

Perceived Recovery and Muscle Fatigue in Professional Soccer Players During Preseason

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Abstract

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<https://doi.org/10.70252/ERIN2946> This study aimed to examine weekly variations and within-subject relationships between internal training intensity (ITI), perceived recovery (TQR), neuromuscular performance (CMJ), and perceived muscle soreness (PMS) during a four-week preseason period in professional soccer players. Twenty-three soccer players (age 22.8 ± 4.4 years; height 182 ± 7 cm; body mass 74.6 ± 6.7 kg) classified as Tier 3 athletes from the Croatian Second Soccer League were monitored using session rating of perceived exertion, TQR scales, countermovement jump tests, and PMS questionnaires. A significant reduction in ITI and concurrent improvement in TQR scores were observed across the preseason, with the highest intensity in week 1 and the lowest recovery in week 2. CMJ height performance declined during peak fatigue but rebounded as training intensity tapered. Repeated-measures correlations revealed negative associations between weekly ITI and TQR of the following week ($r_{\text{rm}} = -0.72$), and between ITI and CMJ ($r_{\text{rm}} = -0.55$), indicating that greater training intensities may impair both perceptual and neuromuscular recovery. The training stimulus-recovery difference index was positively associated with next-day TQR, suggesting it may serve as a sensitive marker of session-level readiness. These findings highlight the interplay between intensity, recovery, and fatigue, emphasizing the utility of low-cost subjective and objective tools for monitoring preseason responses and guiding individualized training strategies in elite soccer settings.

Keywords: Training intensity, subjective measures, professional athletes

Introduction

The preseason period in soccer presents a unique challenge, as it involves a sudden increase in training volume and intensity following an extended summer or winter break. Without an appropriately planned and individualized approach to the preseason phase, players may face a significantly elevated risk of injury.¹ Another major challenge in soccer lies in managing the diverse fitness needs within a relatively large squad, where individual players may vary

significantly in their physical conditioning and readiness.² Previous studies have shown that the preseason period is characterized by considerable fluctuations in training intensities and recovery levels among players, thereby increasing the risk of neuromuscular fatigue and potentially compromising overall player health.³ These fluctuations in training intensities place significant responsibility on the coaching staff when designing and implementing the preseason period training program. It is essential to adopt an individualized training approach that addresses each player's specific needs while maintaining overall team cohesion and ensuring that all athletes progress adequately before the competitive season begins.

The primary objective of every sports team and athlete is to achieve peak performance while simultaneously minimizing the risk of injury.⁴ Although professional sports are commonly associated with health, fitness, and overall well-being, the reality is often markedly different.⁵ Participation at the elite level exposes athletes of all age groups to intense physical demands, which significantly increases the risk of both short-term and long-term injuries, as well as prolonged absences from training and competition.⁶ Indeed, abrupt increases in training intensity and frequency without adequate recovery can precipitate significant deficits in neuromuscular and perceptual readiness.⁷ A congested competition schedule, characterized by a high frequency of events, elevated training intensities, and limited recovery periods, represents a set of interrelated factors that may adversely affect athletes' long-term well-being.^{7,8}

A well-structured training program that maintains an appropriate balance between workload and recovery, combined with the coaching staff's ability to adapt to external, uncontrollable factors, plays a critical role in injury prevention.⁹ The preseason period represents one of the most critical phases of any training plan. However, the elevated training intensities and substantial physical demands characteristic of this phase necessitate careful and consistent monitoring. This includes internal training intensity (ITI), which represents the physiological and psychological strain imposed on an athlete by an external training stimulus,¹⁰ along with subjective indicators of fatigue, and objective assessments of neuromuscular performance.^{11,12}

Recent studies have highlighted the importance of monitoring ITI, demonstrating that the use of accessible, validated, and cost-effective tools, such as session rating of perceived exertion (sRPE) using the Borg CR10 Scale, provides coaching staff with a simple, efficient, and economical means of tracking athletes' physical status and readiness.¹³ The Total Quality Recovery (TQR) scale, a complementary tool to sRPE, assesses athletes' perceived recovery status on a 6-20 or simplified 10-point scale, focusing on psychophysical cues like mood and muscle soreness to help balance training loads and prevent fatigue.¹⁴ The TQR scale is particularly valuable in team sports, as it enables the early detection of inadequate recovery, thereby allowing coaches to adjust training sessions and reduce the risk of overreaching during high-demand periods such as the preseason.¹⁵

Sansone et al,¹⁶ demonstrated the benefits of combining sRPE and TQR in daily and weekly monitoring routines. In their study of semi-professional female basketball players, training intensity showed significant negative correlations with perceived recovery, particularly within the 12 hours following sessions. The training stimulus-recovery difference (TS- Δ), calculated as the difference between pre-session TQR and sRPE, exhibited a very large positive correlation

with next-day recovery status, highlighting its potential as a sensitive marker of athlete readiness. The authors suggest that at the daily level, practitioners could concurrently monitor ITI, TQR, and the TS- Δ to better understand the balance between training load and recovery. While the index showed promising associations with next-day recovery in a study on female basketball players, its application remains limited and has not been adopted in other sports like soccer.

