

SVEUČILIŠTE U SPLITU
KINEZIOLOŠKI FAKULTET

JOSIP MALEŠ

**PRAĆENJE TRENAŽNOG OPTEREĆENJA, OPORAVKA,
DOBROBITI I ADAPTACIJE PROFESIONALNIH
NOGOMETAŠA TIJEKOM PRIPREMNOG PERIODA:
INTEGRACIJA SUBJEKTIVNIH I OBJEKTIVNIH
POKAZATELJA**

DOKTORSKI RAD

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DOKTORSKI RAD

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Split, 2026

PODACI O MENTORU

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Rođen je 13. svibnja 1982. godine u Splitu, gdje je završio osnovno obrazovanje te srednju školu IV. gimnaziju „Marko Marulić“. Diplomirao je kineziologiju na Kineziološkom fakultetu Sveučilišta u Splitu, a doktorat iz kineziologije stekao je 2017. godine na istom fakultetu.

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Primarna područja njegova znanstvenog i stručnog interesa obuhvaćaju metodologiju istraživanja u sportskoj znanosti i kineziologiji, praćenje sportaša, te borilačke sportove. Sudjelovao je na nacionalnim i međunarodnim znanstvenim projektima, uključujući HRZZ projekt te više međunarodnih istraživačkih i razvojnih projekata.

Dobitnik je Nagrade za znanost Sveučilišta u Splitu te međunarodne nagrade John M. Kinney Nestlé Nutrition Award. Također je član uredništava više međunarodnih znanstvenih časopisa, među kojima su BMC Sports Science, Medicine and Rehabilitation, PLOS ONE, Frontiers in Public Health i International Journal of Exercise Science.

ZAHVALE

Popis skraćenica

GPS	(eng. global positioning system)
BMI	indeks tjelesne mase
SD	standardna devijacija
CI	interval pouzdanosti
CV	koeficijent varijacije
RPE	subjektivna procjena napora
sRPE	session rating of perceived exertion
ITI	unutarnji trenažni intenzitet
ITIds	dnevni unutarnji trenažni intenzitet
ITlws	tjedni unutarnji trenažni intenzitet
ITlmean	prosječni tjedni unutarnji trenažni intenzitet
ITlsum	kumulativni tjedni unutarnji trenažni intenzitet
TM	trenažna monotonija
TS	trenažni stres
TS-Δ	razlika trenažnog podražaja i oporavka
WBI	indeks dobrobiti
WB	dobrobit
TQR	ukupna kvaliteta oporavka
TQRpost	dnevna procjena oporavka
TQRfw	oporavak na početku tjedna
DOMS	odgođena mišićna bol
PMS	percipirana mišićna bol
CMJ	vertikalni skok iz čučnja
HRV	varijabilnost srčanog ritma
HR	srčana frekvencija
RHR	srčana frekvencija u mirovanju
RHRmean	prosječna srčana frekvencija u mirovanju
lnRMSSD	logaritmirana srednja kvadratna razlika uzastopnih RR-intervalu
lnRMSSDmean	prosječna lnRMSSD vrijednost
lnRMSSDCV	koeficijent varijacije lnRMSSD
Sleepmean	prosječno trajanje sna
VO ₂ max	maksimalni primitak kisika

IFT	Intermittent Fitness Test
30–15 IFT	30–15 Intermittent Fitness Test
VIFT	maksimalna brzina u 30–15 IFT testu
TE–TA	tehničko-taktički trening
S&C	trening snage i kondicije
SAQ	brzina, agilnost i brzina reakcije
SSG	igre na smanjenom prostoru
HIIT	intervalni trening visokog intenziteta
ANOVA	analiza varijance
η^2	parcijalni eta kvadrat
ES	veličina učinka
d	Cohenov d
r	Pearsonov koeficijent korelacije
rrm	korelacija s ponovljenim mjerenjima
ICC	intraklasni koeficijent korelacije
SWC	najmanja značajna promjena
CL	granice pouzdanosti

SAŽETAK

Nogomet je sport obilježen iznimno velikim brojem visoko intenzivnih kretnji („*stop and go*“) koje uzrokuju značajan psihofizički stres na organizam nogometaša. Zbog naglog povećanja volumena i intenziteta treninga visoka razina stresa je značajno izražena tijekom pripremnog perioda. To naglo povećanje volumena i intenziteta treninga dovodi do povećane akumulacije umora i rizika od ozljede kao posljedice neadekvatne adaptacije na opterećenje. Praćenje u sportu (pa tako i u nogometu) predstavlja sastavni dio suvremenih trenažnih programa pri čemu se koriste različite metode i modeli za procjenu opterećenja i oporavka kod igrača. Integrirani pristup praćenja, koji istovremeno obuhvaća korištenje subjektivnih i objektivnih metoda za dobivanje jasnije slike o stanju sportaša, dobiva na važnosti u teoriji i praksi, a pogotovo u kontekstu pripremnog perioda. Glavni cilj ovog doktorskog rada bio je istražiti odnose između unutarnjeg trenažnog opterećenja, pokazatelja oporavka, dobrobiti i neuromišićne izvedbe tijekom pripremnog perioda kod profesionalnih nogometaša, primjenom integriranog sustava subjektivnih i objektivnih pokazatelja. Istraživanje je provedeno na uzorku od 48 profesionalnih nogometaša (dob: 22.8 ± 4.2 godine; tjelesna visina: 184.4 ± 6.7 cm; tjelesna masa: 77.2 ± 6.5 kg) tijekom dva priprema perioda u trajanju od četiri i pet tjedana, a kojima je prethodio jedan tjedan upoznavanja ispitanika s eksperimentalnim postupcima. Unutarnje trenažno opterećenje procijenjeno je korištenjem sRPE metode, dok su pokazatelji oporavka i adaptacije procijenjeni korištenjem varijabilnosti srčanog ritma (HRV), te kvalitete i trajanje sna. Subjektivne mjere dobrobiti i oporavka procijenjene su uz pomoć upitnika (upitnik dobrobiti, PMS, TQR), dok je procjena neuromišićnog opterećenja i oporavka provedena korištenjem testa vertikalni skok iz čučnja s pripremom. Rezultati su pokazali statistički značajne promjene unutarnjeg trenažnog opterećenja ($p < 0.001$), značajne promjene subjektivnih mjera dobrobiti i oporavka ($p < 0.001$) i neuromišićne izvedbe ($p < 0.001$) tijekom pripremnog perioda. Također su uočene značajne negativne povezanosti između unutarnjeg trenažnog opterećenja i neuromišićne izvedbe ($p = 0.005$), kao i između unutarnjeg trenažnog opterećenja i trajanja sna ($p = 0.045$), dok su značajne povezanosti utvrđene i sa subjektivnim mjerama za percepciju oporavka ($p < 0.001$). Dobiveni rezultati pružaju uvid u složene odnose trenažnog opterećenja, oporavka i izvedbe nogometaša tijekom pripremnog perioda, te kao takvi mogu poslužiti kao smjernice za optimizaciju i bolje planiranje trenažnog opterećenja u nogometu.

