Inter-limb low-frequency fatigue tracks the distribution of training dose rather than the underlying deficit: a case report from a five-week strength camp in an elite youth footballer

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Headline

Training monitoring in football continues to prioritise the quantification of load over the measurement of the biological response to it (Buchheit & Hader, 2025). Within the four-quadrant framework separating load from response and metabolic from neuromuscular domains, low-frequency fatigue (LFF), also known as prolonged low-frequency force depression, occupies the internal neuromuscular response quadrant. It is derived from electrical stimulation combined with force sensing (Ridard et al., 2022; Timbert et al., 2023; Reimann et al., 2024; Tito et al., 2025), and its applied appeal is that it is passive, repeatable and independent of the athlete's motivation.

Two recent applied reports have mapped LFF onto training content. The first characterised modality-specific recovery signatures across the HIIT Science taxonomy in a masters athlete and showed distinct recovery kinetics by session type (Buchheit & Laursen, 2026). The second described the time course of quadriceps LFF across return-to-play in four elite footballers and showed that the acute contractile cost of a session aligned with mechanical-intensity descriptors rather than with volume (Buchheit et al., 2026). Both measured bilaterally, and both interpreted persistent inter-limb asymmetry as an indicator of limb status: in the hamstring cases of the four-case RTP series, an asymmetry that failed to converge by discharge was read as incomplete restoration of limb-level neuromuscular function. That reading rests on an assumption which has not been tested. Inter-limb LFF asymmetry may reflect the athlete's condition, or it may simply reflect how the training dose is distributed between limbs. In a rehabilitation setting, the two are inseparable, because work is naturally biased toward the injured side for exactly as long as the deficit persists. Separating them requires a context in which the asymmetric dosing is deliberate, documented, and then deliberately withdrawn while monitoring continues.

This report describes such a context: a five-week individualised summer camp in an elite youth footballer whose programme opened with explicitly asymmetric unilateral dosing aimed at a hamstring strength deficit, progressed to symmetrical bilateral loading with maximal and supramaximal intent, and finished with a planned taper. The case has a second useful feature. The player arrived ten weeks after a lateral ankle sprain of the left limb, while the strength deficit the camp was built to correct sat in the right hamstring, and the measurement itself was taken at the quadriceps. Injury site, deficit site and measurement site were therefore on three different structures and two different limbs, so any limb-level signal cannot simply be a local echo of the injured tissue.

Aim

This case report had three aims: (i) to describe the time course of bilateral quadriceps LFF across a five-week strength and reconditioning camp in an elite youth footballer; (ii) to relate the acute contractile cost of a session to its content in an applied setting in which no external load quantification was available; and (iii) to test whether inter-limb LFF asymmetry moves with the deliberate distribution of training dose between limbs, or whether it behaves as a fixed property of the athlete.

Methods

Study design

Prospective observational single-case report, prepared in accordance with CARE case report principles (Gagnier et al., 2014; Díaz Ibarra et al., 2023). Monitoring was conducted as part of routine practice at Optimo Sport Clinic Estepona, a private performance and rehabilitation centre; the analysis was performed retrospectively on the complete dataset.

Participant and clinical context

A 16-year-old male winger from the academy of a Top European first-division club (body mass 65 kg at entry, 67 kg at exit). Ten weeks before the camp he had sustained a lateral ankle sprain of the left (dominant) limb through an inversion and plantarflexion mechanism, with rupture of the anterior talofibular ligament and an associated bony avulsion; the syndesmosis, calcaneofibular ligament and midfoot were uninvolved. He arrived cleared for progressive loading, pain free in daily activities and in on-field work, with a residual bilateral dorsiflexion restriction of approximately 5°.

Independently of the ankle injury, isokinetic testing at the club had identified a substantial concentric hamstring strength deficit of the right (non-dominant) limb, 32% at 60°/s, present across three consecutive club assessments over the preceding eight months. The two problems therefore sat on opposite limbs, which is the feature that makes this case informative: the tested muscle group (quadriceps), the injured joint (left ankle) and the strength deficit (right hamstring) were dissociated by design rather than by chance.

Setting and training programme

Five consecutive weeks at a residential performance centre (Optimo Sport, Estepona, Spain), five sessions per week from Monday to Friday, weekends unsupervised and free of scheduled training. Thursday was the only afternoon session; the player was asked to rest on Thursday mornings. Each daily session comprised a main block and three secondary blocks (Table 1).

The programme was structured in two phases followed by a taper. Phase one (weeks 1 and 2) applied deliberately asymmetric unilateral dosing, including R+L+R set structures, targeting the right hamstring deficit. Phase two (weeks 3 to 5) progressed to equal repetitions between limbs with maximal and supramaximal intent, while locomotor content was introduced: ankle-specific isometrics from week 2, indoor running and change-of-direction work on a gym track from week 3, the first purely running session on 2 July (indoors, athletic work without football), the first outdoor pitch session on 6 July, and outdoor pitch sessions on 13 and 15 July. The final three days were tapered at the request of the parent club so that the player would arrive fresh for club testing. Throughout both phases the coaching staff maintained a deliberate emphasis of effort on the deficit side.

