

# Training, psychometric status, biological markers and neuromuscular fatigue in soccer

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**ABSTRACT:** The study examined the relationship between psychometric status, neuromuscular, and biochemical markers of fatigue in response to an intensified training (IT) period in soccer. Fifteen professional soccer players volunteered to participate in the study (mean  $\pm$  SD: age:  $25 \pm 1$  years; body height:  $179 \pm 7$  cm, body mass:  $73.7 \pm 16.2$  kg, experience:  $13.2 \pm 3$  years). Training load, monotony, strain, Hooper index and total quality recovery (TQR) were determined for each training session during a 2-week of IT. Counter-movement jump (CMJ) and biochemical responses [testosterone, cortisol, testosterone-to-cortisol ratio (T/C ratio), creatine kinase, and C-reactive protein] were collected before and after IT. Results showed that IT induced significant increases in cortisol, creatine kinase and C-reactive protein and significant decreases in T/C ratio and CMJ performance from before to after IT ( $p < 0.01$ ,  $p < 0.001$ ,  $p < 0.001$ ,  $p < 0.01$ ,  $p < 0.05$ , respectively). However, testosterone did not differ from before to after IT ( $p > 0.05$ ). Training loads were positively correlated with Hooper index ( $p < 0.05$ ) and negatively correlated with total quality recovery ( $p < 0.05$ ). Hooper index was positively correlated with cortisol ( $p < 0.05$ ), T/C ratio ( $p < 0.01$ ), and creatine kinase ( $p < 0.01$ ), and negatively correlated with CMJ ( $p < 0.05$ ). Furthermore, TQR was negatively correlated with T/C ratio ( $p < 0.01$ ), creatine kinase ( $p < 0.001$ ), and C-reactive protein ( $p < 0.05$ ), and positively correlated with CMJ ( $p < 0.01$ ). Neuromuscular fatigue, muscle damage, and change in the anabolic/catabolic state induced by the IT were related to well-being and perceived recovery state among professional soccer players.

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## INTRODUCTION

It is well known that coaches tend to intensify training loads (TL) during the soccer precompetitive period to maximize performance and to prepare soccer players for heavy physical demands during the long competitive season [1, 2]. Previous investigations have demonstrated that such intensified training (IT) periods increased mental and physical fatigue and were associated with insufficient recovery [2, 3]. Moreover, Freitas et al. [4] showed that reduced lower limb power was related to poor recovery, muscle damage and neuromuscular fatigue, lasting for days after the IT. Likewise, it has been shown that extended periods of persistent fatigue resulted in decreased explosive power in team sports athletes [5]. Similarly, Campbell et al. [6] reported that counter-movement jump (CMJ) performance decreased after a period of intensified TL in soccer players. Understanding the

relationships between psychometric state, neuromuscular fatigue, and biomarkers of fatigue during an IT may allow technical and medical staff to better optimize athletes' performance by applying different recovery strategies to overcome the induced fatigue, especially during this training period.

To identify relevant fatigue and recovery markers related to athletes' during IT, several previous studies have examined CMJ performance to determine neuromuscular fatigue, changes in circulating biomarkers indicative of physiological fatigue and recovery, and perceptible changes reflecting the psychometric states of players [4, 7, 8]. Monitoring these markers can help coaches to adapt TLs for athletes in order to avoid negative effects associated with IT [8]. The increased demands of training during IT elicit an inflammatory response

associated with delayed onset muscle soreness (DOMS) characterized by increased systemic inflammatory markers [e.g., C-reactive protein (CRP), interleukin (IL)-1 $\beta$ , IL-6, and tumor necrosis factor (TNF- $\alpha$ )] and elevations of circulating markers of muscle damage [e.g., creatine kinase (CK), lactate dehydrogenase (LDH), and myoglobin] [9]. It was reported that a decline in neuromuscular performance decline was associated with an increase in circulating concentrations of CRP and CK [4, 10]. Additionally, Jürimäe *et al.* [11] reported that testosterone-to-cortisol (T/C) ratio, an indicator of anabolic/catabolic balance, can be useful in identifying cases of overreaching.

Furthermore, IT-induced neuromuscular, physiological, and hormonal responses likely contribute to psychometric state changes [12, 13]. Indeed, Selmi *et al.* [2] showed that session-RPE, training load, monotony and strain increased during a 4-week IT (pre-competitive period) in soccer players, indicating that players had experienced a high level of fatigue which may have resulted from excessive loads and inadequate recovery. For that reason, monitoring well-being state in association with TL intensification have received much recent attention in recent years [2, 14–16]. For this purpose, researchers have used subjective scales to investigate well-being (e.g., Hooper questionnaire to assess sleep, stress, fatigue and muscle soreness) and recovery [e.g., total quality of recovery (TQR) scale], allowing monitoring fatigue and psychometric status of athletes in order to detect early signs of tiredness and to optimize high-level training performance [2, 4, 15–19]. For example, Selmi *et al.* [17] showed that perceived sleep, stress, fatigue, and muscle soreness are related to the daily TL in professional soccer players. Moreover, Brink *et al.* [20] indicated that the TQR score could be more beneficial for predicting overtraining or injury than predicting performance. At the elite level, studying the relationship between psychometric, physical, and biological responses during IT is of great importance to effectively manipulate the TL, preventing fatigue and allowing sufficient recovery [21–23].