ABSTRACT

Football is activity characterised by extremely large number of high-intensity movements (“*stop and go*”), which create significant psychophysiological stress on the players bodies. High levels of stress are particularly present during the preparatory period due to the sudden increase in training volume and intensity. Such increases in training load leads to greater accumulation of fatigue and an increased risk of injury as a consequence of inadequate adaptation to demands of activity. Monitoring in sport (including football) represent an integral part of modern training programmes, with various methods and models being used to assess training load and recovery in players. Integrated monitoring approach, which includes subjective and objective methods in order to obtain a clearer picture of an athlete’s condition, is gaining importance in both practice and the scientific literature, particularly within the context of the preparatory period. The main aim of this doctoral dissertation was to investigate the relationships between internal training load, recovery indicators, well-being, and neuromuscular performance during the preseason period in professional soccer players, using an integrated system of subjective and objective measures. The study was conducted on a sample of 48 professional football players (age: 22.8 ± 4.2 years; body height: 184.4 ± 6.7 cm; body mass: 77.2 ± 6.5 kg) during two preparatory periods lasting four and five weeks, preceded by one week for familiarization with the experimental procedures. Internal training intensity was assessed using the sRPE method, while recovery and adaptation indicators were evaluated using heart rate variability (HRV) as well as sleep quality and sleep duration. Subjective measures of wellbeing and recovery were assessed with the use of questionnaires (wellbeing questionnaire, PMS, TQR), while neuromuscular load and recovery were assessed with the use of countermovement jump test. The results show statistically significant changes in internal training intensity ($p < 0.001$), subjective measures of well-being and recovery ($p < 0.001$), and neuromuscular performance ($p < 0.001$) during the preparatory period. Significant negative associations were observed between internal training load and neuromuscular performance ($p = 0.005$), as well as between internal training load and sleep duration ($p = 0.045$), while significant associations were also found with subjective measures of perceived recovery ($p < 0.001$). The obtained results provide clear insight into the complex relationships between training intensity, recovery, and performance in football players during the preparatory period and may serve as guidelines for optimising and improving the planning of training load in football.

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1. OSNOVNA STRUKTURA DOKTORSKOG RADA

Ovaj doktorski rad se sastoji od tri izvorna znanstvena rada:

1. Maleš, J., Ouergui, I., Kuna, D., Žuvela, F., De Giorgio, A., & Kuvačić, G. (2022). Monitoring Internal Training Intensity Correlated with Neuromuscular and Well-Being Status in Croatian Professional Soccer Players during Five Weeks of the Pre-Season Training Phase. *Sports*, 10(11).
2. Maleš, J., Ouergui, I., Žuvela, F., Ceylan, H. I., Bragazzi, N. L., De Giorgio, A. & Kuvačić, G. (2025). Relationships between internal training intensity, heart rate variability, sleep duration, and neuromuscular performance in professional soccer players. *Human Movement*, 26(3), 101–114.
3. Maleš, J., Žuvela, F., Bragazzi, N. L., De Giorgio, A., & Kuvačić, G. (2025). Perceived recovery and muscle fatigue in professional soccer players during preseason. *International Journal of Exercise Science*, 18(8), 1212–1227.

2. UVOD

2.1. Nogomet

Nogomet je složena sportska aktivnost obilježena čestim izmjenama kretanja niskog i visokog intenziteta, ubrzanjima, usporenjima, promjenama smjera, skokovima, duelima i ponavljanim ekscentričnim opterećenjima (Silva i sur., 2023; Taylor i sur., 2017). Takva struktura izvedbe rezultira visokim metaboličkim, mehaničkim i neuromišićnim zahtjevima, zbog čega su nogometaši tijekom treninga i utakmica kontinuirano izloženi značajnom fiziološkom i psihološkom stresu (Dalen i sur., 2016; Milanović i sur., 2017). Uz količinu kretanja, važno je naglasiti da zahtjevnost nogometa proizlazi i iz njegove nepredvidive prirode, odnosno stalne izmjene intenziteta aktivnosti i potrebe za ponavljanim izvođenjem eksplozivnih radnji u uvjetima nepotpunog oporavka između pojedinih akcija (Gualtieri i sur., 2023). U određenim razdobljima sezone takvi zahtjevi mogu dovesti do izraženije akumulacije umora, smanjenja radne sposobnosti i povećanog rizika od ozljede, osobito ako odnos između opterećenja i oporavka nije adekvatno uravnotežen (Akenhead i Nassis, 2016; Weston, 2018). Sukladno navedenom, posebno osjetljivo razdoblje godišnjeg trenažnog ciklusa nogometne ekipe je upravo pripremni period, tijekom kojega se u relativno kratkom vremenu povećavaju volumen i intenzitet treninga, a faza odmora je ograničena ritmom treninga i utakmica, a sve s ciljem razvoja motoričkih i funkcionalnih sposobnosti te pripreme igrača za natjecateljsku sezonu (Ekstrand i sur., 2020; Jeong i sur., 2011). Upravo zbog takvih obilježja pripremni period predstavlja specifičan prostor za proučavanje odnosa između trenažnog opterećenja, umora, oporavka i adaptacije, budući da se u toj fazi istodobno očekuju pozitivne trenažne prilagodbe i povećana osjetljivost na prekomjerno opterećenje, odnosno akumulaciju umora i rizik od ozljede igrača (Fessi, Nour, i sur., 2016; Owen i sur., 2015; Pereira i sur., 2022). Stoga sustavno praćenje opterećenja i odgovora organizma na opterećenje predstavlja jedno od ključnih praktičnih i znanstvenih pitanja suvremenog nogometa (P. Afonso i sur., 2025; Anderegg i sur., 2025; Jaspers i sur., 2017).