Table 1. Training content by week
Main and secondary blocks for each training day. Thursday was the only afternoon session in every week. Weekends were unsupervised.

Week	Monday	Tuesday	Wednesday	Thursday (PM)	Friday
1	No session (camp began on Tuesday)	Interview, screening, first loads	Ankle rehab, proprioception, knee extension ISO (quadriceps)	Calf strength, hip lock, core, hamstring long lever (mid–range) strength	Single-leg balance, low-amplitude plyometrics, hinge, hamstring ISO R+L+R
2	Ankle rehab, performance test, knee-dominant squat, hamstring mid-range	Conic pulley prep, upper-body pull, balance, heat room	Ankle and calf, first locomotion drills, Olympic lifts, hinge, hamstring eccentrics	Plyometric prep, braking and deceleration, single-leg squat VBT	Footwork, hip-dominant squat, hip thrust, quadriceps eccentrics
3	Ankle rehab, performance test, knee-dominant squat, hamstring mid-range	Plyometric prep, balance-jump, posterior chain, 1080 acceleration and deceleration	Ankle rehab, trunk stiffness, hamstring ISO, heat room	Run prep, zig-zag and box drill, acceleration and deceleration, ball passes	Footwork, hip-dominant squat, hip thrust, quadriceps eccentrics
4	Run prep, receive and pass, dual task, long HIIT (pitch session)	Plyometric prep, balance-jump, posterior chain, 1080 acceleration and deceleration	Ankle rehab, performance test, squat and single-leg drop-quarter, hamstring cable	Run prep, receive and pass, dual task, heat room	Footwork, knee-dominant squat, hip thrust, quadriceps eccentrics
5	Pitch prep, performance test, moderate chaos, 15 x 15 s	Intensive plyometrics, balance-jump, RDL and hamstring eccentrics, heat room	Pitch prep, moderate chaos, 15 x 15 s	Extensive plyometrics, final testing, quadriceps ISO, core (taper)	Footwork, run-specific ISO, RDL and hamstring eccentrics, heat room

Low-frequency fatigue assessment

Study design

Neuromuscular status was quantified with an electrically evoked contractile assessment system (Myocene, Liège, Belgium) in a standardised seated isometric configuration, with self-adhesive stimulation electrodes placed bilaterally over the quadriceps heads and mechanical output recorded during the stimulation sequence. Both limbs were assessed simultaneously in every trial, so no testing-order effect is possible. The device outputs a fatigue index (Powerdex) computed as the median of 12 ratios of force responses to low- versus high-frequency stimulation, each corresponding to an increasing stimulation intensity (Buchheit et al., 2026).

Assessments were performed on arrival at the facility before any activity (pre) and after the final block of the session (post), within 5 to 10 minutes of completion. Outdoor pitch sessions were the exception: the player returned to the clinic by car with his family, so the post-session measure on those days was taken approximately 30 minutes after the end of exercise. Electrode placement, joint angle and fixation were reproduced across sessions, and the same device and configuration were used throughout.

Reliability thresholds

Under field conditions, Bernard et al. (2023) reported limits of agreement consistent with a typical uncertainty of approximately ±3% for repeated Powerdex measures. Maia et al. (2025) reported coefficients of variation of 4.1% and 3.4% and intraclass correlations of 0.62 and 0.75 for dominant and non-dominant limbs in youth elite soccer players. Changes were therefore interpreted against a 3% minimum detectable change and a more conservative 6% threshold, twice the typical error, for a likely real change (Buchheit et al., 2026).

Monitoring period

Low-frequency fatigue was not measured on 17 and 18 June, the first two days of the camp, which were devoted to the interview, movement screening and the setting of initial training loads. Monitoring therefore covers 21 of the 23 training days. The two unmonitored days are retained on the axes of the figures and as rows in Table 2, without values, so that the training content delivered on those days remains visible.

Training content classification

Sessions were classified from staff records into six categories: indoor running, outdoor pitch, plyometric and braking work, quadriceps-dominant strength, hamstring-dominant strength, and low load (upper body, trunk, heat room). Content dates were verified with the lead coach after the initial analysis. No external load quantification (GPS, accelerometry) and no session-RPE were available, which is the principal limitation of this report.

Strength testing

Isokinetic knee flexor and extensor peak torque was measured at the parent club on 2 April 2026 (before the camp) and on 20 July 2026, three days after the camp ended, at 60°/s and 240°/s concentric and 30°/s eccentric. Within the camp, isometric peak force and rate of force development were assessed on a force frame, and countermovement and hop jumps on dual force plates (Cohen et al., in preparation).

Analysis

Analysis was descriptive and focused on within-player change. The acute response was expressed as the percentage change from the same-morning pre value, which requires no external reference. Baseline trends were expressed relative to the camp mean for each limb (left 85.1, right 75.0 A.U.). Inter-limb asymmetry was calculated as (left - right)/left × 100, with positive values indicating a lower right-limb value. Day-to-day stability was expressed as the change from one morning pre value to the next. Comparisons are reported as the mean difference with its 90% confidence interval and as a standardised effect size. A confidence interval that did not include zero was interpreted as a substantial difference; an interval that included zero was interpreted as unclear.

