External Load Monitoring
Through Wearable Technology
GPS, Accelerometry, and Inertial Measurement Units

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My progression here....

Starts with losing a job....

Global Positioning System (GPS)
Global Navigation Satellite System* (GNSS)

*Includes Russian GLONASS... May soon include European Union's Galileo and China's Beidou
Ultimately, these devices are “integrated microtechnologies”

- GPS/GNSS → Position
- Accelerometer → G-forces/Acceleration (3 planes of motion)
- Gyroscope → Rotations (3 axes – roll, pitch, yaw)
- Magnetometer → Orientation/Direction (outside monitoring)
Brief history of GPS...

- GPS navigation uses atomic clocks to determine the length of time it takes a radio signal to travel from a satellite to the GPS receiver on Earth.
- At least 4 satellites are needed to “triangulate” a signal.
- Since signal travel time can be measured, distance can be accurately measured.
  - This allows us to determine the rate of displacement of a receiver over a given epoch.
  - Thus we can determine velocity from this displacement and time elapsed between position changes.

GPSports Systems (SP-10) was first sport application based system (2003)

- Validation study showed a systematic overestimation of 5% for distance.
- Next attempt at GPS validity wasn’t conducted until 2009-2010.
- Difficulty is with gold standard used for validation.
  - Trundle wheel or tape measure is used to measure a course then timing gates are used to measure velocity.
- Problems:
  - Does the trundle wheel accurately measure distance? (maybe not)
  - Does the starting point for GPS calculations match the actual starting point for the movement?
  - What amount of error is inherent in timing gates? (there is some for determining time)
- These problems were eliminated to some degree by using a VICON system (positional error of only 0.0008%).

Local Positioning Systems (LPS)

- Doesn’t require GPS.
- Uses “nodes” placed around the training facility to locate a player.
- Eliminates one problem but creates others when used in smaller spaces where signal may “bounce” off a wall prior to locating athlete.

Accuracy is improved with sampling rate...

- Distance is improved from 1Hz to 5Hz and even more for 10Hz.
- SEE for actual distance was as great as 32.4% for 1Hz for 15m sprint (high velocity running).
- 5Hz was marginally better at 30.9%.
- 10Hz was around 10.0% for a 15m sprint.
- Velocity of a task (not surprisingly) affects the distance accuracy as well.
  - SEE of 0.4 ± 0.1 m/s to 3.8 ± 1.4 m/s between walking and striding with 5Hz.
  - Low validity for high speed tasks or change of direction tasks.
- Accuracy is improved as distance is increased.
  - As low as 1.5% SEE.
- Modern GPS devices use 10Hz sampling rates with 100Hz triaxial accelerometers.
  - No improvement using 15Hz unless you are downhill skiing.

Reliability mimics accuracy...

- Also affected by sampling rate, velocity, duration of the task, and the type of task being performed.
- Sprinting with 10Hz GPS over a distance of 15-30m has a coefficient of variation (CV) of 0.7-1.3%.
- Once again, the higher the velocity, the lower the reliability.
- Sprinting has lower reliability compared to walking.
- Changes of direction reduce reliability, as well as, repetitive tasks in small court areas.
Most current devices….Maybe better?

- Hoppe et al (2018) compared 18 Hz GPS and 20 Hz LPS units against the Catapult 10 Hz GPS S4 unit using TEE (criterion validity) and CV (reliability)
- 18 Hz GPS outperformed 10 Hz for validity and reliability
  - Distance covered (CV = 1.1 to 5.1%)
  - Sprint mechanical properties (CV = 3.1 to 7.5%)
- 20 Hz LPS outperformed both the 18 Hz and 10 Hz units
- All units had high agreement between devices
- BUT…loss of data due to the removal of outliers resulting from measurement error was greater for 18 Hz (20%) and 20 Hz (15.8%) compared to 10 Hz (10%)
- Practicality is therefore may be limited for 18 Hz and 20 Hz compared to 10 Hz due to potential for data loss across a season

- Measured criterion validity (against video) and reliability of 15 Hz GPS units (GPSports) in Canadian university football players
- High speed velocity was measured (CV = 0.9% excellent)
- Inter-unit reliability was assessed (CV = 1.4 for walking; 7.8 for sprinting (very good to good)
- Collisions were also measured and compared to actual numbers of collisions and tackles (highest accuracy when using 2.65g for linemen and 2.9g for non-linemen as cut-off points)
- These numbers reflect the ability of the tackle algorithm to detect heavier collisions but not low to moderate collisions
- Study authors suggested using individualized (or at least position-specific) cut-off points for high vs. moderate vs. low velocity and collision cut-off points

Division 1 football players (n=29) were monitored using GPS receivers (Catapult Innovations, Melbourne, Australia) during 20 preseason practices.