2.2. Vanjsko i unutarnje trenažno opterećenje u nogometu

U kontekstu sportskog treninga opterećenje se najčešće promatra kroz dva međusobno povezana, ali konceptualno različita aspekta: vanjsko i unutarnje trenažno opterećenje. Vanjsko trenažno opterećenje odnosi se na stvarno izvršeni rad, odnosno na lokomotorne i mehaničke

zahtjeve kojima je sportaš izložen tijekom treninga ili natjecanja (Jaspers i sur., 2017). U nogometu se ono najčešće prati uporabom GPS (eng. *global positioning system*) i LPS (eng. *local positioning systems*) sustava, inercijskih senzora i sličnih tehnologija, a obuhvaća pokazatelje poput ukupne prijeđene udaljenosti, udaljenosti pri velikim brzinama, sprintne udaljenosti, broja ubrzanja i usporenja, promjena smjera, PlayerLoad™-a i drugih varijabli koje opisuju količinu i strukturu izvršenog rada (Casamichana i sur., 2013; Prudholme i sur., 2023). Posebno je važno naglasiti da lokomotorni i mehanički pokazatelji ne odražavaju uvijek iste zahtjeve, budući da primjerice velik broj ubrzanja, usporavanja i promjena smjera može stvarati znatan neuromišićni stres i u situacijama kada ukupna prijeđena udaljenost nije visoka (Oliva-Lozano i sur., 2023).

Unutarnje trenažno opterećenje predstavlja individualni fiziološki i perceptivni odgovor sportaša na zadani vanjski podražaj, a najčešće se procjenjuje pomoću srčane frekvencije, varijabilnosti srčanog ritma, koncentracije laktata, raznih biokemijskih markera te subjektivnih pokazatelja kao što je *session rating of perceived exertion* (sRPE) (Macedo i sur., 2024; Rago i sur., 2020). Za razliku od vanjskog opterećenja, koje opisuje što je sportaš objektivno izvršio, unutarnje opterećenje pruža uvid u to kako je organizam odgovorio na taj podražaj, odnosno koliki je fiziološki i perceptivni stres, pojedini trening ili utakmica izazvao kod konkretnog igrača (Impellizzeri i sur., 2019). Zbog toga, unutarnje opterećenje može biti pod utjecajem brojnih čimbenika, uključujući razinu utreniranosti, trenutačni status oporavka, kvalitetu sna, psihološki stres, prethodno akumulirano opterećenje i fazu sezonskog ciklusa (Ferreira i sur., 2023).

Iako su vanjsko i unutarnje trenažno opterećenje teorijski različiti konstrukti, njihova je međusobna povezanost od presudne važnosti za razumijevanje trenažnog procesa. Naime, isti vanjski podražaj ne mora izazvati jednak unutarnji odgovor kod svakog igrača, niti kod istog igrača u različitim fazama pripremnog ili natjecateljskog razdoblja (Martin i sur., 2023). To potvrđuju i istraživanja u elitnom nogometu koja pokazuju da su vanjski i unutarnji pokazatelji opterećenja međusobno povezani, ali da različite lokomotorne i mehaničke varijable ne pridonose jednako subjektivno percipiranom naporu, što upućuje na to da izvršeni rad i individualni odgovor organizma predstavljaju povezane, ali ne i iste dimenzije trenažnog procesa (Impellizzeri i sur., 2019; Versic i sur., 2022). Razlika između izvršenog rada i individualnog odgovora organizma jedan je od ključnih razloga zašto se u suvremenom nogometu naglašava potreba za integriranim praćenjem sportaša, odnosno istodobnog praćenja opterećenja, oporavka, dobrobiti i ukupnog psihofizičkog stanja (Gdovin i sur., 2023; Halson, 2014; Vanrenterghem i sur., 2017). U skladu s ciljevima ovog rada, istraživački fokus nije

usmjeren na vanjsko trenažno opterećenje, nego prvenstveno na unutarnje trenažno opterećenje te na subjektivne i objektivne pokazatelje oporavka, dobrobiti i neuromišićne izvedbe koji odražavaju odgovor organizma na trenažni proces tijekom pripremnog perioda.

2.3. Integrirani pristup praćenja sportaša

Integrirani pristup praćenju proizlazi iz činjenice da psihofizički odgovor sportaša na trenažno opterećenje nije moguće adekvatno objasniti jednom izoliranom mjerom, budući da uključuje istodobne promjene u fiziološkoj, perceptivnoj i psihološkoj domeni (Enoka i Duchateau, 2016; Lambert i sur., 2005). Posljedično, procjena stanja nogometaša zahtijeva praćenje više komplementarnih pokazatelja koji zajedno mogu pružiti cjelovitiji uvid u odgovor organizma na trenažni i natjecateljski stres (Owen i sur., 2017). Dodatnu potporu takvom pristupu pruža sustavni pregled Saw i sur. (2016), u kojem je istaknuto da su subjektivne mjere samoprocjene odražavale akutna i kronična trenažna opterećenja osjetljivije i konzistentnije od često korištenih objektivnih pokazatelja, pri čemu autori ističu da najveću praktičnu vrijednost ima njihova integrirana interpretacija.