Results

Overview

Twenty-one paired pre and post assessments were completed across the 23 training days (Table 2). Mean pre-session Powerdex was 85.1 A.U. on the left and 75.0 A.U. on the right. Mean acute change was -5.7% (90% CI -7.8 to -3.7) on the left and -9.8% (90% CI -12.9 to -6.6) on the right. The difference between limbs was substantial: 4.1 percentage points (90% CI 1.1 to 7.0; ES 0.59). The right limb lost more than 10% of its morning value on 11 of 21 days; the left limb on 3.

Table 2. Session-by-session Powerdex.
Pre-session values and acute change for both limbs, with inter-limb asymmetry before the session. Positive asymmetry indicates a lower right-limb value. Low-frequency fatigue was not measured on the first two days; the training content delivered on those days is shown for completeness.

Date	Content category	Left pre	Left Δ%	Right pre	Right Δ%	Asymmetry %
17 Jun	Screening, ankle rehab, quadriceps and hamstring isometrics	not measured	not measured	not measured	not measured	not measured
18 Jun	Calf strength, hip lock, positional sense, core	not measured	not measured	not measured	not measured	not measured
19 Jun	Plyometric / braking	86.4	-7.5	78.0	-15.4	9.7
22 Jun	Quadriceps strength	84.6	-3.3	80.4	-8.8	5.0
23 Jun	Low load	86.8	-3.0	71.1	+3.5	18.1
24 Jun	Hamstring strength	85.8	-2.7	75.7	+2.0	11.8
25 Jun	Plyometric / braking	87.3	-23.1	79.7	-17.1	8.7
26 Jun	Quadriceps strength	89.4	-13.8	71.4	-12.9	20.1
29 Jun	Quadriceps strength	85.4	+0.6	70.3	+1.6	17.7
30 Jun	Plyometric / braking	86.4	-10.3	70.2	-17.5	18.8
01 Jul	Low load	87.0	-5.1	80.1	-12.6	7.9
02 Jul	Indoor running	90.7	-7.8	79.3	-27.6	12.6
03 Jul	Quadriceps strength	85.6	-5.0	70.7	-18.4	17.4
06 Jul	Outdoor pitch	83.6	+2.5	80.2	-17.0	4.1
07 Jul	Plyometric / braking	85.7	-7.5	76.4	-7.7	10.9
08 Jul	Low load	84.9	-2.6	69.1	-1.0	18.6
09 Jul	Indoor running	83.3	-6.7	71.4	-2.9	14.3
10 Jul	Quadriceps strength	82.3	-7.9	75.8	-14.9	7.9
13 Jul	Outdoor pitch	81.5	-1.1	71.9	-16.7	11.8
14 Jul	Plyometric / braking	83.7	-7.0	76.6	-6.1	8.5
15 Jul	Outdoor pitch	82.5	-4.7	70.6	-5.2	14.4
16 Jul	Plyometric / taper	82.8	-0.1	71.3	+0.1	13.9
17 Jul	Hamstring strength	83.1	-4.2	82.1	-10.8	1.2

Baseline trajectory

The morning pre value described an inverted U on the left limb (Figure 1A). It rose across weeks 2 and 3, peaked at 90.7 A.U. on 2 July, and then declined. Weeks 2 to 3 averaged 86.9 A.U. and weeks 4 to 5 averaged 83.3 A.U., a substantial fall of 3.6 A.U. or 4.1% (90% CI 2.3 to 4.8 A.U.; ES 2.24). From the peak to week 5, the mean decline reached 8.8%, exceeding the 6% threshold for a likely real change. Over the same period, the right limb baseline was unchanged and the comparison unclear (0.4 A.U., 90% CI -3.1 to 3.8; ES 0.08).

This decline coincided with the programmed transition from gym-based to pitch-based content in weeks 4 and 5, which the lead coach independently identified as the period of greatest locomotor and impact exposure. The force plate data agreed: countermovement jump eccentric rate of force development fell from 9138 N/s (left) and 8009 N/s (right) on 8 July to 2584 and 1890 N/s on 16 July. Heat and fluid restriction are plausible additional contributors that cannot be separated from training load here.