Similarly, perceived muscle soreness (PMS), often monitored via simple self-report scales (e.g., 0-10 ratings of muscle pain), serves as a practical indicator of neuromuscular fatigue and recovery in team sports like soccer, particularly during preseason when training volumes surge and injury risks peak.¹⁷ Elevated soreness levels have been linked to reduced performance, increased injury susceptibility, and delayed recovery in professional players, making it a valuable, low-cost tool for guiding training adjustments and signaling muscle stress from excessive loads.¹⁸ Although technologically advanced tools for monitoring ITI exist, they are often cost-prohibitive and inaccessible. In contrast, low-cost, validated questionnaires provide coaching staff with practical feedback on athletes' fatigue and readiness, enabling longitudinal comparisons, adaptation tracking, and monitoring of physiological progression under training stress.^{19,20}

An additional tool that can complement monitoring methods is the countermovement jump (CMJ) test, which provides a quick and reliable assessment of neuromuscular fatigue and accumulated training intensity in athletes. Incorporating CMJ allows for the early identification of neuromuscular fatigue²¹ or signs of overreaching, thereby providing valuable insights to guide timely training adjustments and reduce the risk of progression toward overtraining syndrome.^{22,23} Therefore, a thorough understanding and consistent monitoring of ITI, TQR, PMS, and neuromuscular status are critical for optimizing the training process, minimizing injury risk, and ensuring that players reach peak conditions for the demands of the upcoming season.

Thus, the primary aim of this study was to examine weekly variations and within-subject relationships between ITI, TQR, neuromuscular performance (CMJ), and PMS during a four-week preseason period in professional soccer players. Specifically, this study aimed to (1) monitor fluctuations in training intensity and recovery status, (2) explore the interaction between subjective and objective indicators of fatigue, and (3) assess the utility of the TS- Δ index as a practical tool for tracking the balance between training stimulus and recovery.

Methods

Participants

Participants of this study were twenty-three male professional soccer players classified as Tier 3 (Highly Trained/National Level) per McKay et al,²⁴ from the same team that competes in the Croatian Second Soccer League. Player characteristics are presented in Table 1. Considering their specific playing position, different physical demands, and differences in training programs, goalkeepers were not included in the study. Inclusion criteria to participate in the

study were: (i) participation in at least 85% of training sessions, and (ii) being healthy (no pain or injury) at the beginning of the preseason phase. Six players did not satisfy these requirements, either due to missing more than 15% of sessions or sustaining an injury and were therefore excluded from further analysis. Participants provided their signed consent after being fully informed of the experimental procedures. All procedures were approved by the Ethics Committee of the University of Split, Faculty of Kinesiology, and were conducted in accordance with the ethical standards outlined in the Declaration of Helsinki and its subsequent amendments for research involving human participants (2181-205-02-05-25-030). This research was carried out fully in accordance with the ethical standards of the *International Journal of Exercise Science*.²⁵

A priori power analysis was first conducted using G*Power 3.1 to determine whether the sample size was sufficient for detecting within-subject changes over time using repeated measures ANOVA. Assuming a medium effect size ($f = 0.3$), $\alpha = 0.05$, power = 0.80, four repeated measurements, the required sample size was estimated at 17 participants. A power analysis for repeated measures correlation (r_{rm}) using the *rmcorr* package in R²⁶ was used to evaluate further within-subject associations between ITI, TQR measures, CMJ and PMS across the 4-week preseason. Based on previous research reporting medium associations between training intensity, neuromuscular performance, and recovery-related measures in team sport athletes,^{12,16,27,28} a correlation of $r_{rm} = 0.30$ was anticipated. Simulation results using 23 participants with four repeated weekly observations each indicated that this design achieves approximately 80% power to detect medium within-subject correlations at $\alpha = 0.05$. These results align with simulation-based recommendations by Bakdash and Marusich,²⁶ who demonstrate that samples of 20–25 participants with 3–5 repeated measures provide sufficient power to detect medium effect sizes.

Table 1. Player characteristics (n = 23).

	Mean $\pm$ SD
Age (years)	22.8 $\pm$ 4.4
Body height (cm)	182 $\pm$ 7
Body mass (kg)	74.6 $\pm$ 6.7
Muscle mass (kg)	64.9 $\pm$ 4.3
Body fat (%)	8.3 $\pm$ 3.7
BMI (kg/m ²)	22.6 $\pm$ 1.7

Legend: BMI – body mass index

Protocol

This study employed a cohort design conducted over a 4-week preseason period, from mid-July to mid-August, during which responses for ITI, TQR, CMJ, and PMS were collected. A typical weekly training schedule is presented in Table 2. During the four-week preseason, players completed on average six to seven training sessions per week (~520–560 total minutes), with the majority consisting of technical-tactical (TE-TA) work such as possession drills, positional play, small-sided games, and speed, agility, and quickness (SAQ) drills. Conditioning elements were regularly integrated and included interval-based running (15–15, 30–30; ~60–80 min week⁻¹),

aerobic running of 4–5 km, and repeated uphill sprints (6–8 repetitions over 200–250 m). Strength and conditioning training (S&C) was performed once to twice weekly indoors (~60–75 min per session), focusing on maximal strength, power, and injury-prevention exercises. Competitive matches or match simulations occurred once to twice per week, contributing substantially to the overall external load. Recovery and regeneration activities (~60–70 min week⁻¹) were scheduled following intensive blocks or competitive fixtures and typically included light technical drills or compensatory gym work. All field-based sessions were conducted outdoors on natural grass pitches during the summer months (average daily temperature 28–34 °C, and average humidity 60–70%, often in the late afternoon or evening to reduce heat exposure), while S&C sessions were held indoors in a gym.

