Introduction

The purpose of this project was to evaluate how the **modified Reactive Strength Index (mRSI)** behaves as a marker of neuromuscular fatigue compared to more traditional output metrics, specifically **Jump Height (JH)** and **Propulsive Net Impulse (PNI)**, over the competitive season in NCAA athletes. This objective directly aligns with the research question and addresses a practical issue in applied sport science: determining which countermovement jump (CMJ) metrics are most sensitive and useful for monitoring athlete fatigue across an entire season.

Regular in-season monitoring of neuromuscular status is essential for optimizing performance, managing accumulated fatigue, and reducing injury risk. The CMJ is a commonly used vertical jump assessment that evaluates lower-body explosive power through the stretch–shortening cycle. It is widely implemented in applied sport settings because it is relatively easy to standardize, quick to administer, and scalable using force plates and timing systems. Historically, CMJ monitoring has relied primarily on outcome-based metrics such as jump height and impulse (Aničić et al., 2023). While these metrics remain valuable, recent literature suggests that mRSI provides additional insight into neuromuscular function, particularly in situations where fatigue affects time to take-off rather than jump height alone (Sole et al., 2018).

From a practical standpoint, mRSI helps address questions that coaches and practitioners commonly consider, such as whether an athlete is moving elastically, how efficiently they are utilizing the stretch–shortening cycle, and whether neuromuscular fatigue may be present even when outward performance appears unchanged. Despite this growing interest, there remains limited applied research examining how mRSI behaves relative to traditional output metrics across a large NCAA dataset spanning multiple teams and competitive seasons. In addition, few studies have explored how threshold-based flagging systems can be implemented in real-world monitoring environments to identify meaningful changes beyond normal test–retest variability. This analysis aims to address these gaps by comparing mRSI, JH, and PNI within a multi-metric fatigue monitoring framework.

Methods

Description of Selected Metrics

This study analyzed longitudinal CMJ testing data collected from **946 unique NCAA athletes** representing **92 teams** across multiple sports between October 2018 and October 2025. The dataset consisted of force-plate–derived CMJ assessments collected primarily using the Hawkins system, which provided consistent measurement of force–time variables required to calculate mRSI, jump height, and propulsive net impulse.

Modified Reactive Strength Index (mRSI) was calculated as jump height divided by time to take-off. Higher mRSI values reflect more efficient and explosive movement patterns, indicating an athlete’s ability to rapidly produce force through the stretch–shortening cycle. Jump height (m) was included as a traditional outcome metric reflecting the vertical displacement achieved during the CMJ and was derived using flight-time or impulse–momentum methods. Propulsive net impulse (PNI) represents the net vertical impulse generated during the propulsive phase of the jump and provides insight into how effectively an athlete produces force over time to initiate take-off.

These metrics were selected because they are well represented in the sports science literature, consistently recorded in the NCAA athlete monitoring database, and have demonstrated acceptable reliability in Division I athletic populations (Aničić et al., 2023). Together, they allow for direct comparison between traditional outcome-based measures and a time-sensitive, ratio-based indicator of neuromuscular performance.

Data Filtering and Cleaning Approach

Before analysis, the dataset was filtered to include only valid vertical CMJ trials containing complete data for mRSI, jump height, and propulsive net impulse. Observations with missing values, implausible measurements, or duplicate test entries were removed. All timestamps were converted to a standardized datetime format and sorted chronologically.

Individual athlete baselines were defined using median values across available tests for each metric. This approach reduces the influence of outliers, such as exploratory testing sessions or occasional submaximal efforts. Team-level averages were also calculated to allow comparisons between an athlete's performance and that of their teammates.

Statistical Methods Used

Rather than relying on inferential hypothesis testing, this study employed a threshold-based flagging approach using two criteria for mRSI. First, based on established reference values for Division I athletes, which range from low (<~0.20) to elite (>~0.60+) (Sole et al., 2018), a decline of ≥10% from an athlete's individual baseline was flagged. Second, an mRSI deviation greater than 15% below the team average was used to identify meaningful departures from typical group performance. These thresholds were selected to exceed reported typical error values for RSImod, increasing confidence that flagged changes reflected meaningful neuromuscular alterations rather than normal variability (Suchomel et al., 2015).

Jump height and propulsive net impulse were evaluated using a ≥7% reduction from individual baseline, consistent with reported reliability and measurement error for CMJ output metrics (McMahon et al., 2018). Collectively, these thresholds provided a structured, evidence-based method for detecting significant changes that may indicate fatigue, suboptimal recovery, or decreased neuromuscular performance.

Results

Across the dataset, **50,000 CMJ test records** from **946 NCAA athletes** were evaluated using the threshold-based criteria. Application of these criteria resulted in **18,971 flagged test instances**, representing **818 unique athletes** who met at least one fatigue-related condition during the monitoring period.

Fatigue flags were observed across all CMJ-derived metrics; however, their frequency and patterns of occurrence varied. mRSI-based criteria accounted for the majority of identified events, with **mRSI deviation from the team average** producing **12,095 flagged instances**, followed by **jump height baseline reductions** (**5,916 instances**) and **mRSI baseline declines** (**3,987 instances**). No propulsive net impulse flags were recorded in the cleaned dataset due to the absence of this metric following data processing.

Notably, many flagged instances occurred when mRSI declined while jump height remained within baseline tolerance, suggesting that mRSI frequently detected neuromuscular changes not immediately reflected in traditional output metrics. In contrast, jump height-related flags tended to occur later and were often associated with larger reductions in performance values, consistent with more pronounced neuromuscular fatigue. Cases in which multiple thresholds were met simultaneously appeared to reflect more global fatigue states rather than isolated metric variability.