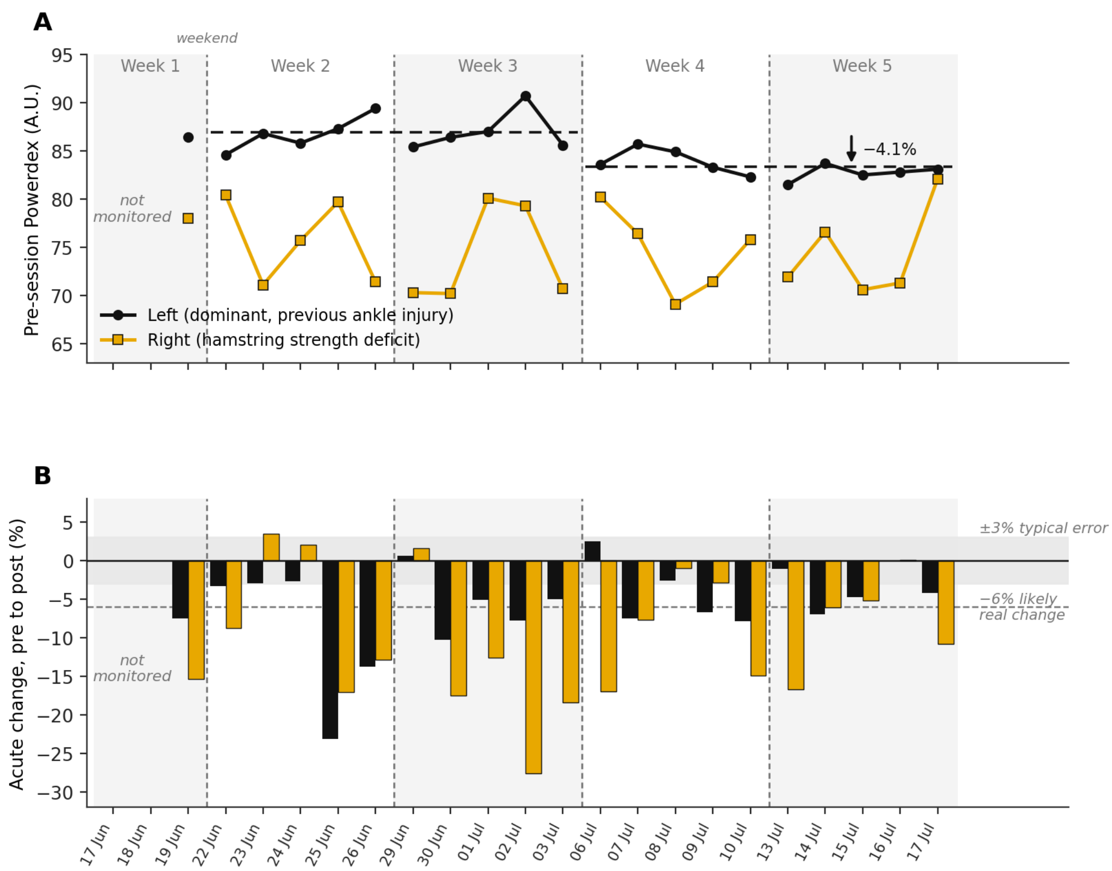

Fig. 1. Bilateral quadriceps low-frequency fatigue across the five-week camp. (A) Morning pre-session Powerdex for both limbs. Dashed lines show the weeks 2–3 and weeks 4–5 means for the left limb. (B) Acute pre-to-post change for every session. The shaded band is the ±3% typical error and the dashed line the 6% threshold for a likely real change. Low-frequency fatigue was not monitored on 17 and 18 June; both days are retained on the axis without values. Lines are broken at weekends.

Acute contractile cost by session content

The ranking of session types by acute contractile cost (Figure 2) reproduced the ordering previously reported in elite football rehabilitation and in a concurrent-training masters athlete (Buchheit et al., 2026; Buchheit & Laursen, 2026). Locomotor content was the most costly, indoor running and outdoor pitch sessions producing right-limb changes of -15.2% and -13.0%, roughly twice the cost of quadriceps-dominant strength work (-8.9%); low-load sessions were indistinguishable from measurement noise, and on two of them the right limb finished slightly above its morning value.

One category was the exception. Plyometric and braking work produced -11.1% on the left and -12.8% on the right, the only content for which the two limbs paid a comparable price. Everywhere else the right-limb cost was approximately twice the left.

Three within-camp contrasts

Three contrasts within the block illustrate the dose–response relationship directly. An identical Monday session repeated one week apart cost -3.3% and -8.8% on 22 June but +0.6% and +1.6% on 29 June, and the lead coach confirmed the later session was the harder of the two. The two largest right-limb decrements of the camp both fell in week 3: -27.6% on 2 July, the first purely running session, and -18.4% the next day, when the same Friday strength session that had cost -12.9% on 26 June now followed a running exposure. That Friday session, repeated three times, produced right-limb decrements of -12.9%, -18.4% and -14.9%, the most repeatable single stimulus in the camp.

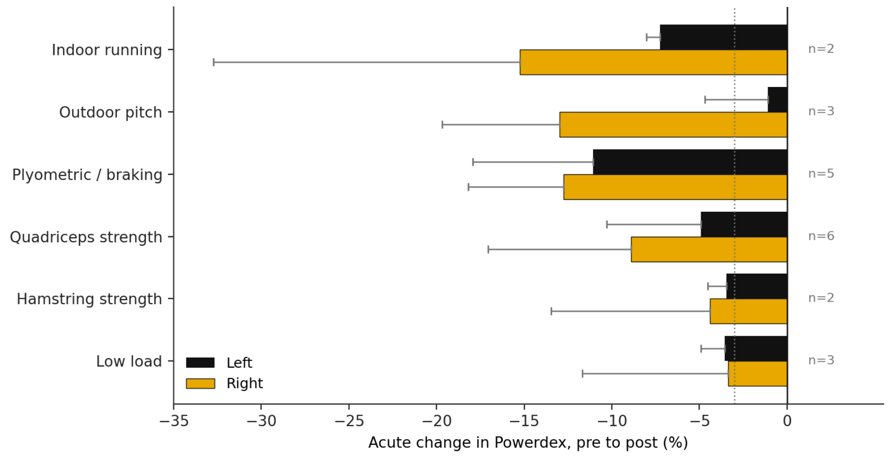

Fig. 2. **Mean acute change in Powerdex by session content category, both limbs, with standard deviations. The dotted line marks the 3% typical error. The two unmonitored days are not included.**