Subjektivne mjere, poput percipiranog napora, ukupne kvalitete oporavka, mišićne boli i opće dobrobiti, imaju značajnu praktičnu vrijednost jer su jednostavne za primjenu, vremenski nezahtjevne, financijski pristupačne i osjetljive na kratkoročne promjene u psihofizičkom stanju igrača (Djaoui i sur., 2017; Saw i sur., 2016). Njihova je dodatna prednost u tome što mogu obuhvatiti i one dimenzije odgovora na opterećenje koje nisu lako dostupne objektivnim metodama, poput subjektivnog osjećaja umora, razine stresa ili opće spremnosti za daljnji trening i natjecanje. S druge strane, objektivne mjere, poput varijabilnosti srčanog ritma, pokazatelja kvalitete i trajanja sna te testova neuromišićne izvedbe, primjerice countermovement jump (CMJ), pružaju dodatne informacije o autonomnom i fiziološkom odgovoru organizma na trenažni proces (Claudino i sur., 2017). Kombiniranjem subjektivnih i objektivnih pokazatelja omogućuje se preciznija interpretacija promjena u statusu sportaša, budući da različite mjere ne odražavaju nužno iste aspekte umora, oporavka i adaptacije (Bauer i sur., 2024; Naughton i sur., 2021).

Dosadašnja literatura uglavnom podupire stajalište da niti jedna mjera kad se promatra izolirano, bilo subjektivna bilo objektivna, nije dovoljna za cjelovitu procjenu stanja nogometaša, nego da najveća vrijednost proizlazi iz njihove međusobne nadopune i integrirane interpretacije (Coutts i sur., 2017; Temm i sur., 2022). Drugim riječima, praćenje usmjereno samo na jednu skupinu pokazatelja može pružiti parcijalnu sliku, dok kombinirani, odnosno

integrirani pristup omogućuje potpunije razumijevanje individualnog odgovora igrača na trenažni proces (Halson, 2014). U tom smislu, integrirani sustav praćenja predstavlja metodološki i praktično opravdan okvir za proučavanje odnosa između opterećenja, oporavka, dobrobiti i neuromišićne izvedbe u profesionalnom nogometu.

2.4. Dosadašnja istraživanja tijekom pripremnog perioda

Dosadašnja istraživanja u nogometu upućuju na to da je pripremini period posebno prikladan za proučavanje odnosa između trenažnog opterećenja, oporavka i adaptacijskih procesa, budući da se upravo u toj fazi sezonskog ciklusa istodobno očekuju i izraženije trenažne prilagodbe i povećana osjetljivost na akumulaciju umora (Lechner i sur., 2023; Perrotta i sur., 2024). Longitudinalna istraživanja provedena tijekom pripremnog razdoblja pokazala su da se u relativno kratkom vremenu mogu uočiti značajne promjene u razini opterećenja, fiziološkim odgovorima i pokazateljima izvedbe, pri čemu veličina i smjer tih promjena ovise o početnom statusu sportaša, strukturi trenažnog programa i sposobnosti oporavka između pojedinih podražaja (Jeong i sur., 2011; Martinho i sur., 2024). Primjerice, Buchheit i sur. (2013) pokazali su tijekom dvotjednog intenziviranog pripremnog kampa da su dnevne varijacije trenažnog opterećenja bile vrlo izražene (CV = 66%), dok su mjere dobrobiti također osjetljivo pratile promjene kroz kamp, pri čemu su upravo trenažno opterećenje, submaksimalna srčana frekvencija i wellness pokazatelji identificirani kao najkorisnije jednostavne mjere za praćenje odgovora sportaša na razdoblje pojačanog rada. Nadalje, istraživanja koja su kombinirala vanjske i unutarnje pokazatelje opterećenja pokazala su da tijekom višetjednih priprema dolazi do progresivnog povećanja trenažnog opterećenja, ali ne nužno i do proporcionalnog porasta subjektivno percipiranog umora, što upućuje na potrebu kontinuiranog i višedimenzionalnog praćenja odgovora igrača na trening (Fessi, Nouira, i sur., 2016).

Tijekom pripremnog perioda najčešće su korištene varijable unutarnjeg opterećenja, poput sRPE (eng. *session rating of perceived exertion*), te različiti subjektivni pokazatelji dobrobiti i oporavka, uključujući umor, kvalitetu sna, mišićnu bol, stres, raspoloženje i ukupnu kvalitetu oporavka (Beéck i sur., 2019). Prednost takvih mjera jest njihova jednostavna primjena, niska cijena i osjetljivost na kratkoročne promjene u psihofizičkom stanju sportaša, zbog čega su osobito korisne u svakodnevnom radu s momčadi (Coyne i sur., 2022; Saw i sur., 2016). Istodobno, iako praktični i jeftini, njihovo je ograničenje u tome što ovise o individualnoj percepciji, motivaciji i dosljednosti ispunjavanja, pa ih nije uvijek moguće

tumačiti kao potpuno stabilne ili objektivno usporedive pokazatelje (Saw i sur., 2015). Upravo zato novija istraživanja sve češće nastoje kombinirati subjektivne mjere s objektivnim pokazateljima, poput varijabilnosti srčanog ritma (HRV), trajanja sna i neuromišićne izvedbe, kako bi se preciznije procijenio odgovor igrača na trenažni proces (Beato i sur., 2024; Shushan i sur., 2022). Takav pristup omogućuje cjelovitiju procjenu psihofizičkog statusa sportaša, budući da se unutarnje trenažno opterećenje ne tumači izolirano, nego u odnosu na pokazatelje oporavka, dobrobiti i fiziološkog odgovora organizma na trenažni proces.