The training program was planned and programmed by the team's coaching staff, and the researchers did not interfere with the planned training process. The research team divided the experimental period into two phases: 1) Familiarization phase: lasted two weeks and involved introducing the soccer players to all measurement instruments and procedures; 2) Data collection phase: lasted for four weeks and encompassed all training sessions during the period, as well as all friendly matches conducted before the start of the competitive season. Each training session was conducted in strictly controlled environments under the strict supervision of coaching staff. Friendly matches were played with standard soccer rules and duration, with official judges and personnel. Participants had two weeks of familiarization with training routines, warm-up protocols, and performance assessment tools used by the research team.

Table 2. Typical weekly training schedule

	Morning	Afternoon
Monday	TE/TA or regeneration training	TE/TA or match
Tuesday	TE/TA or endurance running	TE/TA /interval runs
Wednesday	Gym (Injury prevention/Strength/power)	SAQ and SSG
Thursday	Rest	Circuit drills/Polygon training with possession drills
Friday	TE/TA /circuit drills	"Fun" training (fun group games)
Saturday	TE/TA training	Match simulation or rest
Sunday	Match simulation or rest	Match

Legend: TE-TA – technical and tactical training; SAQ – Speed, agility, and quickness drills; SSG – Small-sided games

Internal Training Intensity (ITI).

ITI was calculated using the sRPE method, as proposed by Foster et al.²⁹ After each training session or match, players were asked to rate the overall perceived exertion using the Borg CR10 Scale, where 1 represented "very, very light" and 10 indicated "extremely difficult." Ratings were collected approximately 15 to 30 minutes after each session to ensure accurate reflection of perceived effort. The sRPE score was then multiplied by training duration (min) to calculate ITI. On days when multiple training sessions occurred, individual ITI values were summed to calculate the total daily internal training intensity. These daily values (ITI_{ds}) were used to compute weekly internal training intensity (ITI_{ws}) by averaging the total daily ITI values over each week. Both daily and weekly ITI scores were retained for further analysis.

Total Quality Recovery (TQR).

Perceived recovery was assessed using a simplified 10-point scale (TQR10).^{30,31} Each morning, approximately 30 minutes before the first training session or match, players were asked to reflect on their overall recovery from the previous day's training (TQR_{post}), where 1 indicated feeling "very, very bad" and 10 represented feeling "exceptionally good." Daily perceived recovery scores were averaged across each week to calculate the weekly TQR value. Additionally, the TQR score collected at the beginning of each week, before the first training session and reflecting recovery from the previous week, was labeled TQR_{fw} (TQR of the following week). Both scores were retained for further analysis. To further capture the interaction between training demands and recovery, the training stimulus–recovery difference (TS-Δ) index was calculated.¹⁶ This metric represents the balance between pre-training recovery status and post-training perceived effort. TS-Δ was determined by subtracting the sRPE score from the TQR (i.e., TS-Δ = TQR – sRPE). The calculated value provides insight into whether an athlete has adequately recovered for the upcoming training intensity.

Countermovement jump (CMJ).

Neuromuscular performance was evaluated using the CMJ test, conducted with OptoJump photoelectric platforms (Microgate srl, Bolzano, Italy). The test took place at the beginning of each week, approximately 30 minutes before the team's first training session. Before testing, players completed a standardized warm-up, which included a 3-minute run at 60% of their maximal aerobic speed (MAS), followed by three submaximal CMJs. A 3-minute recovery period was then provided to ensure players were fully ready before beginning the test. During the CMJ test, players started in an upright standing position and executed a rapid downward (eccentric) movement into a squat, immediately followed by a maximal vertical jump. Players completed three trials, each separated by 15 seconds of rest, while maintaining consistent positioning between the platforms. The best jump height, recorded in centimeters, was retained for analysis as it is considered the most accurate representation of maximal neuromuscular capacity.^{17,32}

Perceived Muscle Soreness (PMS).