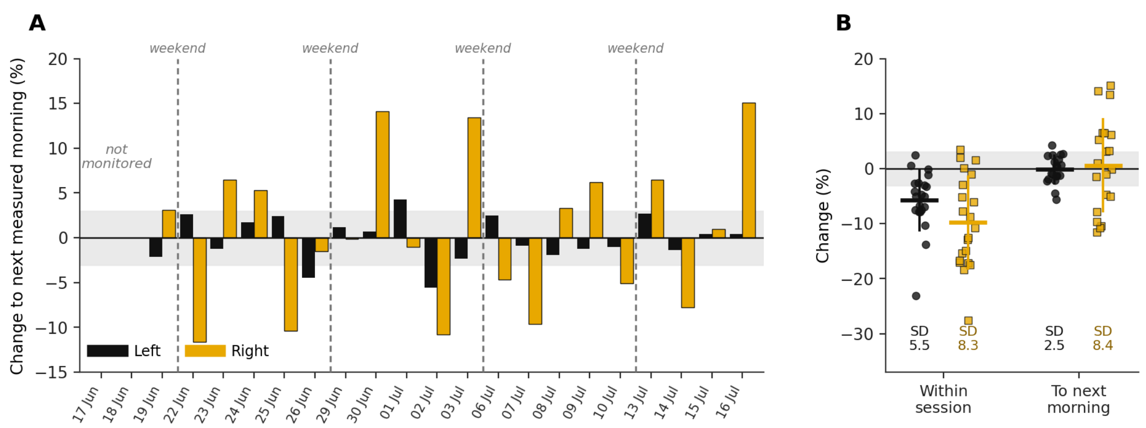

Fig. 3. **Day-to-day stability of the morning baseline. (A) Change from each morning to the next measured morning, both limbs. Dashed lines mark the weekend break; the bar immediately to the left of each spans Friday to Monday. The first two days were not monitored and are retained on the axis without values. (B) All individual values for both change types with mean and standard deviation.**

Day-to-day stability

Mean change from one morning to the next was close to zero on both limbs (left -0.2%, 90% CI -1.1 to 0.8; right +0.6%, 90% CI -2.7 to 3.8), so on average both limbs restored their baseline overnight, including after the largest acute decrements. The dispersion around that mean differed markedly (Figure 3). The left limb had a day-to-day standard deviation of 2.5% and moved more than 5% on one of 20 mornings; the right limb had a standard deviation of 8.4% and moved more than 5% on 13 of 20, six downwards and seven upwards, including three mornings on which it arrived 13 to 15% above the previous day. The ratio of variances was 11.1 (90% CI 5.1 to 24.0). The left-limb dispersion sits within the published reliability for this device and the right-limb dispersion at approximately double it (Maia et al., 2025); the lead coach reported no device errors, no unusual traces and no difference in sensation reported by the player between limbs.

The relationship between the acute cost incurred on a given day and the value recorded the following morning was unclear on both limbs (right r = 0.27, 90% CI -0.13 to 0.59; left r = 0.22, 90% CI -0.17 to 0.55). Across the four weekend gaps the Monday left-limb value averaged 2.5% below the preceding Friday value, while the right averaged 2.5% above; the player was instructed to undertake no training outside the programme.

Inter-limb asymmetry and the distribution of dose

Mean inter-limb asymmetry was 12.1% before sessions (90% CI 10.1 to 14.1) and 15.8% after (90% CI 13.0 to 18.7), so every session widened the gap by a substantial 3.8 percentage points (90% CI 1.0 to 6.6; ES 0.59). It was already 9.7% on the first monitored morning, before any substantial loading had accumulated, indicating a pre-existing difference that the camp did not create.

Across the camp, however, it did not behave as a fixed property (Figure 4): 9.7% in week 1 during the asymmetric dosing phase, rising to 14.9% in week 3, then declining to 11.2% and 10.0% as the programme moved to equal repetitions, and reaching 1.2% on the final morning after three tapered days, with the right limb recording its highest pre-session value of the camp (82.1 A.U.).

The taper itself is visible in the acute data. The extensive plyometric and testing session on 16 July produced changes of -0.1% and +0.1%, no measurable contractile cost on a day that would normally be demanding.