It has been suggested that physical fatigue and poor psychometric status impair soccer-specific physical and technical performance [2]. Conversely, physiological readiness and technical execution are determinants of soccer performance [16]. Small-sided games (SSG) are high intensity soccer-style matches played for brief, predetermined durations interspersed with rest on a reduced-size pitch with a small number of players per team (e.g., 4/side). SSG are used to simultaneously build athletes' physiological fitness through running, sprinting, quickly changing direction, and jumping; technical abilities such as passing, dribbling, tackling, kicking, and heading; and tactical skills such as marking, unmarking, supporting, and cooperation with other players [16]. Recent studies have indicated that technical performance during SSG decreases after IT. For example, Selmi *et al.* [2], showed that successful passes, lost passes, and interceptions were negatively altered after IT, indicating that these variables were negatively influenced by the increase in TL. Coupling measures of well-being and recovery state with TL, thereby better informing TL manipulation, may help to attenuate the decrease in technical execution.

Before using such measures to manipulate TLs, the relationship between the mentioned variables must be established. To the authors' current knowledge, only a single study examined the daily variations of selected physiological and psychometric variables during an intense pre-season training camp in soccer players [23]. This study did not investigate some well-established psychometric, neuromuscular and biomarkers of fatigue (e.g., TQR, CMJ, testosterone, T/C ratio, CK, and CRP) or their relationships. Thereby, the aims of this study were to examine (a) the relationship between daily TL and well-being indices, (b) changes in neuromuscular fatigue and select fatigue biomarkers between pre- and post-IT, and (c) the relationship between neuromuscular fatigue, psychometric status, and select fatigue biomarkers in professional soccer players. It was hypothesized that IT would increase fatigue, decrease neuromuscular performance, and produce changes in biomarkers associated with a higher-fatigue state. Well-being and perceived recovery state would relate to neuromuscular fatigue, muscle damage, and change in the anabolic/catabolic state.

## MATERIALS AND METHODS

### *Participants*

Fifteen professional players (Mean  $\pm$  SD: age: 25  $\pm$  1 years; height: 179  $\pm$  7 cm; body mass: 73.7  $\pm$  16.2 kg; training experience: 13.2  $\pm$  3.1 years) from the same soccer team (3 central defenders, 2 lateral defenders, 4 defensive midfielders, 4 offensive midfielders, and 2 forwards) competing in the national league 1 took part in the study. Subjects trained 6–7 days per week during the study period. Goalkeepers were excluded from the investigation because they did not participate in the same physical training program as the other players. All players did not present any medical conditions or acute or chronic injuries during the whole experimentation period. Prior to enrollment in the study, written informed consent was obtained from each athlete after being informed about the advantages and potential risks of the study. The study was conducted according to the Declaration of Helsinki and was fully approved by the local research ethics committee.

### *Procedures*

The study was conducted over two weeks during the early precompetitive period. Four days before the study, anthropometric characteristics were measured and players performed the VAMEVAL test [24] to assess maximal aerobic speed (MAS) and maximum heart rate (HR<sub>max</sub>) in order to calibrate the intensity of the training sessions. Rating of perceived exertion (RPE) scores were recorded 30 min after each training session to calculate the TL for each player. Fifteen minutes before first daily training session, each participant completed the Hooper questionnaire (i.e., perceived ratings of sleep, stress, fatigue, and muscle soreness) and TQR scale to monitor well-being and perceived recovery. Neuromuscular performance was assessed using counter movement jump (CMJ) height before (T1) and after (T2) the IT period. Blood was collected at T1 and T2 and

**TABLE 1.** Training durations and average internal intensities, training loads, monotony and strain over 2 weeks of intensified training (n = 15).

		Time of training	Duration (min)	RPE	Session-TL (AU)	Daily-TL (AU)
<b>Week-1</b>	Monday	10.00 h	90	3.1	279	279
	Tuesday	9.00 h	70	4.0	280	595
		18.00 h	90	3.5	315	
	Wednesday	9.00 h	75	4.0	302	587
		17.30 h	95	3.0	285	
	Thursdays	10.00 h	90	3.1	279	279
	Friday	9.00 h	75	5.0	375	695
		18.00 h	100	3.2	320	
	Saturday	10.00 h	105	5.0	524	524
	Sunday	Rest	--	--	--	--
<b>Weekly-TL (AU)</b>				2958.5		
<b>Monotony (AU)</b>				2.00		
<b>Strain (AU)</b>				5917		
<b>Week-2</b>	Monday	10.00 h	90	3.6	320	320
	Tuesday	9.00 h	60	4.0	242	552
		18.00 h	90	3.5	311	
	Wednesday	9.00 h	65	5.2	339	609
		18.00 h	90	3.0	270	
	Thursdays	9.00 h	105	3.4	385	358
	Friday	9.00 h	70	5.0	350	667
		18.00 h	90	3.5	317	
	Saturday	11.00 h	65	2.0	130	130
	Sunday	11.00 h	90	5.0	450	450
<b>Weekly-TL (AU)</b>				3085		
<b>Monotony (AU)</b>				2.37		
<b>Strain (AU)</b>				7311		