- Individual observations (n ~ 350) were divided into offensive and defensive position groups
- Movement variables including low-, medium-, high-intensity, and sprint distance, player load, and acceleration and deceleration distance were assessed.
- Perceived wellness ratings (n = 469) were examined using a questionnaire which assessed fatigue, soreness, sleep quality, sleep quantity, stress, and mood
- Results demonstrated significantly (p < 0.05) greater total, high-intensity, and sprint distance, along with greater acceleration and deceleration distances for the defensive back and wide receiver position groups compared with their respective offensive and defensive counterparts.
- Significant (p < 0.05) differences in movement variables were demonstrated for individuals who responded more or less favorably on each of the 6 factors of perceived wellness.
- Data from this study provide novel quantification of the position-specific physical demands and perceived wellness associated with college football preseason practice.
- Results support the use of position-specific training and individual monitoring of college football players.
A retrospective analysis was performed on data collected over the course of the preseason in 10 eligible NCAA Division 1 basketball players. Compared Omegawave readiness scores (internal load) to a countermovement jump (CMJ) (performance index) vs. the previous day's practice PlayerLoad (represents external load).

Results indicated that an increased PL during the previous exposure was associated with decreased CMJ (58.7 ± 4.7 cm vs. 60.4 ± 5.1 cm; p < 0.001) and increased TRIMP (135.1 ± 35.9 vs. 65.4 ± 20.0 AU; p < 0.001), and duration (115.4 ± 27.1 vs. 65.5 ± 20.0 minutes; p < 0.001) despite no differences in Omegawave CNS Readiness scores.

The authors concluded that Omegawave and Catapult technologies provided independent information related to performance and may be effective tools for monitoring athlete performance.

So what does this look like in a field setting?

Catapult metrics of interest...

- Player load – a measure of activity volume
- Player load per minute – a measure of activity intensity
- Total distance – the amount of distance covered in a session
- High speed running – the amount of distance covered at a speed above the high speed threshold (determined by sport, level, position, etc)
- High IMA – the number of high intensity events accrued in any direction (acceleration, deceleration, change of direction left and right)

Usage Example 1:
- Average Player Load can be used to classify the volume of each practice or game. A team can view this metric over time to see how practices and games compare to each other.
**Player Load per Minute**

- Usage Example 1:
  - Player Load and Player Load per Minute can be shown on the same graph. This will create a more complete activity profile showing both the volume and intensity of the practice or game.

- Usage Example 2:
  - Coach A wants to make sure that he is not overworking his players on days leading up to games. The graph below shows the volume and intensity of the two days leading up to games and the games themselves.

**Total Distance**

- Usage Example 1:
  - Coach A wants to compare the distance covered by his receivers during a certain game. The graph below shows the distances of his athletes and allows him to see how they compare to each other.

- Usage Example 2:
  - The graph below shows the average distance covered by one player in each game along with the average of all of the games. Now he has an idea of how much distance they should train to cover.

**High Speed Distance**

- Usage Example 1:
  - Coach A wants to see how much of his receivers’ total distance consisted of high speed running so he plotted both metrics on a single graph.

- Usage Example 2:
  - Coach A wants to compare the running profiles of his receivers, corner backs, and running backs for the last game. The below graph shows him that his receivers ran more both in terms of total distance and in high speed running distance.
Inertial Motion Analysis (IMA)

- **Usage Example 1:**
  - Coach A wants to compare the high intensity events his team is experiencing by position. The graph below shows the High IMA totals of his positions and allows him to see how they compare to each other.

- **Usage Example 2:**
  - Based on his findings above, Coach A wants to see which of his receivers are experiencing the most intensity. The graph below shows the average High IMA each player experiences. Now he has an idea of who is subjected to higher intensity events on an average day.

How I normally explain IMA...

Liberty Mutual tells me “high risk” events = $55, whereas my moderate and low risk events (stops, starts, turns) are not as risky.

They use this data to build a risk profile for you as a driver.

Player Performance

- **Periodization**
  - Player Load and Player Load per minute are good summary numbers that give you an idea of how hard the game or practice was. These numbers can help you create and visualize your practice workloads in order to develop a periodization plan. Generally you want a harder practice earlier in the week, and taper the load as you approach a game.
Injury Risk

• The graph below shows a player’s intensity output against his average over a period of 20 days. His total volume on these days is similar so you can see the decline in his ability to perform intense activities. We would want to look at him closely to try and determine the cause of this decline before an injury occurs.

So what skills do you need to do this work?

• A knowledge of the technical/biomechanical, tactical, and physiological demands of the sport
• An integrative knowledge of how coaches think, along with the needs/concerns/interests of the rest of the support staff (S&C, nutrition, psych, medicine) within an athletic environment
• Outstanding organizational ability in excel (pivot tables, macros, graphing)
• There are other programs but this is where everyone starts
• A team
  • You cannot use this technology to its intent or potential collecting a few weeks data with a few people
  • This technology was designed for real time awareness of an athlete’s acute status and long-term, deep-dive analysis to better understand performance opportunities and injury alerts/risk

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