk

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Injury Definition?

- **Any injury**
  - Including concussion, contusion, and/or laceration
- **Any musculoskeletal injury**
  - Including fracture, dislocation, and/or overuse syndrome
- **Any acute joint sprain or muscle strain**
  - Including upper extremity, core, and/or lower extremity
  - Excluding wrist, hand, and finger injury
- **Any “time-loss” joint sprain or muscle strain**
  - Complete restriction of activity for 1 or more days

Injury Risk Screening

- Demographics (Potential Confounders)
  - Sport; Gender; Prior Injury; Game Exposure
- Movement Efficiency Ratings
  - Functional Movement Screen (FMS); Fusionetics
- Postural Balance
  - Y-Balance Test; BESS
- Core Muscle Endurance (Hold Time)
  - Back Extension; Prone Plank; Side Plank; Wall Sit
- Muscle Strength/Power (Asymmetry)
  - Dynamometry; Single-Leg Vertical/Broad Jump
- Dynamic Movement Tests
  - Landing Error Scoring System; Hop Tests; Closed Kinetic Chain Upper Extremity Stability (CKCUES)
- Muscle Flexibility/Joint Mobility
  - Sit-Reach; Beighton Scale
- Anthropometric Measures
  - Height; Body Mass Index; Estimated Mass Moment of Inertia
- Neurocognitive/Visuomotor Tests
  - ImPACT; CogSport; Erikson Flanker Test; Dynavision
- Self-Reported Status (Surveys)
  - Life Events Survey for Collegiate Athletes; Sport Fitness Index; Center for Epidemiological Studies – Depression (CES-D); Pittsburgh Sleep Quality Index
- Wearable Sensors
  - Inertial Measurement Units; HR Monitors

Interrelationships Among Determinants of Risk for Injury, Re-injury, & Chronic Disability

Injury Prediction

- Not everyone believes it’s possible –
  - Why screening tests to predict injury do not work – and probably never will...: a critical review.
  - Return to play and physical performance tests: evidence-based, rough guess or charade?
  - Predicting future physical injury in sports: it’s a complicated dynamic system.
    - Cook C, 2016, Br J Sports Med

Quantification of Injury Risk Level

- Considerations for interpretation of research findings:
  1. **Outcome (Injury Definition)**
     - Location (UE, Core, LE) – Severity – Type (Acute, Overuse)
  2. **Population (Injury Incidence – Pre-Test Probability)**
     - Gender – Age – Sport – Position – Level of Competition
  3. **Predictor (Single Risk Factor or Composite Indicator)**
     - Value derived from single test or a battery of screening tests?
     - Univariable vs. Multivariable Analysis (Adjusted Effect Estimates)
  4. **Duration of surveillance period**
     - Injury incidence progressively increases over time
- Prediction accuracy (validity) depends heavily on:
  - Number of criterion-positive (injured) cases within cohort
  - Minimum 10 positive cases per variable included in prediction model
Terminology

- **Correlation and Analysis of Variance:**
  - **Bivariate:** 2 continuous variables (X and Y)
  - **Multivariate:** Multiple DVs (Ys) and IVs (Xs)

- **Exposure-Outcome Association:**
  - **Univariable:** 1 predictor (X) of binary outcome (Y)
    - Predictive variable may be continuous or binary
  - **Multivariable:** ≥2 predictors of binary outcome (Y)
    - Predictive variables may be continuous or binary

Univariable 2 X 2 Cross-Tabulation

- **Receiver Operating Characteristic (ROC) Analysis**
  - Continuous variable converted to binary classification
  - Cut-point selected to optimize overall prediction accuracy

RMS*  Injuries  No Injuries  Incidence
≥ .06  7  6  34%
< .06  8  24  25%
Total  15  30

Sensitivity 47%  Specificity 80%
χ²(1)=3.46  1-Sided P=0.067
RR=2.15  90% CI: 1.12 – 4.16
OR=3.50  90% CI: 1.13 – 10.89

* Root Mean Square of Instantaneous Change in Body Mass Acceleration (Jerk)

What is the level of injury risk?

