Modality-Specific Muscle Low-Frequency Fatigue and Recovery Signatures: A Case Report Mapping the HIIT Science Taxonomy

Martin Buchheit, [1 2 3 4 5] **Paul B. Laursen** [4 5 6]

[1]Type 3.2 Performance, Montvalezan, France
[2]Optimo Performance Center, Estepona, Spain
[3]INSEP, Paris, France
[4]HIIT Science, Revelstoke, Canada
[5]Athletica, Revelstoke, Canada
[6]Sports Performance Research Institute New Zealand (SPRINZ), AUT University, Auckland, New Zealand

Low-frequency fatigue | **Neuromuscular monitoring** | **Excitation-contraction coupling** | **Muscle contractility** | **Recovery kinetics** | **Masters athlete** | **Myocene** | **Powerdex** | **Supercompensation** | **Case report**

Headline

Monitoring training in athletic populations often prioritizes the quantification of training load, yet the biological responses and adaptations resulting from that load are less consistently assessed (Buchheit and Hader 2025). Within the four-quadrant monitoring framework, a critical distinction is made between training load (the stimulus) and the athlete's biological response (the output) of the two main biological entities, i.e., the metabolic and neuromuscular systems (Buchheit and Hader 2025). This distinction is a central tenet of the HIIT Science framework, which has classified various "HIIT Weapons" into six distinct types based on their targeted physiological demands for nearly 15 years (Buchheit and Laursen, 2013a & 2013 b; Laursen and Buchheit, 2019). However, while the neuromuscular load associated with these types was conceptually described at the framework's inception, the specific, objective biological neuromuscular responses to each "Type" have remained largely unquantified and unknown.

The metabolic responses are often well-captured via heart rate response during submaximal tests (Buchheit and Hader 2025); however, objective internal neuromuscular response markers remain sparse in practical settings. Current methods typically rely on external performance proxies, such as jump tests on force plates or barbell velocity (Buchheit and Hader 2025). However, these "active" approaches require maximal effort and significant athlete buy-in, adding task demands to already constrained training timelines.

Current research has begun to characterize acute low-frequency fatigue (LFF) responses following football-specific return-to-play (Buchheit et al., 2026), maximal cycling efforts (Maia et al., 2026), and physiological exercise tests (Strepp et al., 2023). Building on these findings, the present case report utilizes LFF monitoring to provide an indirect validation of the HIIT Science training methodology. Low-frequency fatigue (LFF), or prolonged low-frequency force depression, provides a direct index of contractile impairment based on electrical stimulation and force measurements (Bernard 2023; Maia 2025; Reimann 2024; Ridard 2022; Timbert 2023; Tito 2025). LFF represents a preferential loss of evoked force at low stimulation frequencies, reflecting impaired excitation-contraction (E-C) coupling. Crucially, LFF assessment is passive and independent of motivation, making it a robust tool for identifying residual peripheral contractile impairment that may persist even when maximal voluntary force has recovered (Buchheit and Hader 2025). The present case report therefore examines whether LFF can serve as a valid neuromuscular load response marker across distinct HIIT session types, as classified within the Laursen & Buchheit (2019) framework.

Aim

The aim of this case report was to evaluate the HIIT Type-specific neuromuscular response and recovery kinetics in a 47-year-old masters athlete engaged in a concurrent training program (marathon preparation and recreational padel), following the HIIT Science framework (Laursen & Buchheit, 2019). By mapping the objective "contractile cost" of distinct HIIT "weapons" via passive LFF monitoring, the objective was to identify the different neuromuscular responses to each type and provide the necessary data to indirectly validate the conceptual load profiles established 15 years ago (Laursen and Buchheit, 2019). The ultimate goal was to determine the subsequent time course of recovery to optimize session programming and readiness management in a masters athlete.

Methods

Study design

This manuscript was prepared in accordance with CARE case report/case series reporting principles (Gagnier et al., 2013; Díaz Ibarra et al., 2023).

Participant

A 47-year-old male Masters athlete (182 cm, 80 kg) with a team sport background, currently engaging in a concurrent training program of marathon preparation and padel, totaling 6–8 hours per week.