Nadalje, istraživanja koja su pratila odnos početne razine fizičke spremnosti i ishoda tijekom sezone upozoravaju da igrači s nižom aerobnom i neuromišićnom spremnošću mogu biti osjetljiviji na negativne posljedice zahtjevnog pripremnog perioda, uključujući i veći rizik od ozljeda (Eliakim i sur., 2018). S druge strane, visoko, ali adekvatno kontrolirano opterećenje tijekom pripremnog perioda može potaknuti poželjne fiziološke i izvedbene adaptacije, pod uvjetom da je praćeno odgovarajućim oporavkom i da se njegove posljedice sustavno nadziru (Martinho i sur., 2024). Zbog toga su posebnu pozornost privukle varijable poput HRV-a, koji se koristi kao pokazatelj autonomne regulacije i oporavka, te *countermovement jump* (CMJ), koji se često primjenjuje kao praktičan test neuromišićne izvedbe i spremnosti (Plews i sur., 2013; Morales i sur., 2014; Gathercole i sur., 2015; Claudino i sur., 2017). Ipak, literatura pokazuje da HRV i CMJ ne reagiraju uvijek jednako osjetljivo na promjene u opterećenju, zbog čega ih je potrebno tumačiti oprezno i u kombinaciji s drugim pokazateljima (Claudino i sur., 2017; Thorpe i sur., 2015). U tom smislu, istraživanja u elitnom nogometu upućuju na to da subjektivne mjere dobrobiti u nekim okolnostima mogu biti osjetljivije na promjene u dnevnom opterećenju od pojedinih fizioloških i neuromišićnih pokazatelja, što dodatno potvrđuje da HRV i CMJ, iako korisni, ne bi trebali biti interpretirani izolirano (Rabbani i sur., 2018; Thorpe i sur., 2017). Zajednički gledano, ti nalazi potvrđuju praktičnu važnost praćenja u pripremnom periodu, ali i jasno pokazuju da je upravo to razdoblje posebno osjetljivo na narušavanje ravnoteže između trenažnog podražaja i oporavka. Prema tome, pripremini period predstavlja prikladan okvir za istraživanja usmjerena na integrirano praćenje unutarnjeg trenažnog opterećenja, oporavka, dobrobiti te autonomnih i neuromišićnih pokazatelja odgovora na trenažni proces kod nogometaša.

2.5. Ograničenja dosadašnjih istraživanja

Iako je praćenje u nogometu danas dobro uspostavljeno i široko prihvaćeno u istraživačkom i praktičnom kontekstu, neka važna pitanja u literaturi i dalje nisu u potpunosti

razjašnjena. Dosadašnja istraživanja uglavnom su bila usmjerena na pojedine aspekte praćenja, poput unutarnjeg trenažnog opterećenja ili pojedinih pokazatelja oporavka i dobrobiti, dok je njihovo zajedničko promatranje unutar istog analitičkog okvira nešto rjeđe prisutno (Temme i sur., 2022). Zbog toga je ponekad otežano cjelovitije razumijevanje odnosa između trenažnog procesa i odgovora organizma na opterećenje, osobito u specifičnim uvjetima pripremnog perioda kod nogometaša. Uz to, istraživanja su često provedena na manjim uzorcima i u različitim kontekstima praćenja, što može otežati usporedbu nalaza i donošenje jednoznačnih zaključaka (Abarghoueinejad i sur., 2021; Hecksteden i sur., 2022). Iako postoje istraživanja koja povezuju unutarnje trenažno opterećenje s pokazateljima oporavka, dobrobiti, sna, autonomne regulacije i neuromišićne izvedbe, takvi su nalazi i dalje djelomično neujednačeni. (Pereira i sur., 2022). To se posebno odnosi na varijable koje su i u ovom radu odabrane kao važni pokazatelji psihofizičkog statusa sportaša, poput sRPE-a i iz njega izvedenih pokazatelja unutarnjeg trenažnog opterećenja, indeksa dobrobiti, ukupne kvalitete oporavka, percipirane mišićne boli, varijabilnosti srčanog ritma, trajanja sna i CMJ izvedbe. Premda su te varijable pojedinačno dobro zastupljene u literaturi, rjeđe ih se prati zajedno kroz isti longitudinalni okvir, osobito tijekom pripremnog perioda.

Također, pojedine varijable, iako praktično vrlo korisne, imaju i svoja specifična ograničenja. Subjektivne mjere dobrobiti i oporavka osjetljive su i operativno vrlo primjenjive, ali ovise o samoprocjeni sportaša i mogu biti pod utjecajem motivacijskih i kontekstualnih čimbenika (Saw i sur., 2015a; Shankland i sur., 2017). HRV može pružiti vrijedan uvid u autonomni odgovor organizma, ali njegova interpretacija nije uvijek jednoznačna, osobito kada se promatraju kratkoročne promjene ili male dnevne oscilacije (Kamandulis i sur., 2020). Slično tome, iako je CMJ praktičan pokazatelj neuromišićne izvedbe, promatran izolirano ne mora uvijek jednako osjetljivo odražavati sve aspekte umora i oporavka, zbog čega njegova najveća vrijednost dolazi do izražaja kada se tumači zajedno s ostalim pokazateljima unutar istog sustava praćenja (Knihš i sur., 2021).

Unatoč sve većem broju istraživanja, dosadašnja literatura ne donosi uvijek posve ujednačene zaključke. Razlike među nalazima mogu se barem djelomično objasniti trajanjem praćenja, razinom natjecanja, strukturom mikrociklusa, izborom mjernih pokazatelja i primijenjenim statističkim pristupima (Wang i sur., 2021; West i sur., 2019). Zbog toga još nije sasvim jasno koje su mjere osjetljivije na promjene u trenažnom opterećenju, u kojoj se mjeri njihovi odgovori preklapaju te koliko odražavaju različite dimenzije umora, oporavka i adaptacije. Upravo zato i dalje postoji potreba za longitudinalnim istraživanjima koja će unutar jedinstvenog analitičkog okvira jasnije povezati unutarnje trenažno opterećenje s

pokazateljima oporavka, dobrobiti, sna, autonomne regulacije i neuromišićne izvedbe kod profesionalnih nogometaša. U tome se nalazi i temeljna opravdanost ovog doktorskog rada, koji nastoji pridonijeti boljem razumijevanju odnosa između unutarnjeg trenažnog opterećenja i odabranih pokazatelja psihofizičkog statusa sportaša tijekom pripremnog perioda. Takav pristup omogućuje cjelovitiji uvid u međusobnu povezanost opterećenja, oporavka, dobrobiti i odgovora organizma u stvarnim uvjetima profesionalnog nogometa.

2.6. Ciljevi i hipoteze istraživanja

Glavni cilj ovog doktorskog rada bio je istražiti odnose između unutarnjeg trenažnog opterećenja, pokazatelja oporavka, dobrobiti i neuromišićne izvedbe tijekom pripremnog perioda kod profesionalnih nogometaša, primjenom integriranog sustava subjektivnih i objektivnih pokazatelja. Ovim istraživanjem nastojalo se pružiti dublje razumijevanje adaptacije nogometaša i njihove percepcije trenažnog opterećenja tijekom pripremnog razdoblja.