- **Risk Ratio (RR):** Comparison of Injury Incidence
  - Hi-Risk Proportion Injured / Lo-Risk Proportion Injured
- **Odds Ratio (OR):** Comparison of Occurrence vs. Non-Occurrence
  - Hi-Risk Injury Odds / Lo-Risk Injury Odds
- **Hazard Ratio (HR):** Comparison of Instantaneous Injury Rates
  - Hi-Risk Slope / Lo-Risk Slope (Injuries per athlete per unit of time)

Assessment of Predictive Validity

1. **Magnitude of Effect Size Ratio (RR, HR, and/or OR)**
2. **Confidence Interval Lower Limit > vs. ≤ 1.0**
   - 90% CI: 5% expected frequency of values ≤ LL
     - Equivalent to one-sided test of statistical significance

### Association RR HR OR

- **Small:** \( \geq 1.1 \)
- **Moderate:** \( \geq 1.4 \)
- **Large:** \( \geq 2.0 \)
- **Very Large:** \( \geq 3.3 \)

Limitations of the Odds Ratio

A given value for an Odds Ratio can be derived from many different combinations of values for Sensitivity and 1 – Specificity

- **Sensitivity and Specificity**
  - Probability that outcome status will be correctly classified by test result
- **Positive and Negative Predictive Value (PPV and NPV)**
  - Probability that a test will correctly classify an individual as having high-risk vs. low-risk status
- **Positive and Negative Likelihood Ratio (+LR and –LR)**
  - Magnitude of increase (+) or decrease (–) in odds for injury occurrence on the basis of classification as high-risk vs. low-risk status

Univariable Cross-Tabulation Analysis

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Positive</th>
<th>Negative</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predict Positive</td>
<td>True Positive</td>
<td>False Positive</td>
<td>TP+FP</td>
</tr>
<tr>
<td>Predict Negative</td>
<td>False Negative</td>
<td>True Negative</td>
<td>FN+TN</td>
</tr>
<tr>
<td>Total</td>
<td>TP+FN</td>
<td>FP+TN</td>
<td>TP+TN+FP+FN</td>
</tr>
</tbody>
</table>

Risk Ratio = Incidence/Incidence
Odds Ratio = +LR/-LR

Advantage of Likelihood Ratios

Example: N=100; 80% Sensitivity; 80% Specificity

<table>
<thead>
<tr>
<th>Incidence</th>
<th>Injury</th>
<th>No Injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>8</td>
<td>18</td>
</tr>
<tr>
<td>30%</td>
<td>24</td>
<td>14</td>
</tr>
<tr>
<td>50%</td>
<td>6</td>
<td>56</td>
</tr>
<tr>
<td>70%</td>
<td>15</td>
<td>24</td>
</tr>
<tr>
<td>90%</td>
<td>72</td>
<td>2</td>
</tr>
</tbody>
</table>

+LR = Sensitivity/1-Specificity
-LR = 1-Sensitivity/Specificity

OR = +LR/-LR
OR = 4.00/0.25 = 16.00

Key Concepts

“Exposure”
1. Volume of participation in activity presenting injury risk
   - Athlete-Exposures (AEs): Number of practices and games
2. Any factor associated with outcome (predictive variable)

“Confounding”
- Unequal “exposure” within groups that are compared
  - Gender, Sport, Position, Experience, Injury History, Starter Status
- Example: High performance on screening test of agility associated with injury occurrence
  - Starters possess good agility + exposed to greater injury risk

Development of a Prediction Model

1. Process begins with univariable analyses
   - Selection of factors to include in multivariable analysis
     - One-sided test appropriate when focus is whether or not a point estimate exceeds a specified value (e.g., ratio > 1.0)
     - Screening criterion as large as one-sided P < .20 or .25
2. Multivariable analysis identifies best set of predictors
   - Entry of binary variables permits comparison of univariable ORs to “adjusted” multivariable ORs
     - Logistic regression output: EXP(B) = Adjusted OR
3. Prediction accuracy assessed by univariable analysis
   - Multivariable model converted to binary classification
     - High-Risk vs. Low-Risk status

Continuous Variables vs. Binary Categories (Risk Factor + or −)

Binary Categories: High Risk vs. Low Risk
- Cut-point determined by ROC analysis

<table>
<thead>
<tr>
<th>Game Plays</th>
<th>0 – 932</th>
<th>2-Leg Squat</th>
<th>0 – 100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injury</td>
<td>No Injury</td>
<td>Incidence</td>
<td>Injury</td>
</tr>
<tr>
<td>≥ 299</td>
<td>20</td>
<td>36%</td>
<td>≥ 62</td>
</tr>
<tr>
<td>&lt; 299</td>
<td>19</td>
<td>34%</td>
<td>&lt; 62</td>
</tr>
</tbody>
</table>

Sensitivity= 87% Specificity= 40%
Logistic Regression

- Natural log (ln) of “odds” for event occurrence
  - Odds = Probability / (1 – Probability)
  - ln(P/1 – P) = ß0 + ß1X1 + ß2X2 + …
  - In base e = 2.718
  - e^ß = EXP(ß) = change in odds for 1-unit increase in X
- For a binary predictive variable (0, 1):
  - EXP(ß) = “Adjusted” Odds Ratio
    - Adjusted for the effects of other predictors included in model