Low-frequency fatigue

Assessments were performed at the Optimo Sport Training center in Estepona (Spain), and integrated into his routine as a passive, local marker of peripheral electromechanical function that could be repeated frequently without adding additional physical load. Neuromuscular status was quantified using the Myocene electrically evoked contractility system (Liège, Belgium), a portable device previously validated against laboratory-grade femoral nerve stimulation for the detection of low-frequency fatigue (Ridard et al., 2022; Timbert et al., 2023; Reimann et al., 2024; Tito et al., 2025). This system generates a fatigue index known as Powerdex, which is derived from the median value of 12 ratios of force responses to low-frequency versus high-frequency stimulations at increasing intensities.

All assessments followed established standardized protocols, utilizing a seated isometric configuration with bilateral self-adhesive electrodes placed over the quadriceps heads to maximize feasibility and repeatability (Ridard et al., 2022; Timbert et al., 2023; Reimann et al., 2024; Tito et al., 2025). Testing was conducted daily established under consistent pre-training conditions upon arrival at the facility to provide baseline values. Immediate post-session assessments were recorded within two minutes of exercise completion and up to 48h post to characterize peripheral responses to specific training exposures. To ensure data integrity and account for measurement noise, changes were interpreted relative to reported reliability bounds, where a Powerdex depression of approximately 3% was utilized as the minimum threshold to infer a likely real change (Bernard et al., 2023; Maia et al., 2025). All reported data represent the average of both limbs, normalized to the pre-exercise baseline values to facilitate dose-response interpretation.

Training Contents

The sessions monitored during this period represent a mix of steady-state aerobic work, generic HIIT running, small-sided football games, all-out maximal sprint efforts and gym/strength quality work (Table 1).

Table 1. Summary of training sessions and associated internal load metrics

Exercise Name	Prescription	HIIT Type	Time in HR zone (>75% / >85% HRmax, min)	Global RPE (0-10) / RPE -NM (0-10)
30min Bike Sauna Zone 2	Continuous low-intensity cycling in a heat chamber (48°, 25% RH)	Type 1	25 / 0	2 / 2
8 km Zone 2	Continuous steady-state run (36 min)	Type 1	30 / 0	3 / 3
13 km Zone 2	Continuous steady-state run (1h)	Type 1-2	50 / 0	3 / 3
Gym + 1080 accelerations work	Resistance training (3 series of 6 reps, 4 main hip extension exercises, complete rest in between reps) + 6 resisted 10-m accelerations (15-25 kg)	Type 6	N/A	4 / 5
SSG 5v5 Easy	Small-sided football games, low density (45 min)	Type 2	35 / 5	4 / 5
SSG 5v5 Moderate	Small-sided football games, moderate density (45 min)	Type 2-4	30 / 10	6 / 7
Short HIIT	2 x 12 (15s work 90% V_{IFT} / 15s passive rest intervals)	Type 1	10 / 8	8 / 4
RSA 10-0-5 with 1080	2 x 6 resisted (3 kg) sprints with CODs (10m-0-5m), starting every 30 s	Type 4	5 / 2	9 / 8
SIT	4 x 30s maximal all-out sprints (2 min passive rest)	Type 3-5	4 / 2	10 / 10

HR: Heart rate measured in beats per minute (bpm). **CODs:** changes of direction. **Global RPE:** Rating of Perceived Exertion (Borg CR-10 scale). **RPE-NM:** Differential Rating of Perceived Exertion focused on the Neuromuscular system (Borg CR-10 scale). **N/A:** Not applicable or not recorded for the specific session. **HIIT Types:** metabolic and neuromuscular demands as classified by Buchheit & Laursen (2013a, 2013b), Laursen 2019 HIIT Science Blog. **Type 1:** High aerobic, low anaerobic, low neuromuscular demand. **Type 2:** High aerobic, low anaerobic, high neuromuscular demand. **Type 3:** High aerobic, high anaerobic, low neuromuscular demand. **Type 4:** High aerobic, high anaerobic, high neuromuscular demand. **Type 3-5:** Classified as Type 5 by protocol intent; the concentric-only cycling mode produces a Type 3 neuromuscular response profile. **Type 5:** Low aerobic, high anaerobic, high neuromuscular demand. **Type 6:** Low aerobic, low anaerobic, high neuromuscular demand. **V_{IFT}:** speed reached at the end of the 30-15 Intermittent Fitness Test.