Abbreviation: AU: arbitrary units, TL: training load, RPE: rating of perceived exertion

analyzed for biomarkers associated with fatigue (i.e., cortisol, testosterone, T/C ratio, CK, and CRP). Players were familiarized with the well-being indices, TQR scale, RPE scale, and CMJ test prior to the beginning of the study and all measurements were conducted at the same time of day to avoid diurnal variation of the performance.

The training program was organized and monitored by the team staff and included two microcycles (19 training sessions and a day of rest), without friendly games. Three days per week, the players completed two training sessions/day (i.e., one session in the morning and one session in the afternoon; Table 1). Training consisted of continuous running at anaerobic threshold (80–90% of MAS); high intensity interval training to simultaneously challenge aerobic and anaerobic metabolism (100–130% of MAS); SSG of variable intensity; specific high-intensity soccer training drills; repeated sprint

ability (RSA) training with and without elastic resistance and speed with and without change of direction; horizontal and vertical jumping; technical-tactical training; and match simulation. For SSG, 4-a-side games were performed on an outdoor pitch with natural grass on a playing surface of 35 m length x 25 m width. The duration of SSG was 25 minutes accomplished as intervals consisting of 4 bouts of 4 minutes separated by 3 minutes of passive recovery, with encouragement of technical staff, with two touches of the ball, without goalkeepers and with ball availability [25, 26].

#### *Blood Collection and Analysis*

Blood samples were collected from an antecubital vein into EDTA-coated tubes. Plasma was separated by centrifugation within 15 minutes of collection, divided into several aliquots, and frozen at -80°C for

later biochemical analysis of testosterone, cortisol, CK, and CRP. Plasma CK activity was determined spectrophotometrically with a commercial test kit (ABX A11A01632; France). CRP was determined using an enzyme-linked immunosorbent assay (ELISA-PENTRA 400, Horiba ABX, France). Cortisol and testosterone were determined by radioimmunoassay (Immunotech RIA, France). T/C ratio was subsequently calculated.

#### *Vertical jump measurements*

Before the CMJ test, players performed a standardized warm-up, consisting of a 6-min run at a constant speed (65% MAS), followed by two sub-maximal CMJs [27]. No passive stretching was allowed during the warm-up and three minutes of recovery separated the warm-up from the CMJ trials. For the CMJ test, each participant started from an upright standing position, performed a very fast eccentric action followed immediately by a jump for maximal vertical height. Hands remained at the hips throughout the entire movement to eliminate any influence of arm swing. Jump performance was measured using an Optojump (Optojump, Microgate, Bolzano, Italy) [27]. Each player performed three trials separated by three minutes of rest and the best trial was retained for analysis. The jump height was expressed in centimetres.

#### *Training load monitoring*

Values for TL, monotony, and strain are presented in Table 1. During the study period, TL for each session was calculated from the product of the session duration and the player's RPE (i.e. CR10 Borg's scale) [28] and the total weekly TL was calculated as the sum of TLs for each session. Monotony for each week was calculated as the ratio between the mean and standard deviation (SD) of daily TL [29]. Strain for each week was calculated as the product of total weekly TL and monotony [29].

#### *Sleep, stress, fatigue, muscle soreness and recovery state monitoring*

Well-being and recovery state were assessed using the Hooper questionnaire and TQR scale [3, 19], respectively. These measures were completed daily before the first training session. Each player was asked to respond subjectively about quality of sleep, stress, fatigue, and muscle soreness. Each of these parameters was measured separately using subjective rating scales ranging from 1–7 point, where 1 indicated "very very low" (fatigue, stress, and DOMS) or "good" (quality of sleep) and 7 indicated "very very high" (fatigue, stress, and DOMS) or "bad" (quality of sleep). The sum of these four scores was used to calculate the Hooper index (HI). For the TQR scale, athletes rated their recovery from 6 (very, very poor recovery) to 20 (very, very good recovery).

#### *Statistical analyses*

All statistical analyses were performed using SPSS v20.0 (SPSS Inc., Chicago, Illinois, USA) and data are expressed as means  $\pm$  SD. The normality of data was verified using the Kolmogorov–Smirnov test.

