A Multi-Metric Injury Risk Score for Post-Ultra Recovery Monitoring

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Methods

Subject

The subject was a 36-year-old male ultramarathon runner (height: 180 cm, weight: 82.9 kg, VO_2max: 43.14 mL/kg/min) who completed a 160 km trail race with approximately 6,500 m of elevation gain (SOG 160 km). The subject had 20+ previous ultra finishes and reported no pre-existing injuries at the time of the race. Written informed consent was obtained from the subject for the use of his training and physiological data in this analysis.

Data Collection

Training and physiological data were collected daily for 43 days following the race using a Garmin Enduro 2 wrist-worn device and the Runalyze analysis platform. The following metrics were recorded each morning:

- **HRV (Heart Rate Variability):** Measured as the root mean square of successive R-R interval differences (rMSSD) during overnight sleep, expressed in milliseconds.
- **Resting Heart Rate:** Measured during sleep, expressed in beats per minute (bpm).
- **Sleep Duration and Quality:** Total sleep time in hours and subjective sleep score (0–100).
- **Training Load (TRIMP):** Calculated using the Training Impulse method (Banister et al., 1975) based on heart rate and session duration.

Derived Metrics

From daily TRIMP data, the following metrics were calculated:

- **ATL (Acute Training Load):** Exponentially weighted moving average of TRIMP over the preceding 14 days, representing short-term fatigue (Halson, 2014).
- **CTL (Chronic Training Load):** Exponentially weighted moving average of TRIMP over the preceding 84 days, representing long-term fitness.
- **TSB (Training Stress Balance):** CTL - ATL, representing readiness to perform. Negative values indicate accumulated fatigue.

- **A:C Ratio (Acute-to-Chronic Workload Ratio):** ATL ÷ CTL. Values between 0.80–1.30 are considered optimal; values above 1.5 indicate elevated injury risk (Gabbett, 2016).
- **Monotony:** Mean daily TRIMP ÷ standard deviation of daily TRIMP over 7 days. High monotony indicates low variation in training intensity (Foster, 1998).
- **Training Strain:** Sum of daily TRIMP × Monotony over 7 days.

Injury Risk Score (IRS)

The Injury Risk Score was calculated as:

IRS = (Monotony × Strain) ÷ HRV Trend

Where HRV Trend is the ratio of current 7-day average HRV to baseline HRV (established during a 4-week pre-race period). An HRV Trend below 1.0 indicates ANS depression relative to baseline.

IRS thresholds were defined as follows:

- **< 80:** Low risk (continue normal training)
- **80–120:** Moderate risk (consider reduction in training load)
- **120–160:** High risk (mandatory load reduction)
- **> 160:** Very high risk (cease training, prioritise recovery)

Literature Search

A literature search was conducted using PubMed and Google Scholar with the following search terms: “HRV ultramarathon recovery,” “ACWR injury risk runners,” “training monotony overtraining,” and “heart rate variability endurance athletes.” Peer-reviewed journal articles published between 1998 and 2023 were prioritised.

Results

Baseline and Acute Post-Race Data

The subject’s 4-week pre-race baseline showed: HRV = 43 ms (rMSSD), resting HR = 50 bpm, ATL = 74, CTL = 74, TSB = -4, and A:C ratio = 1.05 (within optimal range). On the morning following the 160 km race (Day 1 post-race), key metrics showed significant deviation from baseline:

Metric	Baseline	Day 1 Post-Race	Change
HRV (ms)	43	34	-21%
Resting HR (bpm)	50	58	+16%
Sleep (hours)	7.2	3.1	-57%

Metric	Baseline	Day 1 Post-Race	Change
Body Weight (kg)	84.3	82.1	-2.6%

Recovery Trajectory

By Day 43 post-race, the subject showed substantial recovery across most metrics. HRV had increased to 47 ms, exceeding baseline by 9%. Resting HR decreased to 47 bpm, 6% below baseline. Sleep duration returned to 7.2 hours. However, key workload metrics indicated that full physiological recovery remained incomplete:

Metric	Day 43 Post-Race	Interpretation
ATL	78	Elevated above baseline (74)
CTL	74	At baseline
TSB	-4	Mildly negative – residual fatigue
A:C Ratio	1.05	Optimal range

Metric	Day 43 Post-Race	Interpretation
Monotony	0.14	Low – adequate variation
Training Strain	724	Moderate accumulation
HRV Trend	1.093	Positive (47/43)
IRS	**92.7**	**Moderate risk** 🟡

Despite the subject reporting a subjective readiness score of 6.7/10 ("feeling good") and sleep quality rated as "very good" (7h 12m), the IRS at 92.7 indicated moderate injury risk — primarily driven by elevated training strain (724) accumulated during the recovery period, even as HRV showed positive trending.