Load Monitoring

Cardiovascular and metabolic intensity were monitored throughout all sessions using the Firstbeat Sports system (Firstbeat Technologies Ltd., Jyväskylä, Finland). This allowed for the quantification of internal load via time spent in specific heart rate (HR) zones, specifically focusing on the accumulated minutes above 75% and 85% of the athlete's known maximum heart rate (HRmax) (Buchheit, Akubat et al., 2025). Subjective load was quantified using a dual-rating approach on the Borg CR-10 scale. Upon completion of each session, the participant provided a Global RPE (RPE) to reflect systemic and cardiovascular exertion, and a Neuromuscular RPE (RPE-NM) to specifically rate the perceived fatigue and "heaviness" in the lower limbs (McLaren 2015). This differentiation allowed for a granular comparison between the athlete's perceived local strain and the overall session perceived stress (Buchheit & Hader, 2025). It is important to acknowledge that a significant limitation of this report is the absence of an objective measure of external (neuromuscular) load (e.g., GPS or accelerometry-derived metrics).

Results

Acute Neuromuscular Response (0–4 Hours)

The immediate post-exercise "contractile cost" varied significantly by training modality (Figure 1). Type 1 sessions (Short HIIT, Zone 2, Sauna Bike) remained stable, with Powerdex values staying within the ±3% baseline reliability threshold. Conversely, Type 3-5 (SIT) and Type 4 (RSA) elicited the most profound acute reductions, with initial drops into the severe fatigue zone (<80%). Type 6 (Gym + 1080) demonstrated a moderate reduction, with values dropping to approximately 90% immediately post-exercise. By the 4-hour mark, a divergent recovery was visible, with concentric-dominant Type 5 sessions showing a rapid upward trend toward baseline compared to the more suppressed state of multi-directional Type 4 sessions (Figure 1).

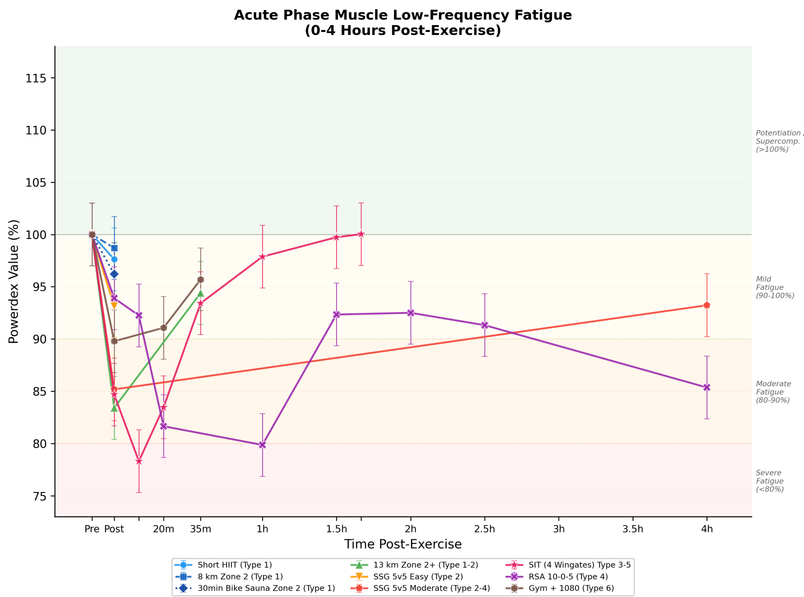

Fig. 1. Acute Phase Muscle Low-Frequency Fatigue Response (0-4 Hours Post-Exercise). See Table 1 for more details about the different training contents.

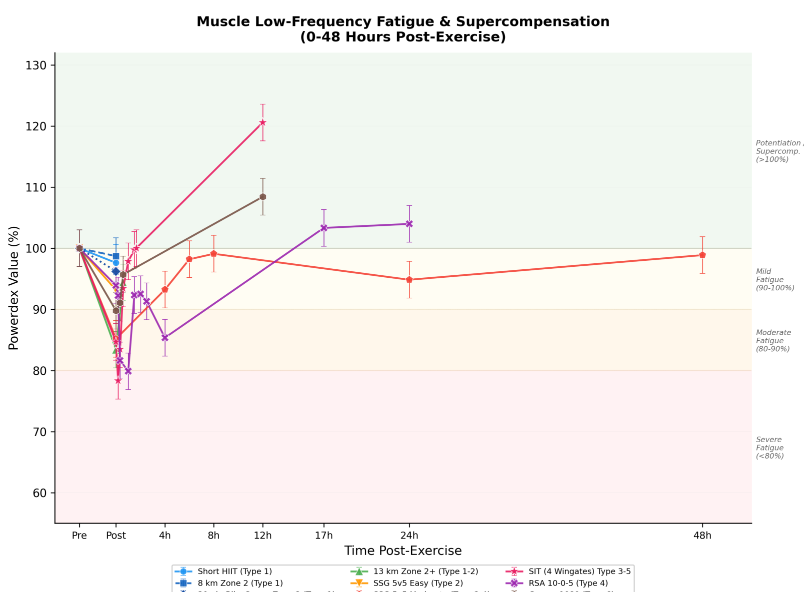

Fig. 2. Long-term Phase Low-Frequency Fatigue Response (0-48 Hours Post-Exercise). See Table 1 for more details about the different training contents.