Perceived muscle soreness was assessed using a self-report questionnaire with a 10-point numerical rating scale. Athletes were asked to rate their level of muscle soreness on the morning at the beginning of each week by responding to the statement, "My muscle pain is...", using a 10-point scale, where 1 indicated very intense pain and 10 represented no pain at all. The weekly assessment reflected accumulated training soreness, offering a practical indicator of neuromuscular fatigue and recovery while minimizing player burden and remaining sensitive to training-induced changes.³³

Statistical Analysis

Descriptive results are presented as means, standard deviations (SD), 95% confidence intervals (95% CI), and coefficients of variation (CV%). Data normality was evaluated using the Shapiro-Wilk test, and Mauchly's test was employed to assess sphericity. In cases where the assumption

of sphericity was violated, Greenhouse–Geisser corrections were applied. A one-way repeated measures ANOVA was used to examine differences across the four weeks of the pre-competition phase. Additionally, partial eta squared (η_p^2) was calculated as a measure of effect size for the ANOVA, following these interpretation guidelines: small (>0.01), medium (>0.06), and large (>0.14). Tukey's post hoc test was conducted to explore pairwise differences when significant main effects were observed. Effect sizes were reported as Cohen's d and interpreted according to these thresholds: trivial (<0.2), small (>0.2 – 0.6), moderate (>0.6 – 1.2), large (>1.2 – 2.0), very large (>2.0 – 4.0), and extremely large (>4.0).³⁴ Correlations between variables were analyzed using repeated measures correlations (*rmcorr* R package), which account for intra-individual variability over time. The repeated-measures correlation coefficient (r_{rm}) was interpreted as follows: trivial (<0.1), small (0.1 – 0.3), moderate (>0.3 – 0.5), large (>0.5 – 0.7), very large (>0.7 – 0.9), and almost perfect (>0.9 – 1.0).³⁴ Confidence intervals (95% CI) were estimated through parametric bootstrapping with 1,000 resamples. A significance level of $p < 0.05$ was applied to all statistical tests. All analyses were performed using SPSS (Version 29.0; IBM Corp., Armonk, NY, USA) and R (version 4.1.3, R Core Team). All figures were created using GraphPad Prism (Version 9; GraphPad Software, San Diego, CA, USA).

Results

Figure 1 illustrates daily variations in sRPE values and CV% across all measured days. A significant time effect was found for sRPE between weeks ($F_{(3,66)} = 57.38$, $p < 0.001$, $\eta_p^2 = 0.73$ [large]), with perceived effort in week 1 being higher than in week 2 ($ES = 2.66$ [very large]), week 3 ($ES = 2.76$ [very large]), and week 4 ($ES = 3.18$ [very large]). Week 2 ($ES = 0.74$ [moderate]) and week 3 ($ES = 0.74$ [moderate]) were significantly higher than week 4. The CV% ranged from 5.2% to 25.8%, with the highest variability observed on days 3 and 6, both occurring near match days. Lower CV values were noted on non-match days, such as day 1 and MD between days 6–8, indicating greater consistency in sRPE responses during training or recovery phases.

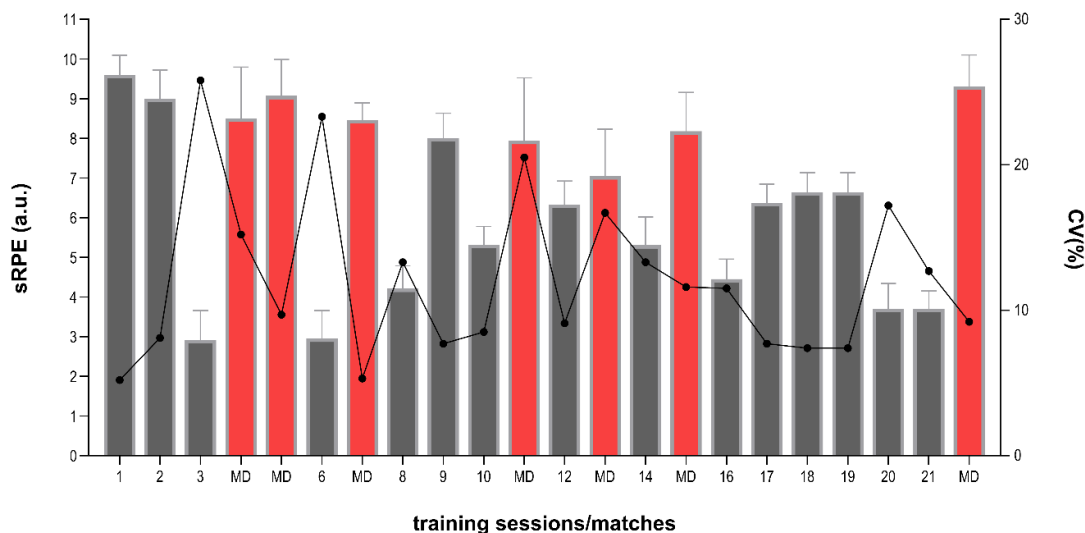


Figure 1. Daily variations in sRPE within included match days (MD) are highlighted in red. The bars represent sRPE values with standard deviation (SD). Coefficient of variation (CV%) is shown as a black line following the y-axis.