Parcijalni ciljevi ovog istraživanja bili su

1. Istražiti tjedne promjene unutarnjeg trenažnog opterećenja, statusa dobrobiti i izvedbe vertikalnog skoka iz čučnja tijekom petotjednog pripremnog perioda kod profesionalnih nogometaša, te ispitati odnos doza–odgovor između unutarnjeg trenažnog opterećenja i izvedbe vertikalnog skoka iz čučnja u odnosu na varijacije mjera statusa dobrobiti
2. Analizirati odnos između unutarnjeg trenažnog opterećenja i ključnih pokazatelja oporavka i izvedbe, uključujući varijabilnost srčanog ritma, trajanje sna i izvedbu vertikalnog skoka iz čučnja, tijekom petotjednog pripremnog perioda kod profesionalnih nogometaša.
3. Ispitati tjedne varijacije i odnose u varijablama unutarnjeg trenažnog opterećenja, subjektivne percepcije oporavka, neuromišićne izvedbe i mišićnog umora tijekom četverotjednog pripremnog perioda, te dodatno procijeniti korisnost indeksa $TS-\Delta$ kao praktičnog alata za praćenje ravnoteže između trenažnog podražaja i oporavka.

Hipoteze ovog istraživanja bile su:

- H1)** Postoje značajne tjedne promjene unutarnjeg trenažnog opterećenja, dobrobiti i neuromišićne izvedbe kod profesionalnih nogometaša.
- H2)** Veće unutarnje trenažno opterećenje značajno je povezano s nižim vrijednostima dobrobiti, nižom varijabilnošću srčanog ritma, kraćim trajanjem sna i slabijom izvedbom vertikalnog skoka iz čučnja.
- H3)** Postoje značajne tjedne varijacije subjektivne percepcije oporavka, neuromišićne izvedbe i percipirane mišićne boli kod profesionalnih nogometaša. Veće unutarnje trenažno opterećenje značajno je povezano s lošijim oporavkom, izraženijom mišićnom boli i slabijom neuromišićnom izvedbom, pri čemu indeks $TS-\Delta$ predstavlja koristan pokazatelj ravnoteže između trenažnog podražaja i oporavka.

3. GENERALNE METODE

U ovom dijelu doktorskog rada prikazan je sažeti i objedinjeni pregled temeljnih obilježja izvornih istraživanja uključenih u rad. Prikaz obuhvaća zajedničke elemente istraživačkog dizajna, etički okvir provedbe, karakteristike uzorka, eksperimentalni postupak, praćene varijable i mjerne instrumente te način prikupljanja i obrade podataka. Time se na jednom mjestu objedinjuju ključne sastavnice svih uključenih radova, dok su specifičnosti pojedinih istraživanja detaljnije prikazane u poglavljima koja slijede.

3.1. Etičko odobrenje

Svi postupci provedeni u okviru istraživanja za ovaj doktorski rad bili su odobreni od strane Etičkog odbora Kineziološkog fakulteta Sveučilišta u Splitu te su provedeni u skladu s etičkim načelima Helsinške deklaracije iz 1975. godine i njezinim kasnijim izmjenama koja se odnose na istraživanja na ljudima (brojevi odobrenja: 2181-205-02-05-22-015 i 2181-205-02-05-25-030). Prije uključenja u istraživanja, svim igračima su jasno objašnjeni ciljevi, dizajn i postupci istraživanja, kao i mogući zahtjevi povezani s praćenjem trenažnog procesa. Svi sudionici dali su pisani informirani pristanak prije početka prikupljanja podataka. Sudjelovanje je bilo u potpunosti dobrovoljno, a ispitanici su u svakom trenutku mogli povući svoj pristanak bez ikakvih posljedica za njihov trenažni ili natjecateljski status. Istraživanja su imala neintervencijski, longitudinalni dizajn te istraživači nisu utjecali na planiranje, sadržaj niti intenzitet trenažnog procesa, koji je u potpunosti bio pod kontrolom stručnog stožera kluba. Prikupljeni podaci obrađivani su povjerljivo i anonimno, isključivo u znanstvene svrhe.

3.2. Uzorak ispitanika

Ukupno 48 igrača (dob: 22.8 ± 4.2 godine; tjelesna visina: 184.4 ± 6.7 cm; tjelesna masa: 77.2 ± 6.5 kg) SuperSport Prva NL (drugi rang Hrvatske nogometne lige), iz dvije ekipe i kroz dvije ligaške sezone, sudjelovalo je u istraživanjima za potrebe ovog doktorskog rada. Veličina uzorka razlikovala se među pojedinim istraživanjima, ovisno o ciljevima i mjernim postupcima svake studije. Tako su u prvoj studiji sudjelovala 22 profesionalna nogometaša, u drugoj 10 igrača, a u trećoj 23 profesionalna nogometaša. U daljnje analize uključeni su samo ispitanici koji su sudjelovali u najmanje 85 % planiranih trenažnih jedinica tijekom promatranog pripremnog razdoblja te su bili zdravstveno sposobni za sudjelovanje u punom

trenažnom procesu na početku istraživanja, bez prisutnosti akutnih ozljeda ili bolnih stanja. Ispitanici su bili isključeni iz daljnjih analiza ako su tijekom istraživanja zadobili ozljedu ili drugo zdravstveno stanje koje je onemogućavalo redovito treniranje, ili ako su koristili farmakološke terapije koje bi mogle utjecati na perceptivne, neuromišićne ili autonomne pokazatelje (npr. lijekove koji djeluju na kardiovaskularni ili živčani sustav).