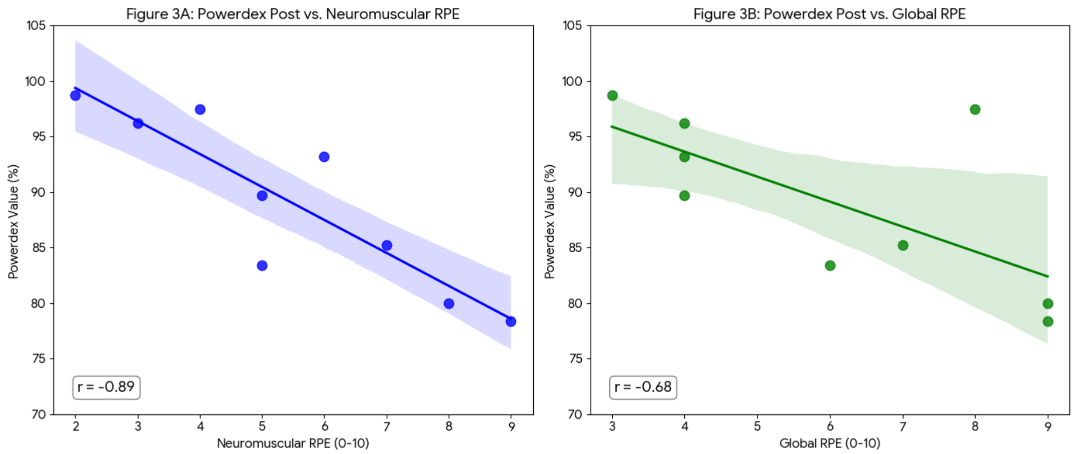

Fig. 3. A: Association between Powerdex Post Session Value and Neuromuscular RPE. B: Association between Powerdex Post Session Value and Global RPE. The shaded translucent band around the regression line represents the 95% Confidence Interval (CI) for the regression estimate.

Longitudinal Recovery and Supercompensation (0–48 Hours)

The recovery kinetics over 48 hours revealed distinct patterns of potentiation and residual fatigue (Figure 2). A significant supercompensation effect was observed at the 12-hour mark for high-intent sessions: Type 3-5 (SIT) peaked at ~121%, followed by Type 6 (Gym + 1080) at ~108%, and Type 4 (RSA) at ~103%. While Type 3-5 and 6 sessions returned to or exceeded baseline within 4–12 hours, Type 4 (RSA and SSG Moderate) sessions exhibited a "long-tail" recovery signature. In these sessions, Powerdex values remained depressed or only returned to baseline levels between 24 and 48 hours post-exercise (Figure 2).

Correlation of Neuromuscular Response and Internal Load Metrics

Correlation analysis between the acute Powerdex response (post-exercise) and internal load metrics revealed a very strong negative relationship with Neuromuscular RPE ($r = -0.89$; Figure 3A). Global RPE demonstrated a moderate negative correlation ($r = -0.68$; Figure 3B). Regarding cardiovascular markers, time spent >85%HRmax showed a moderate negative correlation with the acute Powerdex drop ($r = -0.55$), while time spent above 75% HRmax exhibited no measurable relationship with post-exercise contractility ($r = 0.04$). These values indicate that the athlete's subjective perception of local muscle strain (RPE-NM) was the most accurate proxy for the objective "contractile cost" across the various HIIT Science types.

Conclusion and practical applications

These findings provide an indirect validation of the HIIT Science framework (Buchheit & Laursen 2013a, 2013b, Laursen & Buchheit 2019, Laursen 2019 HIIT Science Blog). It is important to distinguish between the two: HIIT Science classifies training "Types" based on the stimulus (load), whereas this study measures the biological output (response) via Powerdex. While load and response are not the same and should not be interchanged, there is a clear implicit link: a greater drop in muscle contractility (LFF) likely reflects a higher neuromuscular load. By showing that specific "Types" of training consistently trigger predictable neuromuscular recovery signatures, this study uses objective biological data to support the core principles of the HIIT Science methodology.