Figure 2 displays the weekly variations in mean ITI and TQR. The repeated measures ANOVA revealed a statistically significant time effect for the ITI ($F_{(3,66)} = 138.29$, $p < 0.001$, $\eta_p^2 = 0.86$ [large]), with week 1 being higher than week 2 (ES = 1.75 [large]), week 3 (ES = 3.67 [very large]), and week 4 (ES = 3.66 [very large]). Week 2 was higher than week 3 (ES = 2.19 [very large]) and week 4 (ES = 2.18 [very large]). Likewise, a statistically significant time effect was determined in TQR ($F_{(3,66)} = 93.54$, $p < 0.001$, $\eta_p^2 = 0.81$ [large]), with perceived recovery being higher in week 1 than week 3 (ES = 0.7 [moderate]). Week 2 was lower than week 1 (ES = 3.22 [very large]), week 3 (ES = 2.65 [very large]), and week 4 (ES = 3.8 [very large]).

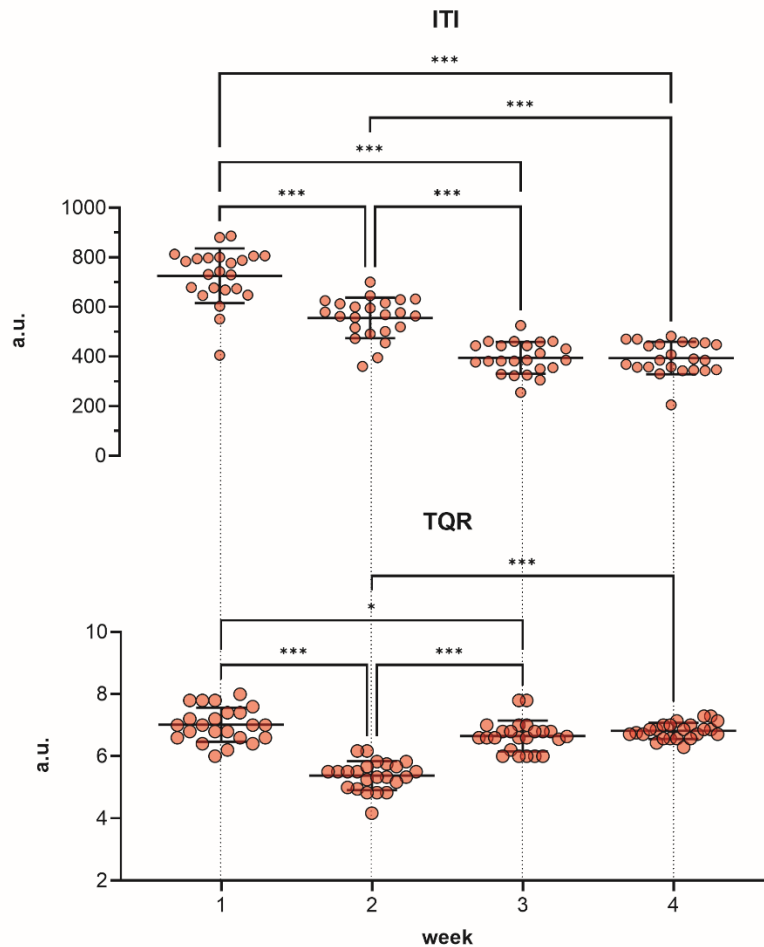


Figure 2. Weekly variations in ITI and TQR over a four-week period. Every dot represents an individual data point, and the black horizontal line indicates the mean value for every week. * $p < 0.05$, *** $p < 0.001$.

Weekly variations in CMJ and PMS are illustrated in Figure 3. CMJ performance significantly changed over time ($F_{(3,66)} = 26.35$, $p < 0.001$, $\eta_p^2 = 0.55$ [large]), with performances in week 2 being lower than week 1 (ES = 1.38 [large]), week 3 (ES = 1.25 [large]) and week 4 (ES = 0.84 [moderate]). Furthermore, PMS values showed statistically significant time effect ($F_{(3,66)} = 8.06$, $p < 0.001$, $\eta_p^2 = 0.27$ [large]), where higher values were observed in week 3, when compared to

week 1 (ES = 0.93 [moderate]) and week 2 (ES = 0.8 [moderate]). Similarly to week 3, week 4 also indicates higher values than in week 1 (ES = 0.93 [moderate]) and week 2 (ES = 0.8 [moderate]).