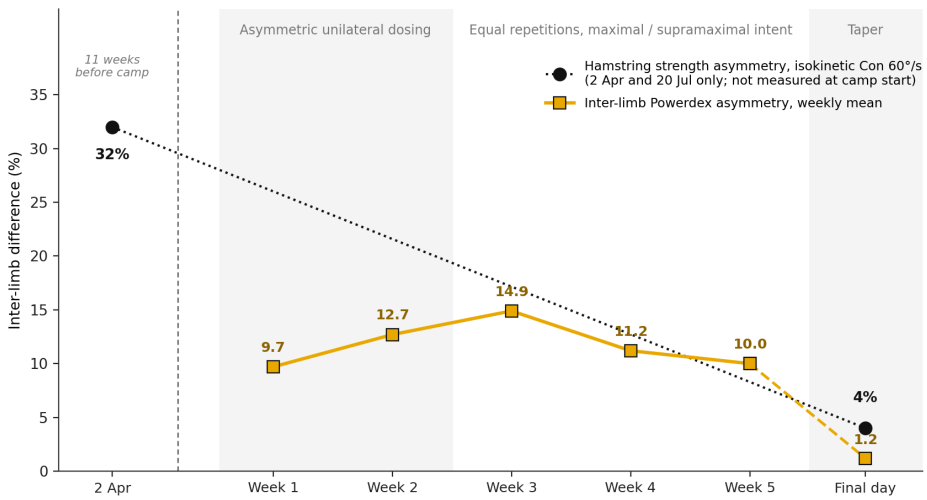

Fig. 4. Inter-limb Powerdex asymmetry by week against the programming phase, with the two isokinetic hamstring assessments shown for comparison. The isokinetic assessment was performed 11 weeks before the camp began and three days after it ended. Strength was not measured at the start of the camp, so the dotted line spans a period that includes both the ankle injury and the camp itself, and does not imply a trajectory between the two points.

Table 3. Isokinetic peak torque before and after the camp
Club assessments on 2 April 2026 and 20 July 2026 (three days after the camp ended). Values in N·m. Asymmetry is the difference relative to the stronger limb.

Variable	R Apr	R Jul	Δ R	L Apr	L Jul	Δ L	Asym Apr	Asym Jul
Knee extensors, concentric 60°/s	147.5	197.8	+34%	173.2	223.6	+29%	15%	12%
Knee extensors, concentric 240°/s	128.0	160.0	+25%	153.6	168.4	+10%	17%	5%
Knee extensors, eccentric 30°/s	179.1	244.9	+37%	191.8	262.0	+37%	7%	7%
Knee flexors, concentric 60°/s	64.0	106.3	+66%	94.0	110.9	+18%	32%	4%
Knee flexors, concentric 240°/s	57.0	87.2	+53%	86.2	85.6	-1%	34%	2%
Knee flexors, eccentric 30°/s	78.6	148.4	+89%	115.0	141.5	+23%	32%	5%

Strength outcomes

Between the pre-camp and post-camp isokinetic assessments, the right knee flexors improved by 66% concentrically at 60°/s, 53% at 240°/s and 89% eccentrically at 30°/s (Table 3). Concentric hamstring asymmetry at 60°/s fell from 32% to 4%. Knee extensor peak torque improved bilaterally by 25 to 37%. Body mass increased from 65 to 67 kg, so these gains are not attributable to mass alone.

Three caveats apply. The April assessment was the player's lowest knee extensor test of four club assessments, so part of the extensor improvement represents recovery from a low point; relative to November 2025 the right knee extensor gain is 4%, whereas the right knee flexor gain is 40% and therefore represents genuine adaptation. The post-camp test was performed three days after the camp ended, when the left limb LFF baseline was still 5 to 9% below its own camp peak. Isokinetic strength was available at two time points only, whereas LFF was measured daily, so the two measures can be compared for start and end state but not for time course or variability.

Discussion

The central observation of this case is that inter-limb LFF asymmetry was not a fixed characteristic of the player. It changed systematically across the five weeks, and in step with the way training was distributed between limbs: it rose through the asymmetric phase and into the first equal-repetition week, then fell, reaching its lowest value after the taper, and reached its lowest value of the camp after a planned taper (Figure 1). The measure responded to the dose it was given. That signal also appeared on the limb opposite the recent ankle injury, so it cannot be read as a local consequence of the injured tissue.

This is useful in two ways worth separating. The asymmetry behaved as a delivery check: more work on one side produced more fatigue on that side, so the signal confirmed the corrective programme was being applied as written. Independently, the asymmetry that persisted through the middle of the camp still describes a limb accumulating more contractile cost (i.e., greater fatigability) than its counterpart for a given day of training, and still argues for caution when the player returns to full club training. The two readings are complementary rather than competing, but neither can be applied to a single day's value without knowing how the preceding days were distributed between limbs.

Two features of the data limit how far this interpretation can be pushed. The asymmetry was already present on the first monitored morning, so a baseline inter-limb difference existed that the programme did not create. And the week 3 peak coincides both with the tail of the asymmetric dosing phase and with the introduction of running, so the two candidate causes cannot be fully separated within 21 days of observation.

Dissociation between strength adaptation and fatigue asymmetry

The limb that gained the most strength was also the limb that remained the most fatigable within sessions and the least stable between days (Figure 4).

The two measures describe different things. Isokinetic peak torque describes the force the limb can produce under maximal voluntary effort, that is, its capacity. The morning Powerdex value describes readiness on that day, and the pre-to-post change describes fatigability, the contractile cost of the work just completed. The practical corollary is that an isokinetic test taken at the end of a block describes what the limb can do, not the readiness it has on the day or how much the next session will cost it (Buchheit et al., 2026). In this case the player produced his best ever isokinetic values three days after a camp in which his left-limb readiness was still 5 to 9% below its own peak.

Content specificity of the response

That the same ordering emerged here from session labels alone, without any external load quantification, suggests the signal is robust to the coarseness of the dose description, at least at the level of session category (Figure 2).