A one way analysis of variance was used to compare mean weekly TL, monotony, strain, well-being indices and TQR between periods, and Scheffe test was used as post-hoc. A paired t test was used to examine differences between T1 and T2 for CMJ, testosterone, cortisol, T/C ratio, CK, and CRP. Effect size was calculated using Cohen's *d* (ES) [30]. Effect sizes' magnitudes were considered as trivial ( $0 < d \leq 0.20$ ), small ( $0.20 < d \leq 0.50$ ), medium ( $0.50 < d \leq 0.80$ ), or large ( $d > 0.80$ ). Pearson product moment correlation coefficients were used to examine the relationships between average ratings of the sleep quality, stress, fatigue, muscle soreness, HI, and TQR during 2-week IT with changes of outcomes (CMJ performance, testosterone, cortisol, T/C ratio, CK, and CRP), and the relationships between the daily TL and perceived sleep quality, fatigue, stress, muscle soreness, and TQR. The magnitude of correlation coefficients was considered as trivial:  $r, 0.1$ ; low:  $0.1-0.3$ ; moderate:  $0.3-0.5$ ; large:  $0.5-0.7$ ; very large:  $0.7-0.9$ ; nearly perfect:  $0.9$ ; and perfect:  $1$  [31]. Statistical significance was set at  $p < 0.05$ .

## RESULTS

Data from 247 individual training loads and daily ratings of sleep quality, stress, fatigue, muscle soreness, HI and TQR throughout the IT were included in the analyses. Training frequency and TLs are presented in Table 2.

A significant ( $p < 0.05$ ) effect of time was found for TL, monotony, and strain (Figure 1). Training load, monotony and strain scores increased from weeks 1–2 ( $p < 0.01$ ,  $p < 0.05$ ,  $p < 0.01$ , respectively).

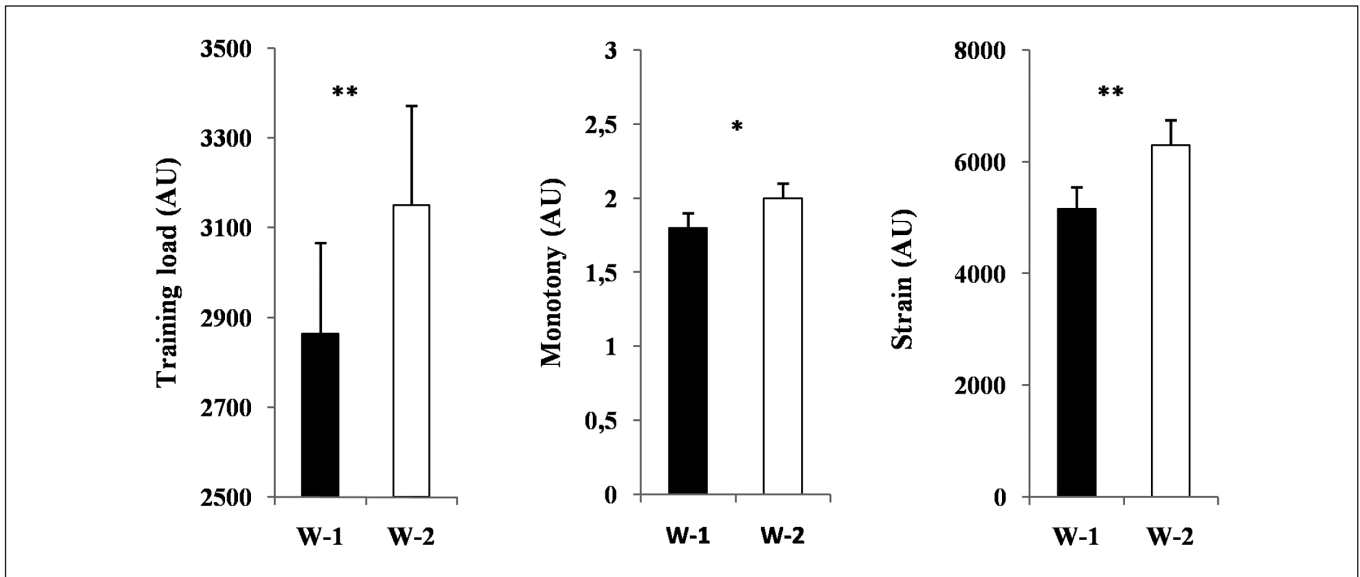
Fatigue, muscle soreness, HI and TQR scores increased from weeks 1–2 ( $p < 0.01$ ,  $ES = 0.56$ ;  $p < 0.01$ ,  $ES = 0.70$ ;  $p < 0.05$ ,  $ES = 1.03$ ;  $p < 0.01$ ,  $ES = 3.63$ , respectively), however, no difference was observed for sleep quality and stress scores (Figure 2).