Importantly, by characterizing the Powerdex response across a heterogeneous array of off- and on-field training modalities, this report facilitates a transition from broad training response quantification toward a granular, system-specific assessment of neuromuscular recovery kinetics. Such differentiation remains paramount for operationalizing dose-response relationships, moving the focus from simple exposure towards objective biological output (Buchheit & Hader 2025).

Type 1 Modalities as "Neuro Low Cost"

Modality-specific responses confirm that Type 1 sessions, such as short Zone 2 runs and the 30-min sauna bike, represent a "low-cost" neuromuscular stimulus. In these sessions, Powerdex values remained within the established 3% reliability threshold, suggesting no significant onset of LFF beyond measurement noise (Figure 1). The integration of thermal stress during the sauna bike session serves as a strategic mechanism to elevate cardiovascular internal load while successfully decoupling metabolic demand from neuromuscular strain. These findings reinforce the Type 1 classification (Laursen & Buchheit 2019), prioritizing aerobic metabolic pathways with a negligible cost to the peripheral contractile apparatus.

Physiological Drivers of Severe LFF (<80%): The Metabolic "Extra Cost"

Training modalities eliciting moderate (80–90%) or severe (<80%) LLF (Figure 1, specifically Type 4 -RSA/SSG Moderate- and Type 3-5 -SIT-), were characterized by high mechanical intensity and acceleration-deceleration density (Table 1). This aligns with recent evidence in elite football where LFF responses aligned more closely with mechanical-intensity metrics, such as mechanical work and time spent in high-intensity acceleration/deceleration zones, than with volume descriptors alone (Buchheit et al., 2026).

At the cellular level, these deep drops reflect a rightward shift of the force-frequency relationship due to impaired excitation-contraction (E-C) coupling. In these high-intensity types, the impairment is significantly exacerbated by a "metabolic layer." During maximal efforts, the accumulation of metabolites such as inorganic phosphate (Pi) and hydrogen ions (H^+) interferes with E-C coupling. Mechanistically, Pi reduces the amount of Ca^{2+} released from the sarcoplasmic reticulum and decreases the sensitivity of troponin to Ca^{2+}, effectively depressing force-generating capacity even when neural drive is maintained (Dutka et al., 2005; Posterino & Fryer, 1998). The critical role of this metabolic interference is highlighted by the response to SSG Easy (Type 2). Despite involving multi-directional movement patterns close to Type 4 sessions (RPE-NM 5 vs 7), the SSG Easy did not induce a severe contractile drop. This is precisely because this easier session is not "lactic" in nature; the sub-maximal intensity prevents the significant metabolite flux required to disrupt E-C coupling. In the high-intensity types (RSA and SIT), the Neuromuscular RPE (RPE-NM: 8-9) served as a highly accurate subjective proxy for this objective "neuro extra cost," differentiating local muscle strain from the systemic demand (Global RPE). This subjective-objective link was statistically validated by a very strong negative correlation between the acute Powerdex index drop and RPE-NM (r = -0.89; Figure 3A), which significantly outperformed the Global RPE (r = -0.68; Figure 3B) as a mediator of contractile impairment. This corroborates findings in highly-trained road cyclists, where a large association was identified between LFF scores and perceived fatigue (r = -0.50) (Maia et al., 2026).

Differentiating Recovery Kinetics: Intent, Mode, and Metabolic Debt

A critical finding of this study is that the recovery trajectory, and specifically the timing of a supercompensation "rebound", was likely dictated by the interaction between contraction mode and metabolic intensity.

The "Threshold of Intent" for Supercompensation

Significant supercompensation (Powerdex >100%) followed RSA (Type 4), SIT (Type 3-5), and Gym + 1080 (Type 6). The common thread is the "all-out," high-intent nature of the contractions, which likely triggers post-activation potentiation (PAP) mechanisms. Notably, the SSG Moderate (Type 4) session failed to elicit a rebound. Despite involving multi-directional movements and a high RPE-NM (7), the lack of true maximal neural drive meant the stimulus was insufficient to trigger the potentiation effect needed to overcome the initial contractile cost.