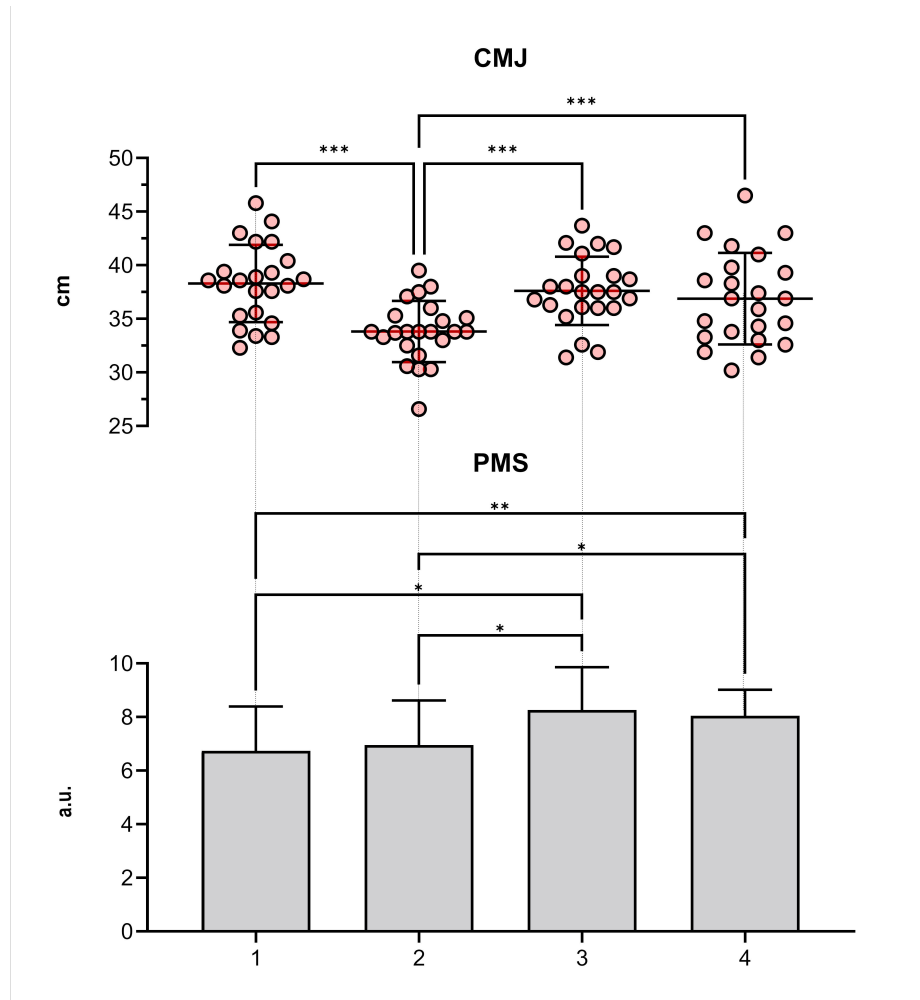


Figure 3. Weekly variations in neuromuscular performance (CMJ) and PMS over a 4-week period. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

The TS- Δ index and TQR_{fw} values are presented in Figure 4. The TS- Δ index remained negative throughout all match days, with values ranging from -0.19 to -2. The highest perceived recovery was recorded at the beginning of the last week, while the lowest was noted in week 2.

Table 3. Repeated-measures correlation between training intensity and perceived recovery (n = 23)

pair	r_{rm}	p	95% CI
ITI _{ds} vs. TQR _{post}	-0.23	< 0.001	-0.32 to -0.143
TS- Δ vs. TQR _{post}	0.28	< 0.001	0.192 to 0.369
ITI _{ws} vs. TQR _{fw}	-0.72	< 0.001	-0.835 to -0.547

Legend: r_{rm} - repeated-measures correlation coefficient; p - significance level; 95% CI - 95% confidence intervals for r_{rm}

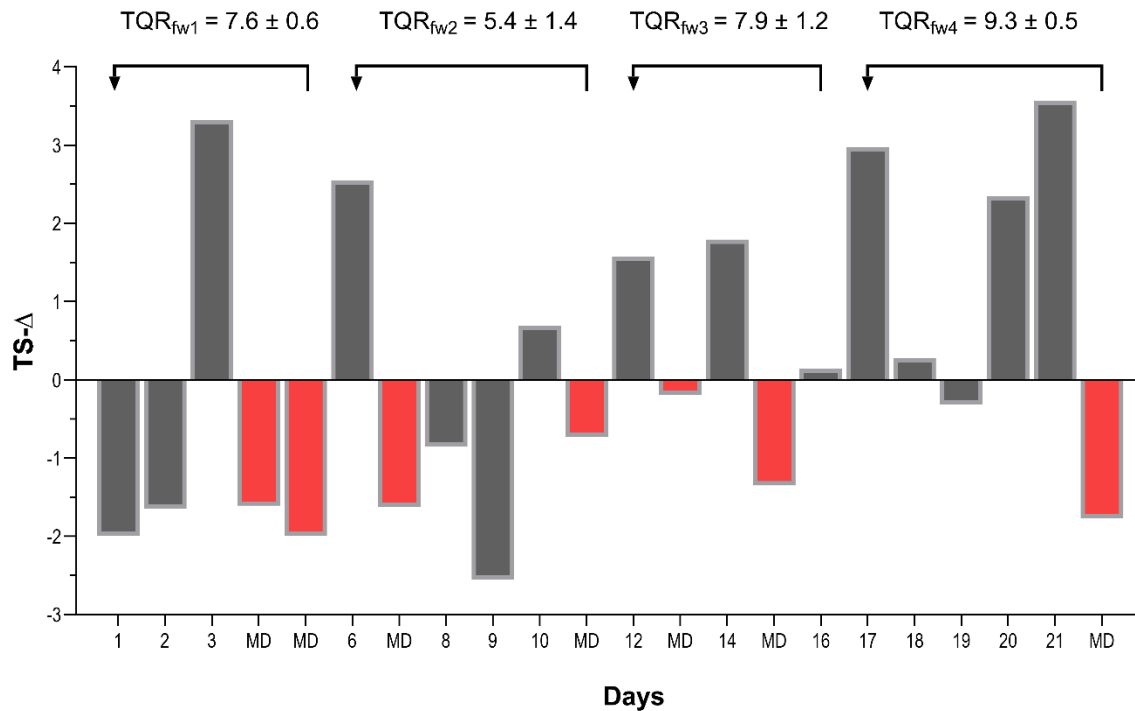


Figure 4. Daily variations in the TS-Δ index and TQR_{fw}.