For biochemical variables, cortisol, CK, and CRP significantly increased from T1 to T2 ( $p < 0.01$ ,  $ES = 1.12$ ;  $p < 0.001$ ,  $ES = 2.62$ ;  $p < 0.001$ ,  $ES = 1.61$ , respectively). Whereas, T/C ratio significantly decreased from T1 to T2 ( $p < 0.01$ ,  $ES = 1.03$ ). Counter-movement jump performance significantly decreased from

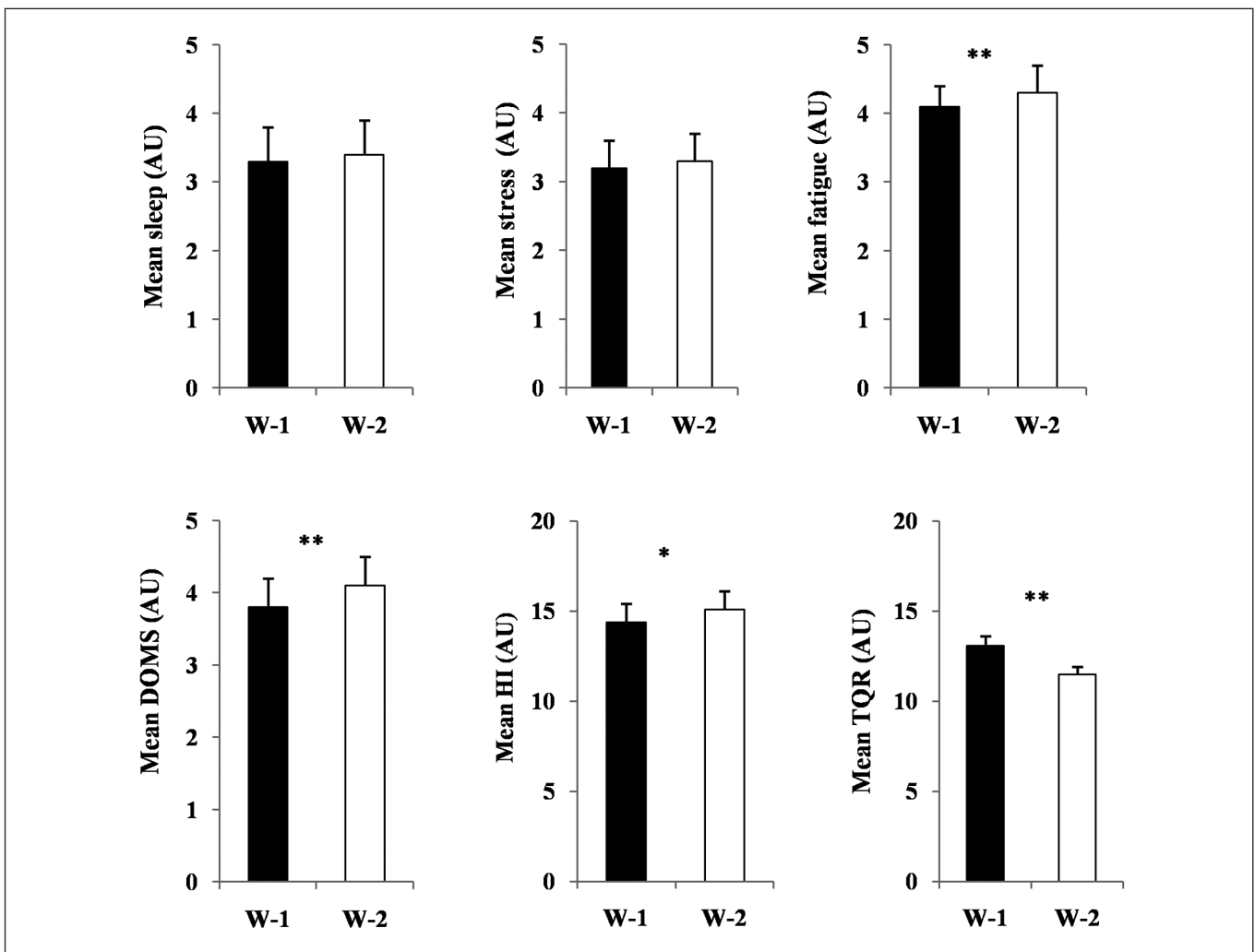
**TABLE 2.** The numbers of weeks during the training period, training session per week, training sessions per period, training days per week and overage weekly TL over 2 weeks analyzed in the present study.