Rapid Rebound: Concentric and Non-Metabolic Priming

The timing of the rebound was significantly faster in concentric-dominant modalities:

- **Concentric + High Metabolite (Type 3-5):** Despite the SIT causing a severe initial drop and high Global RPE (9), a rapid rebound occurred within 4 hours. This recovery signature mimics a **Type 3** response (where metabolic demand is high, but the neuromuscular cost is transient). Because the stimulus was cycling-based (concentric-only), the absence of eccentric-induced structural damage allowed for the rapid restoration of E-C coupling as soon as metabolites were cleared. This suggests that the "contractile cost" of SIT is largely metabolic in a cycling context; it is hypothesized that a running-based SIT (involving high-speed decelerations) would produce a "long-tail" recovery more akin to the **RSA (Type 4)** protocol.
- **Concentric + Low Metabolite (Type 6):** The Gym + 1080 session (resisted sprints/hip extension with complete rest) provided a unique "readiness-positive" signature. By using concentric-only movements and long rest periods, the metabolic cost was minimized (Global RPE: 4). This allowed high-intent contractions to "prime" the system, yielding a manageable contractile cost (∼90%) and a potentiation rebound without the deep fatigue-hole of anaerobic sessions.

The "Long-Tail" Recovery: The Eccentric-Metabolic Tax

In contrast, a "long-tail" recovery kinetic (48+ hours) was exclusive to sessions combining high eccentric loading with significant metabolic interference, most evident in the RSA session with COD (Type 4). The high density of decelerations and COD maneuvers imposes a mechanical tax that requires a significantly longer window for restoration compared to concentric-only modalities, regardless of their metabolic intensity (Figure 2).

Strategic Programming and the Weekly Plan

Visualizing the precise recovery time course allows for the strategic sequencing of a training plan for both healthy (Buchheit 2024) and injured (Buchheit, Balaña et al. 2025) athletes. This objective data transitions programming from a theoretical "best guess" to an individualized, response-led model.

Autoregulation: The "Go/No-Go" Decision

The use of "Pre" baseline measures when athletes check in at the training facility provides a critical safety net. If the baseline Powerdex is significantly depressed (e.g., >6% below the athlete's rolling average), the planned session could be downshifted. This prevents the "stacking" of neuromuscular debt, which is a strong driver of overuse injuries and chronic performance stagnation. Moreover, this objective check prevents the initiation of gym-based strength or power sessions while in a state of neuromuscular fatigue. From a concurrent training perspective, attempting a high-quality resistance stimulus with compromised muscle contractility is suboptimal; the residual fatigue can interfere with the specific signaling pathways required for adaptation, effectively blunting the desired training effect and exacerbating the "interference effect" between conflicting energy systems. The robust correlation (r = -0.89) between the Powerdex response and RPE-NM (Figure 3A) provides the athlete and coach with a statistically-validated 'internal compass.' It suggests that when the LFF passive assessment is unavailable, the subjective perception of muscle heaviness following the previous session may serve as a reliable surrogate for objective readiness, allowing for high-fidelity autoregulation even in field-based settings.

The HIIT vs. Zone 2 Trade-off: A Cost/Benefit Approach

When neuromuscular fatigue is high, replacing a scheduled HIIT session with a Type 1 (Zone 2/Continuous) session is a viable strategy to manage neuro load. However, this must be approached as a cost/benefit decision. While this substitution successfully preserves the peripheral contractile apparatus, it is recognized that the cardiovascular and metabolic stimuli are not perfectly equivalent. As highlighted by Inglis et al. (2024) and recent meta-analyses (BI et al, 2026) comparing HIIT to continuous training, HIIT often elicits superior or more time-efficient adaptations in VO2max, stroke volume, and peripheral metabolic signaling. Therefore, the practitioner must weigh the "benefit" of preventing further neuromuscular LFF against the "cost" of a potentially attenuated metabolic stimulus. In a concurrent training model, this allows for the maintenance of aerobic volume during periods of high "contractile cost" without causing further damage to the E-C coupling mechanism.

The 12-Hour "Priming" Window

The 12-hour supercompensation rebound observed after Type 6 (Gym + 1080 with complete rest) and Type 5 (cycling SIT) sessions offers a unique window for "priming." A low-volume, high-intent session performed in the morning can serve as a potentiation tool for a subsequent high-quality session (e.g., technical skill work or high-speed intervals) in the evening. This leverages the acute improvement in E-C coupling expression without the long-lasting structural fatigue associated with Type 4 field work.

