Part 1.4 - Literature Review & Metric Selection

Introduction

The integrated athletics database used in this project contains millions of records from Hawkins force plate assessments, Kinexon GPS/accelerometry, and Vald strength diagnostics. To guide our analysis, we selected five metrics that are both highly represented in the dataset and widely supported in sports science literature: Jump Height (Hawkins), Peak Propulsive Power (Hawkins), Total Distance (Kinexon), Accumulated Acceleration Load (Kinexon), and MaxForce Left/Right (Vald). These metrics collectively represent three core physical performance domains: neuromuscular power, external workload, and maximal strength or asymmetry. The following literature review summarizes the scientific relevance of each metric and establishes the rationale for our research question.

Jump Height (Hawkins - Countermovement Jump)

Countermovement jump (CMJ) height is a widely validated indicator of lower-body explosive power and neuromuscular function. When collected with force plates, CMJ height reflects underlying force-time characteristics that offer a sensitive view of an athlete's mechanical output and readiness. Research consistently demonstrates strong associations between CMJ performance and sprint acceleration, maximum velocity, and change-of-direction ability in elite athletes (Loturco et al., 2019). CMJ height is also highly responsive to neuromuscular fatigue, with reductions commonly observed following high training loads or competition (Gathercole et al., 2015). Normative CMJ values for trained athletes typically fall between 30-50 cm depending on sport and sex, with power-dominant sports displaying the highest values (Markovic & Mikulic, 2010). Recent work further emphasizes evaluating phase-specific force-time variables, particularly braking and propulsive phases, to gain a more complete understanding of neuromuscular status (McMahon et al., 2018). These characteristics make CMJ height a valuable and sensitive metric for daily athlete monitoring.

Peak Propulsive Power (Hawkins - Force Plate Propulsive Phase)

Peak propulsive power represents the highest mechanical power output generated during the propulsive phase of the CMJ, integrating both force and velocity to describe an athlete's explosive capacity. This metric is strongly associated with performance in sprinting, jumping, and multi-directional sport tasks (Suchomel et al., 2016). Peak power is also sensitive to neuromuscular fatigue and training adaptations, often responding earlier and more dramatically than jump height alone (Gathercole et al., 2015). Because relative peak power (normalized to body mass) strongly differentiates competitive levels among athletes, it is frequently used in strength and conditioning to assess power development, track progress, and tailor individualized training programs (Markovic & Mikulic, 2010). Together with CMJ height, peak propulsive power provides a robust picture of neuromuscular performance and readiness.

Total Distance (Kinexon - GPS External Load)

Total distance represents the cumulative locomotor distance covered during training sessions or competition, typically measured through GPS or IMU units. Although it does not provide direct insight into movement intensity, it remains one of the most fundamental indicators of external workload in team sports. Classic research shows that elite soccer and rugby players routinely accumulate between 8-13 km during matches, with substantial positional variation (Bangsbo et al., 2006). Modern GPS monitoring is now a core component of training load management, microcycle planning, and player conditioning strategies (Cummins et al., 2013). While total distance alone does not reliably predict injury, large acute spikes relative to an athlete's chronic load have been consistently linked to increased soft-tissue injury risk (Gabbett, 2016). As such, tracking total distance longitudinally is essential for evaluating volume load, managing fatigue, and supporting recovery planning.

Accumulated Acceleration Load (Kinexon - Mechanical Load / Accel–Decel Load)

Accumulated acceleration load reflects the overall mechanical stress imposed by accelerations and decelerations throughout training and competition. These rapid movements place substantial eccentric and neuromuscular demands on tissues, often exceeding those associated with high-speed running alone (Akenhead et al., 2013). Systematic reviews highlight that frequent high-intensity acceleration and deceleration events contribute to neuromuscular fatigue, muscle damage, and delayed recovery (Harper et al., 2019). Because acceleration-based load is influenced by each device manufacturer's algorithms, absolute normative thresholds are rarely used; instead, practitioners focus on within-athlete and within-team comparisons (Buchheit & Simpson, 2017). Acceleration load therefore provides a critical dimension of mechanical workload that complements distance-based metrics, allowing for a more complete understanding of total training stress.

MaxForce Left/Right (Vald Strength Testing - Unilateral Peak Force)

MaxForce quantifies the peak force produced during unilateral or bilateral strength assessments and serves as a primary indicator of maximal strength capacity. Vald systems provide left and right sided force outputs, enabling calculation of inter-limb asymmetry, an important component of injury-risk profiling. Several prospective studies have linked strength imbalances exceeding 10-15% with increased risk of hamstring strains and lower-limb injuries in elite athletes (Croisier et al., 2008). However, more recent reviews emphasize that asymmetry alone does not always impair performance or consistently predict injury, as many athletes naturally exhibit stable asymmetries without negative outcomes (Bishop et al., 2018). Regardless of the debate, maximal strength remains a critical determinant of sprinting, jumping, and change-of-direction ability (Silva et al., 2015). Thus, MaxForce offers valuable information regarding strength capacity, rehabilitation status, and readiness.

Identified Research Gap

Although CMJ performance, GPS-derived workload metrics, and strength/asymmetry measures are each well-established individually, far fewer studies integrate these systems simultaneously. Most research analyzes force-plate metrics, GPS load, or strength testing in isolation rather than examining how neuromuscular performance responds to fluctuations in external workload or how strength asymmetry may moderate these responses. Additionally, few studies leverage large-scale, multi-sport, longitudinal datasets such as the one in this project. This creates a meaningful gap in understanding how changes across domains interact within and between athletes over time.

Proposed Research Question and Hypotheses

Research Question (RQ):
How do neuromuscular performance metrics (Jump Height, Peak Propulsive Power), GPS-derived external workload metrics (Total Distance, Accumulated Acceleration Load), and maximal strength/asymmetry (MaxForce left/right) interact longitudinally across collegiate athletes, and can deviations from team norms indicate early signs of undertraining, overtraining, or changes in athlete readiness?

Hypotheses:

- **H1:** Athletes who experience prolonged periods of high external load, particularly high acceleration load, will demonstrate short-term reductions in Jump Height and Peak Propulsive Power relative to their baseline values.

- **H2:** Athletes with greater inter-limb asymmetry (MaxForce left vs. right) will exhibit more variability in CMJ performance and may demonstrate different load–response patterns compared to more symmetrical teammates.

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