Weeks (n)	2
Training sessions per week (n)	9–10
Training sessions per period (n)	19
Training Days per week (n)	6–7
Average weekly TL (AU)	> 3000

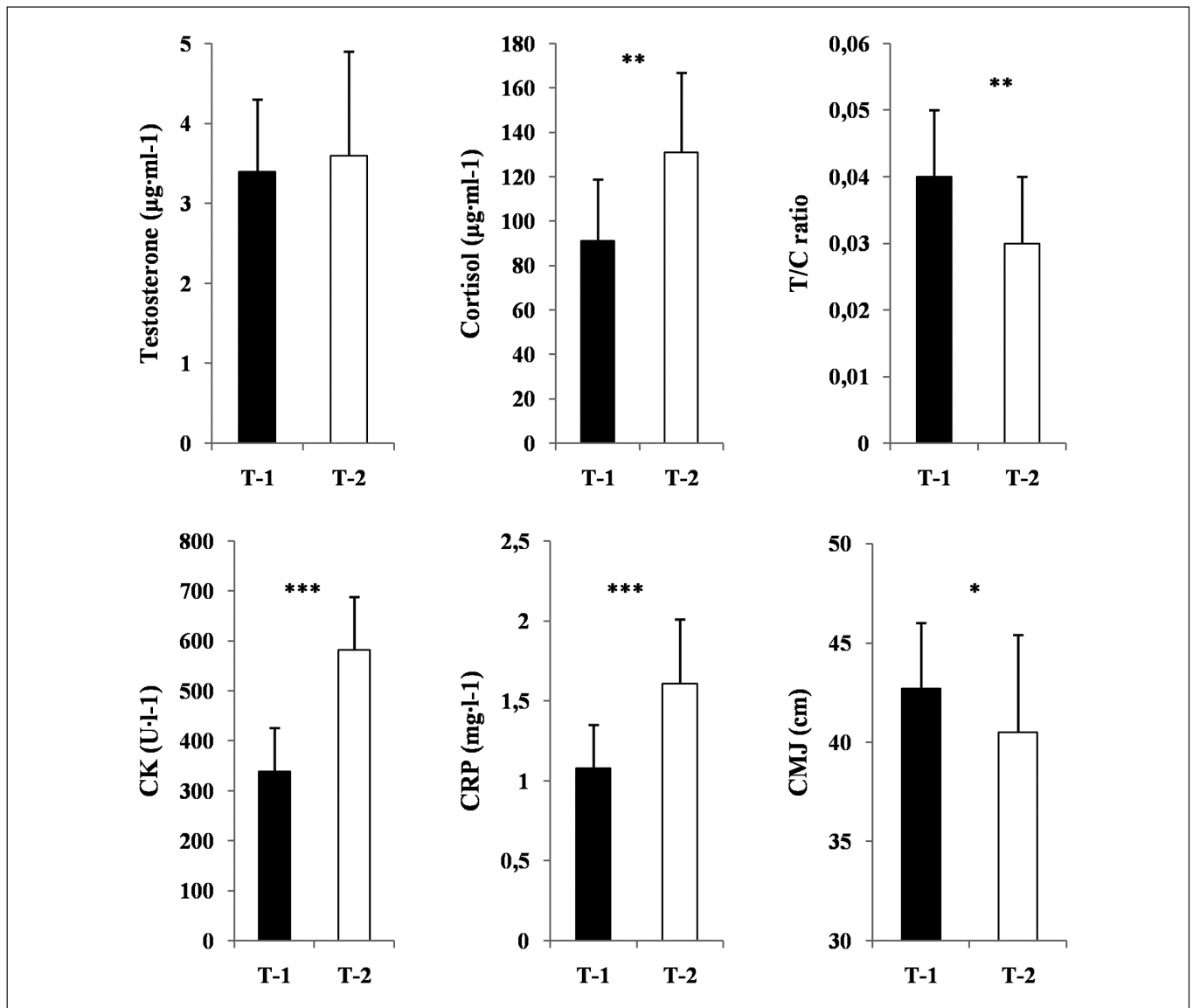
Abbreviation: AU (arbitrary units), n: number



**FIG. 1.** Weekly average training loads, monotony, and strain measured throughout the 2-week intensive training period (Values are means  $\pm$  SD; n = 15). Abbreviation: W-1: week-1, W-2: week-2, AU: arbitrary units, asterisks indicate a value higher than the value for the preceding week; \*p < 0.05, \*\*p < 0.01, \*\*\*p < 0.001.



**FIG. 2.** Weekly average rating of well-being indices and recovery state measured throughout the 2-week intensive training period. (Values are means  $\pm$  SD; n = 15). Asterisks indicate a value different from the preceding week, \*p < 0.05, \*\*p < 0.01. Abbreviation: AU: arbitrary units, W-1: week-1, W-2: week-2, DOMS: delayed-onset muscle soreness, HI: Hooper index, TQR: total quality recovery (TQR).



**FIG. 3.** Changes in biological parameters and counter movement jump performance pre (T1) and post (T2) 2-week intensive training period (Values are means  $\pm$  SD;  $n = 15$ ).

Abbreviation: T/C ratio: testosterone to cortisol ratio; CK: creatine kinase; CRP: C-reactive protein; CMJ: counter movement jump. \*Different from T1 ( $p < 0.05$ ), \*\*different from T1 ( $p < 0.01$ ), \*\*\*different from T1 ( $p < 0.001$ ).

**TABLE 3.** Correlation coefficient between biological and performance measurements after intense training period (T2) and training load and psychometric indices during 2-week IT.