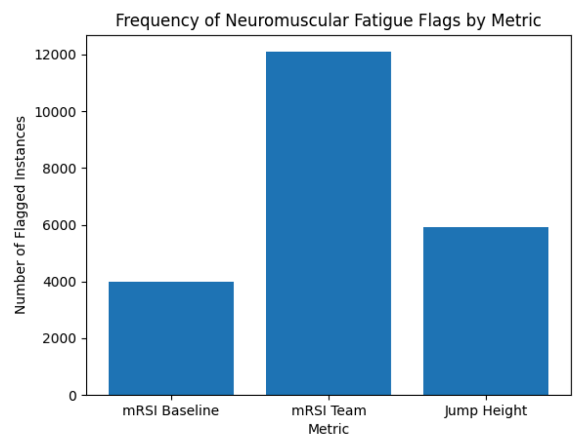
Tables and figures:

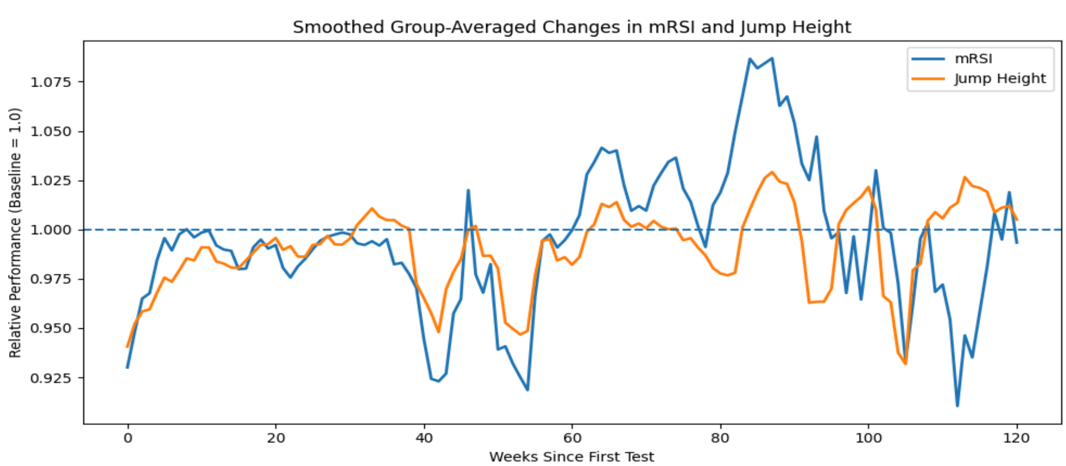
Dataset Summary (Table 1):

	Characteristic	Value
0	Total CMJ records analyzed	50000
1	Unique athletes	946
2	Unique teams	72
3	Available CMJ metrics	Jump Height(m), mRSI
4	Baseline method	Median of all available tests per athlete
5	Study design	Longitudinal, observational
6	Monitoring period	Competitive seasons (2018–2025)

Flagging Summary (Table 2):

	Flag Type	Number of Flagged Instances
0	mRSI baseline drop (≥10% vs baseline)	3987
1	mRSI team deviation (>15% from team average)	12095
2	Jump Height baseline drop (≥7% vs baseline)	5916
3	Propulsive Net Impulse drop (≥7% vs baseline)	0
4	Total flagged tests	18971
5	Unique athletes flagged	818





Discussion

The primary findings of this analysis indicated that mRSI demonstrated greater sensitivity to neuromuscular fatigue across the competitive season compared to traditional output metrics such as jump height. Group-averaged, baseline-normalized trends showed that mRSI frequently declined while jump height remained within baseline tolerance, suggesting that mRSI captures early neuromuscular changes that are not immediately reflected in outcome-based performance measures. This observation is consistent with existing literature indicating that time-sensitive CMJ variables are more responsive to changes in stretch–shortening cycle efficiency than output-only metrics (Suchomel et al., 2015).

While previous research has established normative mRSI values and reliability within NCAA populations, much of that work has been cross-sectional or limited in duration. The present analysis extends this literature by examining mRSI longitudinally across a large, multi-team NCAA dataset and directly comparing it with jump height. The finding that jump height reductions tended to occur later and with greater magnitude supports prior evidence suggesting that output metrics often reflect more advanced or global fatigue states (McMahon et al., 2018).

These results suggest that mRSI may be particularly useful for early detection of neuromuscular fatigue, allowing practitioners to intervene before observable declines in jump height occur. The frequent occurrence of isolated mRSI flags indicates that athletes may maintain jump height through compensatory strategies despite underlying neuromuscular fatigue or inefficiencies. Surprisingly, concurrent declines across mRSI and jump height appeared to reflect more global fatigue states, supporting the use of a multi-metric monitoring approach. Overall, these findings both confirm existing knowledge regarding output metric behavior and highlight the added value of mRSI in applied athlete monitoring.

Limitations and Future Directions

Several limitations should be considered. Propulsive Net Impulse data were unavailable after cleaning, which limited comparisons to mRSI and jump height. Additionally, testing frequency varied across athletes and teams, which may have influenced group-level averages, particularly later in the monitoring period when fewer observations were available.

Future research would benefit from more complete metric coverage, including force- and impulse-based variables, as well as contextual information such as training load, competition exposure, and recovery status. Incorporating injury outcomes or subjective readiness measures could further clarify the practical significance of early mRSI changes. Finally, sport- and position-specific analyses may reveal fatigue patterns that are not evident when data are examined at the aggregate level.

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