A repeated-measures correlation analysis revealed several significant correlations between training intensity and perceived recovery (Table 3). First, ITI_{ds} showed a small negative correlation with TQR_{post}, indicating that as ITI_{ds} increased, TQR_{post} tended to decrease. Second, TS-Δ exhibited a small positive correlation with TQR_{post}, suggesting that higher TS-Δ values were associated with greater TQR_{post} scores. Lastly, ITI_{ws} demonstrated a very large negative correlation with TQR_{fw}, indicating a robust inverse relationship between these two measures.

Multiple significant correlations between the training intensity, neuromuscular performance, and perceived muscle soreness are presented in Table 4. Specifically, ITI_{ws} showed a moderate negative correlation with PMS, indicating that higher ITI values were associated with lower PMS severity. Similarly, ITI_{ws} exhibited a large negative relationship with CMJ, suggesting that increases in training intensity corresponded to lower CMJ performance. In contrast, CMJ demonstrated a moderate positive correlation with PMS, implying that greater perceived muscle soreness was associated with reduced CMJ performance.

Table 4. Repeated-measures correlation between training intensity, neuromuscular performance, and perceived muscle soreness (n = 23)

pair	r_{rm}	p	95% CI
ITI _{ws} vs. PMS	-0.33	0.02	-0.566 to -0.051
ITI _{ws} vs. CMJ	-0.55	< 0.001	-0.725 to -0.317
CMJ vs. PMS	0.47	< 0.001	0.213 to 0.668

Legend: r_{rm} - repeated-measures correlation coefficient; p - significance level; 95% CI - 95% confidence intervals for r_{rm}

Discussion

This study investigated how professional soccer players respond to the demands of a four-week preseason period by exploring weekly changes and within-subject relationships between ITI, TQR, neuromuscular performance (CMJ), and PMS. The main findings showed that internal training intensity (ITI) declined while perceived recovery (TQR) showed an increasing trend. ITI was negatively associated with TQR both on the next-day and in the following week, and higher weekly ITI was linked to lower CMJ and lower start-of-week PMS; furthermore, TS- Δ showed a small positive association with next-day TQR.

The progressive reduction in ITI likely reflects a deliberate tapering strategy following an initial overload phase. Similar taper patterns have been documented in Premier League preseason studies, where early overload is followed by structured reductions to optimize adaptation.³⁵ Furthermore, previous research highlights that early preseason is typically characterized by elevated training demands intended to provoke physiological adaptation.³⁶ The progressive decline in ITI, and a corresponding increase in TQR scores, indicates a tapering effect and enhanced recovery capability over the preseason. The significant decrease in TQR during the second week points to peak fatigue accumulation, aligning with prior studies on early-preseason overload.¹⁶

CMJ performance patterns were consistent with acute fatigue, particularly pronounced in the second week. The suppressed CMJ performance at this stage is consistent with heightened training and match intensity, a response commonly associated with neuromuscular fatigue.³⁷ PMS scores may indicate reduced soreness later in the preseason. Although the absolute improvement (1–1.5 points on a 10-point scale) is relatively modest, it reflects a perceptible reduction in soreness, which can likely be attributed to adaptive responses as training intensity tapered and match frequency declined. The first three weeks included two matches, while the final week included only one. Research on elite youth athletes indicates that high-intensity training and frequent matches may hinder recovery,³⁸ while fixture congestion with inadequate rest worsens PMS.³⁹ Nonetheless, changes may not correspond to meaningful improvements in readiness or performance across a heterogeneous squad.

Addressing the second aim, repeated-measures correlations quantified within-player associations between internal training intensity and both subjective and objective markers of fatigue and recovery. Notably, higher weekly ITI values were strongly associated with lower perceived recovery in the following week ($r_{rm} = -0.72$), potentially reinforcing the delayed effects of cumulative intensity on athlete readiness. This finding may underscore the cumulative nature of training stress and its delayed impact on perceived readiness, consistent with previous observations in team sports that link increased weekly intensity to subsequent reductions in recovery markers.¹⁶ This delayed effect may be particularly important in congested training phases, where residual fatigue accumulates and athletes are unable to recover before the next training cycle begins fully.