Summary of Sequencing Principles

- **Type 1 (Low Cost):** Serves as the primary tool to maintain cardiovascular volume when the "cost" of HIIT is deemed too high for the current neuromuscular state.
- **Type 4 (SSG/RSA):** Requires a deliberate 48-hour recovery window before another high-intent neuromuscular stimulus due to the "long-tail" eccentric/metabolic tax.
- **Type 3-5/6 (cycling SIT/Gym with complete rest):** Provides an optimal 12-hour supercompensation window for quality-heavy work, provided structural damage is minimized.

Key Practical Applications

- **RPE-NM as a Load Proxy:** Perceived "muscle heaviness" (RPE-NM) may be a valid proxy for neuromuscular load. Its high correlation (r = -0.89) with objective fatigue response (i.e., LFF) allows it to reliably estimate a session's "contractile cost."
- **Pre-Baseline Go/No-Go:** A >6% drop (i.e., 2x the typical error) in baseline Powerdex could signal incomplete "neuromuscular contractile capacity recovery." Downshifting sessions may then be a way to avoid suboptimal adaptation and the "interference effect" in the gym.
- **Type 1 "Neuro Low-Cost" Foundation:** Sessions like Zone 2 runs or Sauna Bike maintain aerobic volume with negligible neuromuscular cost (<3% drop). They are the primary tools for preserving fitness during the 48-hour recovery "long-tails" of taxing Type 4 work.
- **Modality-Dependent SIT Recovery:** Cycling-based SIT (Type 5) mimics a Type 3 signature (high metabolic, low neuromuscular cost). Its concentric-only nature allows a rapid 4-hour rebound once metabolites clear, avoiding the delayed recovery typical of eccentric-heavy field work.
- **12-Hour Priming Window:** High-intent, concentric-only sessions (Type 5/6) trigger peak supercompensation (up to 121%) at 12 hours, the optimal window for matches or high-skill work.
- **48-Hour Recovery Rule:** Multi-directional Type 4 sessions (RSA/SSG) require a 48-hour recovery window due to the combined eccentric and metabolic "extra cost."
- **HIIT vs. Zone 2 Trade-off:** Swapping HIIT for Type 1 may help to protect muscles from excessive fatigue, but requires a cost-benefit approach, as the metabolic stimulus may be attenuated.

References

1. Bernard O, André N, Audiffren M. (2023). Repeatability and reproducibility of an on-field device for measuring low-to high-frequency muscle force ratio. In: Proceedings of the 28th Annual Congress of the European College of Sport Science (ECSS); Jul 2023; Paris, France.

2. Bi Z, Yin M, Xu K, Marcotte-Chénard A, Zhong Y, Gu Z, Vollaard N, Metcalfe R, Nassis G, Girard O, Bishop D, Li Y. One Size Does Not Fit All: A Meta-Analysis of 115 Trials Comparing High-Intensity Interval and Moderate-to-Vigorous-Intensity Continuous Training Across Diverse Participants, Protocols, and Outcomes. Scand J Med Sci Sports. 2026 Mar;36(3):e70243. doi: 10.1111/sms.70243. PMID: 41804294.

3. Buchheit M, Akubat I, Ellis M, Campos M, Rabbani A, Castagna C, Malone S. Revisiting dose–response relationships between heart rate zones, TRIMPs, and aerobic-related physiological and performance markers in elite team sports. Sports Performance & Science Reports, #269, Oct 2025.

4. Buchheit M, Balaña O, Ogden A, Saniel G, Harries S. Structuring the daily progression from return-to-run to full team integration. Sport Perf & Science Reports, #251, Feb 2025.

5. Buchheit M, Barba Balda E, Lopez Sagarra A, Carruthers T, Ogden A, Marques J, Hader K, Millet GY. Monitoring low-frequency fatigue during return-to-play in elite football: physiological basis and a four-case series. Sports Performance & Science Reports, #289, Apr 2026.

6. Buchheit M, Douchet T, Settembre M, McHugh D, Hader K, & Verheijen R. The 11 Evidence-Informed and Inferred Principles of Microcycle Periodization in Elite Football. Sport Performance & Science Reports, #218, Feb 2024.

7. Buchheit M, Hader K. Data everywhere, insight nowhere: a practical quadrant-based model for monitoring training load vs. response in elite football. Sport Perf & Science Reports, #258, May 2025.

8. Buchheit M, Laursen PB. (2013a). High-intensity interval training, solutions to the programming puzzle: Part I: cardiopulmonary emphasis. Sports Med. 43(5):313-38.