This finding is consistent with the observation by Stanley et al. (2013) that cardiac autonomic recovery may precede musculoskeletal recovery by several weeks. The subject's HRV had normalised by Day 43, but connective tissue adaptations — particularly in tendons and ligaments — require 8–16 weeks for full remodelling following extreme ultra-endurance events (Kjaer et al., 2009). The moderate IRS reading served as a cautionary signal that tissue vulnerability persisted despite apparently reassuring HRV and subjective data.

Discussion

The primary finding of this case study is that a composite, multi-metric injury risk score (IRS) identified elevated risk in a post-ultra recovery period even as individual metrics (HRV, A:C ratio) appeared normalised, and subjective readiness was high. This supports the position that single-metric monitoring is insufficient for complex return-to-training decisions following extreme endurance events (Bourdon et al., 2017).

Relationship to Existing Literature

The A:C ratio has been extensively studied in team sports. Gabbett (2016) demonstrated in a cohort of elite rugby players that an A:C ratio above 1.5 was associated with a 2–4 fold increase in injury risk over the subsequent 7 days. While the current subject's A:C ratio did not exceed 1.5 during the analysis period, the composite IRS still flagged moderate risk due to the contribution of training strain and the residual effects of acute HRV depression in the early post-race period. This suggests that for ultra-endurance athletes, a multi-metric approach may be more sensitive than A:C ratio alone.

HRV has been proposed as a practical, non-invasive marker of training adaptation and recovery (Plews et al., 2013). However, its interpretation is nuanced. Buchheit (2014) noted that HRV should not be viewed in isolation but rather integrated with other training and lifestyle markers. The current case study supports this integrative approach: HRV alone at Day 43 (47 ms, above baseline) would suggest full recovery, yet the elevated training strain and monotony history kept the IRS in the moderate risk zone.

Training monotony — a measure of the day-to-day variation in training load — has been linked to overtraining syndrome and increased illness risk. Foster (1998) found that high monotony, even at moderate absolute training loads, was predictive of upper respiratory tract infections in competitive athletes. In the present case, monotony was low (0.14), reflecting the subject's varied recovery activities (alternating rest, walking, and light jogging). This low monotony partially offset the elevated strain, keeping the IRS from reaching the high-risk threshold. Had the subject engaged in repetitive, similar-intensity recovery runs, monotony would likely have been higher, potentially pushing the IRS above 120.

Practical Applications for Coaches and Athletes

The IRS offers several practical advantages. First, it integrates data already available to most ultramarathon runners who use a GPS wrist-worn device, requiring no additional equipment. Second, it provides a single, interpretable output (a numerical score with colour-coded risk bands) that can be communicated simply to an athlete, reducing cognitive load. Third, it can be automated through wearable-to-cloud platforms, enabling daily monitoring without coach intervention.

Limitations

Several limitations should be acknowledged. This is a single-subject case study (n=1), and the findings cannot be generalised without validation in larger cohorts. The IRS thresholds proposed (80, 120, 160) are provisional and derived from this single case; they require prospective validation against injury outcomes. Additionally, the study did not include direct measures of musculoskeletal recovery, such as creatine kinase (CK) levels or imaging, relying instead on surrogate workload markers. Finally, the calculation of training strain is dependent on the accuracy of TRIMP, which may vary between devices and algorithms.

Future Directions

Future research should prospectively validate the IRS against injury outcomes in a larger cohort of ultramarathon runners, ideally over multiple training and racing cycles. Integration with direct markers of muscle damage (CK, myoglobin) and connective tissue remodelling (biomarkers of collagen turnover) would strengthen the physiological basis of the score. Machine learning approaches could also be explored to optimise the weighting of individual components and refine risk thresholds.

Conclusion

This case study demonstrates that a composite Injury Risk Score integrating training monotony, training strain, and HRV trend can identify elevated injury risk in a post-ultra recovery period, even when individual metrics appear normalised and subjective readiness is high. The findings support the value of multi-metric over single-metric monitoring for ultramarathon runners, who face a unique dissociation between subjective and objective recovery markers following extreme endurance events. While the IRS requires prospective validation, it represents a practical, low-cost tool that leverages existing wearable data to support safer return-to-training decisions. For coaches and athletes managing the complex post-ultra recovery period, a tool that says “your HRV looks good, but your training strain is still elevated — wait another day” may offer more protection than any single number alone.

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