The moderate negative relationship between daily ITI and TQR_{post} ($r_{rm} = -0.23$) further suggests that acute intensity is also reflected in perceptual recovery status, although to a lesser extent than accumulated weekly ITI. This aligns with Kentt  and Hassm n's model,⁴⁰ which proposed

that recovery should not be treated as a static construct but should be evaluated within the broader context of training exposure and athlete-specific stress tolerance.

The negative association between ITI and CMJ performance ($r_{rm} = -0.55$) suggests that greater training stress is linked to reduced neuromuscular performance, as reported by Gathercole et al.⁴¹ These findings support the integration of simple monitoring tools, such as CMJ testing and TQR questionnaires, as practical strategies to detect fatigue and adjust training accordingly. Moreover, the negative relationship between ITI and PMS ($r_{rm} = -0.33$) suggests that reduced weekly intensity was associated with higher PMS scores, a pattern likely reflecting taper-related recovery and, over time, adaptive reductions in soreness through neuromuscular and cellular mechanisms;⁴² however, this interpretation would require confirmation using physiological markers (e.g., creatine kinase [CK], interleukin-6 [IL-6], cortisol). Lastly, the observed link between CMJ and PMS ($r_{rm} = 0.47$) suggests that players reporting less soreness also demonstrated better neuromuscular performance. This supports the utility of PMS assessments as a practical indicator of readiness, as reductions in soreness appear to correspond with improved jump performance.⁴³

Regarding the third aim, TS- Δ index (TQR – sRPE) was typically negative on match days. Rather than indicating maladaptation, the negative match-day values likely reflect intentional overload early in preseason, followed by taper-related improvements in recovery and reduced intensity, consistent with structured periodization models.⁴⁴ Conceptually, TS- Δ may complement the acute:chronic workload ratio by capturing session-level mismatches between readiness and demand⁴⁵ and it builds on the recovery–training interaction framework of Kentt  and Hassm n.⁴⁰

When athletes report a positive TS- Δ (i.e., feeling more recovered than the exertion required), they also tend to rate their overall recovery status more favorably. This is consistent with Sansone et al.,¹⁶ who reported that TS- Δ values closely tracked 12-hour post-session TQR scores and were highly sensitive to day-to-day fluctuations in readiness. Given the limited evidence to date and small positive association with TQR, TS- Δ should be interpreted as an exploratory, complementary indicator rather than a stand-alone decision tool, warranting further validation across sports and contexts.

The findings of this study offer several practical insights for coaches, performance staff, and sports scientists working in elite soccer environments. First, the observed inverse relationship between ITI and both TQR and CMJ performance suggests the potential importance of managing cumulative training stress, particularly during the early preseason period. Despite their simplicity, monitoring tools such as session-RPE, TQR, and CMJ performance appear sensitive to weekly fluctuations in training intensity. They may serve as effective, low-cost strategies for guiding real-time training adjustments. However, further validation in diverse contexts is needed. The TS- Δ index showed preliminary promise as a metric for day-to-day readiness and could potentially aid coaches in identifying sessions exceeding an athlete’s recovery capacity. It may contribute to more individualized decision-making when tracked alongside weekly ITI and TQR trends, especially in large squads where players’ recovery profiles vary. Integrating both perceptual (TQR, PMS) and performance-based (CMJ) measures

into regular monitoring routines can help identify early signs of neuromuscular fatigue and reduce the risk of overload during high-demand periods like the preseason.

The present study has some limitations that must be acknowledged. The study was limited to a single team from the Croatian Second Soccer League, which may affect generalizability to other competitive levels or female athletes. The relatively small sample size ($n = 23$) may limit the statistical power for detecting smaller effect sizes and interactions. Additionally, although the study utilized validated measures, reliance on self-reported recovery and soreness metrics may introduce response bias. The lack of biochemical or physiological markers (e.g., creatine kinase, heart rate variability [HRV]) restricts the mechanistic interpretation of fatigue and recovery patterns. Lastly, the number of matches per week was not included as a covariate in the study design, which may have influenced internal load and recovery markers.

Future studies should consider multi-team or multi-league designs to enhance generalizability and explore inter-individual variability in greater depth. Integrating physiological markers with perceptual and performance-based measures could provide a more holistic understanding of training adaptation and fatigue mechanisms. Combining TS- Δ with HRV metrics (e.g., lnRMSSD) could elucidate underlying autonomic mechanisms of fatigue. Investigations extending into the competitive season could further elucidate how preseason intensity management strategies influence injury risk, performance trajectories, and long-term player health. Moreover, exploring machine learning approaches to model individualized recovery profiles based on multidimensional input (e.g., TQR, CMJ, GPS metrics) could advance personalized training prescriptions.

This study highlighted the dynamic interaction between internal training intensity, perceived recovery, neuromuscular performance, and muscle soreness during the preseason period in elite soccer players. The findings indicated that higher training intensities were associated with reduced recovery and lower neuromuscular performance, supporting the potential value of integrating low-cost monitoring tools into regular practice. The TS- Δ index may serve as an exploratory indicator of session-level readiness, with further validation needed. Together, these insights support the application of individualized, evidence-informed training strategies to optimize performance and mitigate fatigue-related risks during high-demand periods such as the preseason.

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