3.3. Generalni eksperimentalni postupak

Eksperimentalni postupci provedeni su tijekom pripremnih perioda nogometnih klubova NK Solin i NK Croatia Zmijavci, koji su trajali četiri, odnosno pet tjedana. Istraživanja su provedena neposredno nakon ljetne pauze i završila su s početkom natjecateljske sezone. Prikupljanje rezultata i praćenje igrača provedeno je u realnim uvjetima rada nogometne ekipe, bez vanjske intervencije istraživača. Eksperimentalni postupci provedeni su u dvije faze: pripremni period za natjecateljsku sezonu 2020./2021. i pripremni period za natjecateljsku sezonu 2024./2025. Nogometaši ekipe NK Solin svoje su nogometne treninge izvodili na službenom stadionu kluba „Pokraj Jadra“ i na pomoćnom nogometnom terenu na „Vranjicu“, a kondicijske treninge snage unutar prostorija kluba. Nogometaši NK Croatia Zmijavci svoje su nogometne treninge izvodili na nogometnom stadionu nogometnog kluba NK Kamen Podbablje u „Ivanbegovini“, a kondicijske treninge snage unutar prostorija „fitness centra 21“ u Imotskom. Redoslijed prikupljanja podataka bio je jasno definiran prije početka istraživanja i od njega se nije odstupalo tijekom provedbe eksperimenta. Za vrijeme trajanja istraživanja igrači su svoje slobodno vrijeme provodili kao i obično bez upletanja istraživača.

3.4. Mjerni instrumenti

Antropometrija. Antropometrijska mjerenja na igračima su provedena na početku eksperimentalnog postupka, odnosno na prvi dan priprema. Mjerenje tjelesne visine napravljeno je uz pomoć prijenosnog stadiometra Harpenden Portable Stadiometer 603 VR (Holtain 194 LTD, Crosswell, UK), tjelesna masa i indeks tjelesne mase (BMI; tjelesna masa u kg / visina u m²) izmjereni su uz pomoć dijagnostičke vage Tanita (BC 418). Mjerenja su provedena prema standardiziranim protokolima navedenih uređaja.

Subjektivne mjere napora. Subjektivna percepcija napora procjenjivana je na dnevnoj bazi tijekom trajanja eksperimentalnog postupka. U svim istraživanjima skupljani su rezultati subjektivne percepcije napora (RPE), a evaluirana je uz upotrebu Borg CR10 skale. Ispitanici

su maksimalno 30 min nakon trenažnog procesa ili nogometne utakmice odgovarali na pitanje: „Koliko je za vas bio zahtjevan današnji trening?“ i ocjenjivali napor na ljestvici od 1 (najmanji napor) do 10 (najveći napor). Osim maksimalnih dnevnih i tjednih vrijednosti, izračunate su prosječne dnevne i tjedne vrijednosti sRPE-a. Temeljem dobivenih sRPE vrijednosti i vremenskog trajanja trenažne jedinice ili nogometne utakmice (vrijeme provedeno u igri) izračunata je vrijednost unutarnjeg trenažnog intenziteta (ITI) prema formuli $ITI = sRPE \times \text{trajanje aktivnosti (min)}$, pri čemu se u ovom doktorskom radu (i izvornim istraživanjima) razlikuje globalna procjena napora pojedine trenažne jedinice (session-RPE; Borg CR10) od njezine kvantifikacije u arbitrarnim jedinicama koja uključuje i trajanje aktivnosti. Na taj se način dobiva sRPE-izvedena vrijednost u A.U. ($RPE \times \text{min}$), što je u literaturi poznato kao session-RPE metoda te se standardno koristi za praćenje unutarnjeg opterećenja jer integrira komponentu intenziteta i volumena (trajanja) u jedinstvenu mjeru. U originalnim objavljenim radovima, termin “unutarnji trenažni intenzitet (ITI)” korišten je kako bi se izbjegla uporaba termina training load (“load”) u engleskom jeziku, sukladno recentnim raspravama o terminološkoj nepreciznosti tog pojma (Staunton i sur. 2022); pritom ITI predstavlja sRPE-izvedenu mjeru u arbitrarnim jedinicama ($RPE \times \text{min}$), odnosno metrički ekvivalent unutarnjeg opterećenja koje uključuje i vremensku komponentu. U skladu s dijelom nogometne literature, u ovom doktorskom radu ta se sRPE-izvedena vrijednost naziva ITI, pri čemu je važno naglasiti da predstavlja metrički ekvivalent sRPE-baziranog unutarnjeg opterećenja (A.U.), a ne “čisti” intenzitet bez vremenske komponente. Sličan terminološki pristup prisutan je i kod Silve i sur. (2022), gdje se RPE množi s trajanjem radi dobivanja s-RPE vrijednosti, a zatim se iz nje izvode tjedni pokazatelji poput weekly training intensity i mean training intensity.

Subjektivna percepcija oporavka. Subjektivna percepcija oporavka (TQR) procjenjivana je jednostavnim pitanjem: „Kako procjenjujete vaš oporavak od prethodnog treninga?“. Ispitanici su odgovarali na postavljeno pitanje do 30 min prije početka trenažnog procesa ili nogometne utakmice i ocjenjivali su svoju razinu oporavka na ljestvici od 1 (vrlo, vrlo loš) do 10 (izrazito dobar). Uz maksimalne vrijednosti su izračunate i prosječne dnevne i tjedne vrijednost TQR-a.

Percepcija mišićne boli. Percepcija mišićne boli (PMS) procjenjivala se pomoću kratkog upitnika s numeričkom ljestvicom od 1 do 10. Ispitanici su na početku svakog tjedna, u jutarnjim satima, ocjenjivali svoju razinu mišićne boli odgovarajući na tvrdnju „Moja mišićna bol je...“, pri čemu je vrijednost 1 označavala vrlo jaku bol, a 10 potpuni izostanak boli. Tjedna procjena omogućila je uvid u akumuliranu mišićnu bol kao praktičan pokazatelj oporavka i odgovora na prethodno trenažno opterećenje.

Subjektivne mjere dobrobiti. Procjena dobrobiti je napravljena uz korištenje standardiziranog upitnika dobrobiti (WBI-Index). Upitnik obuhvaća pet pitanja, odnosno pet komponenti umora koje ispitanici procjenjuju na subjektivnoj osnovi; umor, procjena kvalitete sna, razina stresa, raspoloženje, odgođena mišićna bol. Ispitanici su upitnik ispunjavali do 30 min prije početka treninga ili nogometne utakmice (prve aktivnosti u danu). Svaki odgovor se vrednovao na ljestvici od 1 (nisko) do 5 (visoko). Jedinica ukupnog indeksa dobrobiti je dalje izračunata kao zbroj svih pet pojedinačnih komponenti, gdje je najmanja moguća vrijednost mogla biti 5, a najviša 25. Također su izračunate prosječne dnevne i tjedne vrijednosti indeksa dobrobiti, te pojedinačnih pitanja upitnika.