	Sleep	Stress	Fatigue	Muscle soreness	HI	TQR
TL	0.15	0.08	0.55*	0.56*	0.65**	-0.60*
Testosterone	0.08	0.06	0.03	0.12	0.21	-0.02
Cortisol	-0.17	-0.57*	0.38	-0.57	0.55*	-0.25
T/C ratio	0.18	0.39	0.30	0.56*	0.40	-0.13
CK	0.12	0.45	0.58*	0.29	0.65**	-0.60*
CRP	0.44	0.02	0.43	0.55*	0.29	-0.39
CMJ	-0.40	-0.34	-0.60*	-0.63*	-0.70**	0.68**

\*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$ ; TL: training load; HI: Hooper index; TQR: total quality recovery; T/C ratio: testosterone to cortisol ratio; CK: creatine kinase; CRP: C-reactive protein; CMJ: counter movement jump.

T1 to T2 ( $p < 0.05$ ,  $ES = 0.54$ ). No difference in testosterone was observed between T1 and T2 ( $p = 0.09$ ,  $ES = 0.18$ ) (Figure 3).

Training load was positively correlated with perceived fatigue ( $r = 0.55$ ,  $p < 0.05$ , large), muscle soreness ( $r = 0.56$ ,  $p < 0.05$ , large) and HI ( $r = 0.65$ ,  $p < 0.01$ , large) and negatively correlated with TQR ( $r = -0.60$ ,  $p < 0.01$ , large); stress was negatively correlated with cortisol ( $r = -0.57$ ,  $p < 0.05$ , large); fatigue level was positively correlated with CK ( $r = 0.58$ ,  $p < 0.05$ , large) and negatively correlated with CMJ ( $r = -0.60$ ,  $p < 0.05$ , large); muscle soreness was positively correlated with T/C ratio ( $r = 0.56$ ,  $p < 0.05$ , large) and CRP ( $r = 0.55$ ,  $p < 0.05$ , large) and negatively correlated with CMJ ( $r = -0.63$ ,  $p < 0.01$ , large); HI was positively correlated with cortisol ( $r = 0.55$ ,  $p < 0.05$ , large) and CK ( $r = 0.65$ ,  $p < 0.01$ , large) and negatively correlated with CMJ ( $r = -0.70$ ,  $p < 0.01$ , very large) and TQR was negatively correlated with CK ( $r = -0.60$ ,  $p < 0.01$ , large) and positively correlated with CMJ ( $r = 0.68$ ,  $p < 0.01$ , large) (Table 3).

## DISCUSSION

The purpose of this study was to investigate the effects of IT on neuromuscular fatigue and fatigue biomarkers (CK, CRP, testosterone, cortisol, and T/C ratio), and to verify the relationship between fatigue and psychometric state. The major findings of the present study indicate that TL, monotony, and strain increased progressively during the IT. Likewise, CK, CRP, and cortisol increased, whereas T/C ratio decreased significantly from before to after IT. Furthermore, several relationships were found between biomarkers, neuromuscular fatigue and psychometric variables.

The increased TL throughout the intensified training period was likely due to progressive overload of the physical training program designed by the coaching staff to prepare players to handle the upcoming season physical demands. In the present study, TL was progressively increased over the 9–10 sessions using a variety of training modalities including SSG. The SSG were performed in a high-intensity interval manner; this type of exercise can increase the perception of effort and the overall session TL [25, 32]. Several authors have shown that the TL during SSG increases with fewer players, larger pitch size, encouragement of technical staff, fewer ball touches, and the absence of a goalkeeper [25, 32]. The average weekly TL ( $> 3000$  a.u), monotony ( $> 2$  a.u), and strain ( $> 5000$  a.u) observed are considered very high [23, 33]. Similarly, results from recent investigations indicated that high monotony and strain were related to a high level of fatigue and resulted from cumulative effects of sustained high TL [13, 34]. Buchheit et al. [23] reported that excessive loads produced a high level of fatigue and insufficient recovery during intensified training cycle in professional soccer players. Moalla et al. [15] showed that high TL during IT produced negative psychometric responses suggesting that the perceived sleep, stress, fatigue and muscle soreness are related to the daily TL in professional soccer players. Furthermore, Selmi et al. [2] showed that high TL during IT negatively affected wellness and recovery which may

be explained by the relationship between TL, TQR and well-being indices found in the present investigation. It is known that high TL can induce changes in hormonal balance and muscle damage, and such imbalance can be associated with psychometric fatigue indicators [3]. In the present study, a 2-week IT elicited increased neuromuscular fatigue, greater circulating concentrations of markers associated with muscle damage, reductions in psychometric indicators of well-being, and poor perceived recovery. Several previous studies have also reported that TL intensification caused psychological disturbances such as poor sleep quality, increased stress and fatigue, more muscle soreness, and a poorer recovery state [3, 10, 19].