The plyometric and braking category was the exception, being the only content for which both limbs paid a comparable cost. Bilateral jumping and braking impose eccentric quadriceps demand on both sides at once, whereas running and change-of-direction content interacts with the individual's movement strategy and therefore distributes asymmetrically. This is consistent with the coaching staff's observation that the player was compliant and inactive through the posterior chain during jumping and running.

A related pattern appears in the return-to-play case series (Buchheit et al., 2026): in the anterior cruciate ligament case the operated limb showed its largest acute suppression after the pitch session with the highest acceleration and deceleration density, while a higher-load but less braking-dominant session was better tolerated. Braking and deceleration content therefore appears to be the exposure most likely to expose a limb-specific vulnerability, whether the limb is post-surgical or, as here, carrying a strength deficit. That the same category loaded both limbs equally in the present case may reflect the difference between a bilateral gym-based plyometric stimulus and unilateral braking on the pitch. This remains a single-case observation.

Day-to-day instability as a candidate signal

The threefold difference in day-to-day dispersion between limbs (Figure 3) is, to our knowledge, not something previously described with this measure. The device produced no errors and the player reported no difference in sensation between limbs, so a measurement explanation appears unlikely without being formally excluded.

The direction of those swings deserves comment, because seven of the thirteen were upward, three by 13 to 15%. A morning value substantially above the previous day cannot be explained by incomplete recovery. It is more consistent with a rebound in evoked contractile function after a demanding stimulus, of the kind described in the masters athlete report, where Powerdex exceeded baseline at 12 hours after high-intent sessions, reaching approximately 121% after sprint interval work and 108% after gym-based work with complete rest (Buchheit & Laursen, 2026); post-activation potentiation is the usual mechanistic candidate (Tillin & Bishop, 2009; Seitz & Haff, 2016; Rassier & Macintosh, 2000). If the right limb was both fatiguing more and rebounding more, its greater dispersion may reflect a limb operating at a wider amplitude of neuromuscular response rather than one that simply recovers poorly, which is a materially different proposition.

If real, this suggests that the variability of a limb's day-to-day readiness may carry information its mean does not: a limb whose morning value is unpredictable is a limb whose response to the next session is also unpredictable, which is precisely where a passive daily measure has most to offer. Testing it would require repeated same-day duplicate measures to partition biological from technical variance, which were not available here.

Methodological observations

Two practical points emerged that are relevant to anyone implementing this measure in a field setting.

First, the post-session delay was not uniform. Gym-based sessions were measured within 5 to 10 minutes of completion, whereas outdoor pitch sessions were measured approximately 30 minutes after the end of exercise because of travel. The masters athlete report showed that a substantial proportion of the acute decrement is already recovered within the first hour after some session types, with divergent trajectories by modality by the four-hour mark (Buchheit & Laursen, 2026). The pitch-session costs reported here are therefore underestimates, and the ranking in Figure 2 is conservative.

Second, sessions incorporating heat-room exposure as the final block were measured shortly after that exposure and were conducted with restricted fluid intake. Elevated muscle temperature and dehydration act in opposite directions on evoked force, and the two cannot be separated here; those days should not be interpreted as clean low-cost sessions.

What this case does not show

It does not demonstrate that the player became more fatigue-resistant across the camp, which was the outcome we expected from five weeks of concentrated strength work and which has been observed during return-to-play in previous cases (Buchheit et al., 2026). On the left limb, the acute cost did decrease, from -7.3% in weeks 2 to 3 to -3.9% in weeks 4 to 5, a difference of 3.4 percentage points (90% CI -0.8 to 7.7; ES 0.62) (Figure 1). The interval includes zero, so the change is unclear, but the point estimate is moderate and the interval is markedly asymmetric around zero: this should be read as suggestive rather than absent, and a larger sample would very plausibly resolve it. On the right limb the corresponding change was 2.6 percentage points (90% CI -4.1 to 9.2; ES 0.30) and the weekly pattern was not monotonic, returning to -14.9% in week 3 when running was introduced.

The interpretation we favour is that a comparable contractile cost was being produced by progressively harder content. The programme is documented in detail (Table 1), locomotor content was introduced and then increased across weeks 3 to 5, and the repeated Monday contrast shows an identical session category costing nothing one week after it had cost 3.3% and 8.8%, the later session being the harder of the two. Without an objective marker of external load this cannot be quantified, but given the documented progression, it is a more reasonable reading than the alternative that nothing changed.