9. Buchheit M, Laursen PB. (2013b). High-intensity interval training, solutions to the programming puzzle. Part II: anaerobic energy, neuromuscular load and practical applications. Sports Med. 43(10):927-54.

10. Díaz Ibarra EA, Abella Pinzón JA, Medina YF. Methodology: How to develop a case report or case series report. Rev Colomb Reumatol (Engl Ed). 2023;30(2):129-136. doi:10.1016/j.rcreue.2021.05.012.

11. Dutka TL, Cole L, Lamb GD. (2005). Calcium phosphate precipitation in the sarcoplasmic reticulum reduces action potential-mediated Ca2+ release in mammalian skeletal muscle. Am J Physiol Cell Physiol. 289(6):C1502–C1512. doi:10.1152/ajpcell.00273.2005.

12. Gagnier JJ, Kienle G, Altman DG, Moher D, Sox H, Riley D; CARE Group. The CARE guidelines: consensus-based clinical case reporting guideline development. J Clin Epidemiol. 2014;67(1):46-51. doi:10.1016/j.jclinepi.2013.08.003. PMID: 24246719.

13. Inglis EC, Iannetta D, Rasica L, Mackie MZ, Keir DA, Macinnis MJ, Murias JM. Heavy-, Severe-, and Extreme-, but Not Moderate-Intensity Exercise Increase $\dot{V}$O2max and

Thresholds after 6 wk of Training. Med Sci Sports Exerc. 2024 Jul 1;56(7):1307-1316. doi: 10.1249/MSS.0000000000003406. Epub 2024 Feb 3. PMID: 38376995.

14. Laursen P, Buchheit M. (2019). Science and Application of High-Intensity Interval Training. Human Kinetics.

15. Laursen P. Why the HIIT Types Matter: A Roadmap to Better Programming. HIIT Science [Internet]. 2018 [cited 2026 Mar 12]. Available from: `https://hiitscience.com/why-hiit-types-matter/`

16. McLaren SJ, Graham M, Spears IR, Weston M. The Sensitivity of Differential Ratings of Perceived Exertion as Measures of Internal Load. Int J Sports Physiol Perform. 2016 Apr;11(3):404-6. doi: 10.1123/ijspp.2015-0223. Epub 2015 Jul 27. PMID: 26218099.

17. Maia F, Nakamura FY, Tito S, Ribeiro J. (2025). Test-retest reliability of Myocene for assessing lower limb low-frequency fatigue: a cross-condition reliability study. Meas Phys Educ Exerc Sci. doi:10.1080/1091367X.2025.2592622.

18. Maia F, Nakamura FY, Tito S, et al. A Short Maximal Effort Induces Greater Low-Frequency Fatigue than Prolonged Cycling in Highly-Trained Road Cyclists. Int J Exerc Sci. 2026;19(1):1-11.

19. Posterino GS, Fryer MW. (1998). Mechanisms underlying phosphate-induced failure of Ca2+ release in single skinned skeletal muscle fibres of the rat. J Physiol. 512(Pt 1):97–108. doi:10.1111/j.1469-7793.1998.097bf.x.

20. Reimann M, Rosenthal T, Ferrauti A. (2024). Validity of low frequency fatigue (LFF) as a marker of muscle function after a strength, endurance or sprint training under field conditions. In: Proceedings of the 29th Annual Congress of the European College of Sport Science (ECSS); 2024 Jul 2-5; Glasgow, Scotland.

21. Ridard J, Rozand V, Millet GY, Lapole T. (2022). On-field low-frequency fatigue measurement after repeated drop jumps. Front Physiol. 13:1039616. doi:10.3389/fphys.2022.1039616.

22. Strepp T, Blumkaitis J, Haller N, Stöggl T. Effects of a physiological exercise test and a HIIT shock microcycle on muscle fatigue measured with a novel device: case study on acute and chronic changes. ICSS; 2023

23. Timbert T, Babault N, Methenitis S, Cometti C, Amiez N, Paizis C. (2023). The effect of bodyweight support and incline running on triceps surae electromyographic activity. Appl Sci (Basel). 13(17):9620. doi:10.3390/app13179620.

24. Tito S, Maia F, Correia M, Ribeiro J. (2025). Recovery Patterns of Low-frequency Fatigue in Elite Youth Soccer Players after Official Matches. Int J Sports Med. 46(4):263-270. doi:10.1055/a-2456-2151.