The present study showed that CMJ height decreased significantly after the IT compared to before the IT. This result was supported by previous findings that demonstrated that CMJ performance decreased following 6-week training period with a progressive overload in semi-professional rugby league players [35]. Similarly, Los Arcos et al. [36] found that accumulated TL, as well as accumulated training volume were negatively correlated with CMJ performance changes after 9 weeks of training in young professional male soccer players. Altogether, these findings indicated that preseason IT may increase neuromuscular fatigue and that the decreased neuromuscular performance is likely affected, at least in part, by high TL, persistent fatigue, and suboptimal recovery during IT [37]. Reduced CMJ performance, which was associated with the magnitude of muscle damage marker change (CK), may be due to fatigue accumulation [4]. Some studies have suggested that CMJ measurement might be a useful, non-invasive measure for adjusting TL throughout IT by monitoring and detecting decrements in muscular performance [6, 19, 21]. Indeed, Claudino et al. [5] showed that CMJ performance decreased after overreaching (4-week IT) and increased after tapering (2 weeks) in soccer players. Further lending support the usefulness of CMJ in monitoring fatigue was the finding of the present study which reported that the reduced in CMJ performance corresponded with greater psychological fatigue, greater muscle soreness, and poorer perception of recovery quality but not to sleep quality or stress. This finding was similar to the findings of Blake et al. [38] who showed that neuromuscular fatigue status was related to fatigue and muscle soreness but not to sleep and stress. Overall, the relationship between CMJ performance and recovery indices suggested that measuring CMJ during IT might be useful in monitoring fatigue and manipulating TL to achieve functional overreaching in team sport athletes [39].

In the present study, CRP concentrations increased from before to after IT and were correlated with muscle soreness. Similarly, Fatouros et al. [1] showed that CRP concentrations increased during 3 weeks of high training volume performed during 6 days per week. Moreover, Neubauer et al. [40] found that CRP increased following IT. Together, these findings suggest that IT increased basal inflammation, likely as a result of increasing TL [1]. In the present study, an increase in circulating CK was observed from before to after IT, indicating the presence of muscle damage [20], and well-being and

perceived recovery were inversely associated with CK which agrees with previous reports [41, 42]. Therefore, in association with the results of previous investigations, our findings suggested that the TQR scale and Hooper index could be used as markers of fatigue and recovery. However, further investigations are needed to provide important specific information about the relationships between these variables and how they can be used to adapt TL.

In the present study, testosterone did not change whereas cortisol increased significantly after IT which consequently decreased T/C ratio from before to after IT, similar to what was reported in a previous study [6]. The ratio decrease might reflect a more catabolic state at the end of the intensified period compared to the beginning of training [35]. Moreover, the increase in cortisol concentration could be influenced by psychological stress induced by the training load intensification [43]. In the present study, a positive relationship between cortisol and psychological stress was recorded, supporting the finding of Jürimäe *et al.* [11] who showed a positive relationship between cortisol and psychological stress. Moreover, the T/C ratio was significantly associated with muscle soreness which is similar to those reported by Ouergui *et al.* [44] during judo training, indicating that IT increased muscle damage and soreness and reduced recovery.

Together, these data suggest that increased fatigue and poor recovery state of players during IT is associated with a change in the biological markers, supporting the usefulness of Hooper questionnaire and TQR scale as indicators of recovery in soccer players during IT. The results from the present study suggest that the performance of frequent, demanding training sessions during precompetitive IT induced high levels of physical and psychological stress on soccer players, associated with alterations in their hormonal status, physical performance, perceived recovery and well-being. Because of the close association between physical and psychometric measures, the well-being scale and TQR appear to be appropriate and useful measures for monitoring recovery and fatigue.

While this study has described important variables indicative of psychometric status during IT and relationships between psychometric status, neuromuscular performance and fatigue biomarkers, several limitations must be acknowledged. First, the sample was small and included only male subjects, thereby limiting the generalizability of conclusions. This also prevented assessment of outcome measures according to positional roles. Second, we did not include measures of other physical parameters such as longer-duration anaerobic and aerobic performance. Such measures would be a valuable addition for fatigue assessment during IT. Third, while the physical and technical demands during the training period were controlled, it was not possible to control extra activities (e.g., leisurely outings, stress from studying, etc.) that players engaged in outside of training sessions. Finally, investigating these responses in the tapering period would be beneficial to determine the usefulness of these fatigue and recovery measures during a training period with lower TL.

## CONCLUSIONS

This study demonstrated that IT with high TL increased neuromuscular fatigue, markers of muscle damage, and changes anabolic/catabolic state among professional soccer players. The changes in these performance measures and biomarkers were associated with psychometric indices of players' well-being and perceived recovery state. This study supported the importance of using TQR scale and well-being indices as simple, non-invasive, and useful markers for monitoring fatigue and recovery of professional soccer players. It is possible that these measures are also useful for informing and manipulating TL during IT in soccer players in order to prevent excessive fatigue and overtraining.

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## Conflict of Interest

The authors declare that they have no conflict of interest.

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