Key points for practitioners

- Inter-limb LFF asymmetry moved with the deliberate distribution of unilateral work, so it can be used as a check that a corrective programme is being delivered as intended. An asymmetry read on a single day, without knowing how the preceding days were distributed between limbs, is not interpretable.
- A residual asymmetry through the middle of the camp still argues for caution when the player returns to full club training. The two readings are complementary, not alternatives.
- The ankle injury was on the left ankle, the strength deficit on the right hamstring, and the measurement at the quadriceps. The fatigability signal followed the deficit rather than the injured joint, so a quadriceps measure can report limb-level status arising from a problem elsewhere in that limb.
- Isokinetic strength describes capacity. The morning Powerdex value describes readiness on the day, and the pre-to-post change describes fatigability. Clearing a player to return to full club training on isokinetic values alone covers only the first of the three.
- Locomotor content carried roughly twice the contractile cost of gym-based strength work, and the ordering of session types matched previous reports even though the dose was described by session label alone.
- Plyometric and braking work was the only content that loaded both limbs comparably. Running and pitch content did not.
- The mean day-to-day change was near zero on both limbs, but the dispersion differed threefold. Reporting only the mean would have hidden the most distinctive feature of this dataset. The upward swings are as informative as the downward ones and may reflect a rebound in excitability after demanding work.
- A planned taper was visible in the data within three days, as a zero-cost session followed by the highest right-limb value and the lowest asymmetry of the camp.
- Post-session timing must be standardised and documented. A 30-minute delay imposed by travel systematically underestimates the cost of the sessions that matter most.

Limitations

No external load quantification was available: no GPS, no accelerometry, no session-RPE and no volume records. The dose axis is therefore categorical, and the acute responses cannot be scaled against exposure as in previous work using mechanical-intensity descriptors (Buchheit et al., 2026) or differential RPE (Buchheit & Laursen, 2026; McLaren et al., 2016). Adding a single neuromuscular RPE per session would have supplied a dose axis at negligible cost and is the most obvious improvement for future camps.

The design is a single case with no control condition, so the association between programming phase and asymmetry is observational. Measurements were confined to the quadriceps, and therefore describe nothing about the calf, the peroneals or the injured ankle itself. No delayed post-session measures were taken beyond the following morning, so the recovery kinetics described elsewhere (Buchheit & Laursen, 2026) could not be characterised, and the upward day-to-day swings could not be resolved into a recovery curve. Isokinetic strength was assessed at two time points only. The participant was a 16-year-old in a period of growth, gaining 2 kg during the observation window; the Powerdex index is a ratio and should be robust to changes in body size, but this has not been demonstrated in an adolescent population. Finally, low-frequency fatigue was not monitored on the first two training days of the camp.

Declarations

Confidentiality: The participant is a minor. Written informed consent for the use of monitoring data for research purposes was obtained from the player and from his parent. The case is reported without names or unique identifiers, and potentially identifying contextual details have been removed, aggregated.

Data availability: De-identified data supporting the findings are not publicly available due to confidentiality restrictions. Aggregate data are available from the corresponding author on reasonable request, subject to institutional approval and consent.

Use of generative artificial intelligence: A generative AI assistant (Claude, Anthropic) was used for statistical analysis, figure production and drafting and language editing. All data were collected by the authors, and the design, analytical decisions and interpretation are their own. The tool was used as an assistant, not as a source of scientific content. All outputs were reviewed and verified by the authors, who take full responsibility for the manuscript. The assistant is not an author.

References

1. Bernard O, André N, Audiffren M. 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. 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.

3. 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. Sport Perf & Science Reports. #289, Apr 2026.

4. 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.

5. Buchheit M, Laursen PB. Modality-specific muscle low-frequency fatigue and recovery signatures: a case report mapping the HIIT Science taxonomy. Sport Perf & Science Reports. #290, Apr 2026.

6. Buchheit M, Lopez Sagarra A, Boskovic A, Komino P, Norman D, Hader K. GPS 3.0: from distance into zones toward better proxies of internal neuromuscular load in elite football. Sport Perf & Science Reports. #280, Feb 2026.

7. Cohen D, Kotsifaki R, Buchheit M. What the jump? A comprehensive guide for force plate jump analysis in sports performance and rehabilitation. Sport Perf & Sci Reports. In preparation 2026.

8. 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.

9. 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.

10. Lee MJC, Reid SL, Elliott BC, Lloyd DG. Running biomechanics and lower limb strength associated with prior hamstring injury. Med Sci Sports Exerc. 2009;41(10):1942-1951.

11. Maia, F., Nakamura, F. Y., Tito, S., & Ribeiro, J. (2026). Test-Retest Reliability of Myocene for Assessing Lower Limb Low-Frequency Fatigue: A Cross-Condition Reliability Study. Measurement in Physical Education and Exercise Science, 30(3), 287–293 https://doi.org/10.1080/1091367X.2025.2592622.

12. 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;11(3):404-406.

13. Rassier DE, Macintosh BR. Coexistence of potentiation and fatigue in skeletal muscle. Braz J Med Biol Res. 2000;33(5):499-508.

14. Reimann M, Rosenthal T, Ferrauti A. 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); Jul 2024; Glasgow, Scotland.

15. Ridard J, Rozand V, Millet GY, Lapole T. On-field low-frequency fatigue measurement after repeated drop jumps. Front Physiol. 2022;13:1039616.

16. Seitz LB, Haff GG. Factors modulating post-activation potentiation of jump, sprint, and upper-body ballistic performances: a systematic review with meta-analysis. Sports Med. 2016;46(2):231-240.

17. Tillin NA, Bishop D. Factors modulating post-activation potentiation and its effect on performance of subsequent explosive activities. Sports Med. 2009;39(2):147-166.

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

19. Tito S, Maia F, Correia M, Ribeiro J. Recovery patterns of low-frequency fatigue in elite youth soccer players after official matches. Int J Sports Med. 2025;46(4):263-270.