Continuous Variables vs. Binary Categories (Risk Factor + or -)

Entry as continuous variables:
- Model ß^2 (2) = 16.96; P < .001; Nagelkerke R^2 = .264

Entry as categorical variables:
- Model ß^2 (2) = 9.77; P = .008; Nagelkerke R^2 = .285

Inertial Measurement Unit (IMU)

- High Player Load value = High Rate of Change in Acceleration
  - Forward – Backward
  - Right – Left
  - Up – Down

Continuous Variables vs. Binary Categories (Risk Factor + or -)

N=77
- Core or LE Injury
  - 39 injured: 51%

Univariable ORs
- 8.95
- 4.44

Continuous Variables vs. Binary Categories (Risk Factor + or -)

N=45
- UE, Core, or LE Injury
  - 32 injured: 71%

Univariable ORs
- 7.33
- 8.21

Continuous Variables vs. Binary Categories (Risk Factor + or -)

N=45
- UE, Core, or LE Injury
  - 32 injured: 71%

Univariable ORs
- 4.13
- 5.28

Continuous Variables vs. Binary Categories (Risk Factor + or -)

N=45
- UE, Core, or LE Injury
  - 32 injured: 71%

Univariable ORs
- 7.33
- 8.21
Continuous Variables vs. Binary Categories (Risk Factor + or −)

<table>
<thead>
<tr>
<th>Factors + Injury No Injury % Injured</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

Fisher’s Exact One-Sided P < .004

Sensitivity = 78%
Specificity = 69%
OR = 8.04 (90% CI: 2.39 – 27.03)

Probability ≥ .71

<table>
<thead>
<tr>
<th>Injury No Injury Incidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Back</td>
</tr>
<tr>
<td>Line</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

P = .074

Inertial Load CoV ≤ .15

<table>
<thead>
<tr>
<th>Injury No Injury Incidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥ 2</td>
</tr>
<tr>
<td>0 or 1</td>
</tr>
</tbody>
</table>
| Total | 45 | 32 | 85%

Cox Regression

- Time-to-event analysis (survival analysis)
- Hazard: Probability that an individual will experience outcome event with specified time interval
- Hazard Ratio: Comparison of instantaneous risk for injury at any point during specified time interval
- Cumulative Hazard: Number of events expected by the end of the specified time interval (if repeatable)
- Cumulative Injury Incidence: Proportion of group members who have experienced outcome event at successive time points
Cox Regression – Binary Prediction

N = 39  4-Factor Prediction Model
≥ 2 Positive Factors vs. 0 or 1 Positive Factor
HR = 7.70 (90% CI: 2.75, 21.57)

Cumulative Injury Incidence
(Observed)

Cumulative Hazard
(Predicted Injury Occurrences)

Cumulative Survival
(Predicted Injury Avoidance)

1 – Cumulative Survival
(Predicted Injury Incidence)


- Why screening tests to predict injury do not work – and probably never will…. a critical review.

- At least 3 steps needed to validate a screening test:
  1. A strong relationship must be established between the test result (dichotomous categories) and injury risk
  2. Validate the relationship in multiple cohorts (same criteria for high risk classification)
  3. Document that an intervention is more beneficial for athletes with high risk than the general athletic population (high risk + low risk)

Retrospective-Prospective Analyses of Screening Test Results
- Retrospectively-derived cut-points used to prospectively classify high vs. low risk

High School Football Players  N=61

<table>
<thead>
<tr>
<th>Factor</th>
<th>Previous Injury</th>
<th>Season Injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>SFI</td>
<td>≤ 88</td>
<td>4.53 4.42 2.39 1.82</td>
</tr>
<tr>
<td>Y-AR%Diff</td>
<td>≥ 2.4</td>
<td>2.52 1.40 3.81 2.92</td>
</tr>
<tr>
<td>HTH (s)</td>
<td>≤ 24</td>
<td>2.11 2.23 1.64 1.45</td>
</tr>
<tr>
<td>Factors +</td>
<td>≥ 2</td>
<td>3.67 - 5.23 -</td>
</tr>
</tbody>
</table>

Summary
- Model components and cut-points are highly specific to injury definition and cohort characteristics
- Persisting effects of prior injury and volume of exposure to high-risk conditions are potential confounders
- Any strong interactions between potential predictors should be identified and included in multivariable analysis
- Likelihood ratios are better indicators of screening test classification accuracy than PPV and NPV
- Time-to-event analysis of a binary risk classification model may augment evidence of its predictive validity
- Precision of an estimate of exposure-outcome association (RR, HR, or OR) is reflected by confidence interval limits

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