Trajanje sna i srčana frekvencija u mirovanju. Trajanje sna i srčana frekvencija u mirovanju pratili su se kod dijela ispitanika uz pomoć pametnih fitness narukvica (Xiaomi Mi Fit Band 4). Ispitanici su tijekom eksperimentalnog postupka nosili narukvicu svaku noć tijekom spavanja, od odlaska na spavanje do buđenja, bez promjene svojih uobičajenih navika spavanja. Svakoga jutra istraživaču su dostavljali zabilježene podatke o ukupnom trajanju sna i srčanoj frekvenciji u mirovanju. U daljnjoj analizi korištene su prosječne tjedne vrijednosti trajanja sna (Sleepmean) i srčane frekvencije u mirovanju (RHRmean)

Varijabilnost srčanog ritma. U istraživanjima je kao objektivni pokazatelj autonomne regulacije korištena varijabilnost srčanog ritma (HRV). Mjerenja su se provodila u jutarnjim satima na selektiranom poduzorku od 10 ispitanika. Ispitanici su se testirali svakoga jutra neposredno nakon buđenja, prije doručka i bilo kakve tjelesne aktivnosti. Ispitanici su prethodno bili upoznati s protokolom mjerenja s protokolom testiranja te su u ležećem položaju mirovali unaprijed definirano vrijeme od 5 minuta, nakon čega su uz pomoć mobilne aplikacije HRV Elite i srčanog senzora Polar H10 snimali RR-intervale. Prikupljene podatke po završetku mjerenja dostavljali su istraživaču prema prethodno dogovorenim uputama. U daljnjoj analizi korištene su vrijednosti lnRMSSD, prosječne vrijednosti lnRMSSD-a (lnRMSSDmean) te koeficijent varijacije HRV-a (lnRMSSDCV).

Procjena neuromišićne funkcije. Procjena neuromišićnih funkcija ispitanika u svim se istraživanjima vršila korištenjem CMJ testa. Testiranje CMJ-a provodilo se jednom tjedno, uvijek prije prvog treninga na početku tjedna. Za provođenje testa koristila se standardizirana mjerna oprema fotoelektričnog sustava OptoJump (Microgate Srl, Bolzano, Italija). Prije izvođenja testa ispitanici su imali do 15 min za adekvatno zagrijavanje, a test su izvodili tri puta, s pauzom od 15 do 20 sekundi između pokušaja. U daljnjoj analizi korištena je samo najbolja vrijednost visine skoka.

3.5. Broj pojedinačnih opažanja

Tijekom provedbe sva tri istraživanja prikupljen je velik broj mjerenja, pri čemu je ostvareno približno 5100 pojedinačnih opažanja (mjerenja). Najveći udio opažanja odnosi se na dnevna mjerenja subjektivne percepcije napora (sRPE), unutarnjeg trenažnog intenziteta (ITI) te subjektivnih pokazatelja dobrobiti (WBI i njegove pojedinačne komponente), koji su prikupljeni kontinuirano tijekom cijelog eksperimentalnog razdoblja. Subjektivna percepcija oporavka (TQR) i pojedini pokazatelji mišićne boli prikupljeni su na dnevnoj ili tjednoj razini, ovisno o istraživanju i korištenom upitniku. Procjena neuromišićne funkcije (CMJ) provedena je jednom tjedno, dok su objektivne fiziološke mjere (HRV i RHR), kao i objektivni pokazatelji sna, prikupljeni svakodnevno na selektiranom poduzorku ispitanika. Antropometrijske varijable i pokazatelji funkcionalnih sposobnosti procijenjeni su na početku istraživanja. Takav višerazinski longitudinalni dizajn omogućio je detaljno praćenje akutnih i kumulativnih promjena tijekom pripremnog razdoblja te opravdava primjenu statističkih metoda prilagođenih ponovljenim mjerenjima.

4. IZVORNI ZNANSTVENI RADOVI

4.1. Izvorni znanstveni rad 1: Monitoring Internal Training Intensity Correlated with Neuromuscular and Well-Being Status in Croatian Professional Soccer Players during Five Weeks of the Pre-Season Training Phase



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Monitoring Internal Training Intensity Correlated with Neuromuscular and Well-Being Status in Croatian Professional Soccer Players during Five Weeks of the Pre-Season Training Phase

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Abstract

This study aimed to investigate the changes in internal training intensity, well-being, and countermovement jump (CMJ) performance and to determine their relationship across five weeks of the pre-season training phase in professional soccer players. A total of 22 professional male soccer players (age = 21.7 ± 4 years, body height = 185.9 ± 6.3 cm, body weight = 79 ± 6.3 kg, BMI = 22.8 ± 1.4 kg·m⁻²; VO₂max = 52.9 ± 3.2) from the Croatian Second League voluntarily participated in this study. The players spent 2230 ± 117 min in 32 technical/tactical and strength/conditioning training sessions, mostly at the low intensity zone (61%), and played 8 friendly matches at a high intensity (>90%). A one-way repeated measure of analysis ANOVA revealed a significant difference between weeks in CMJ performance ($F(1,22) = 11.8$, $p < 0.001$), with CMJ height in weeks 4 and 5 being likely to very likely higher than that noted in week 1. Moreover, significant differences between weeks were found in all internal training intensity measures (average [$F(1,22) = 74.8$, $p < 0.001$] and accumulated weekly internal training intensity [$F(1,22) = 55.4$, $p < 0.001$], training monotony [$F(1,22) = 23.9$, $p < 0.001$],

and training strain [$F(1,22) = 34.5, p < 0.001$]). Likewise, differences were observed for wellness status categories (fatigue [$F(1,22) = 4.3, p = 0.003$], sleep [$F(1,22) = 7.1, p < 0.001$], DOMS [$F(1,22) = 5.7, p < 0.001$], stress [$F(1,22) = 15.6, p < 0.001$]), mood [$F(1,22) = 12.7, p < 0.001$], and overall well-being status score ($F(1,22) = 13.2, p < 0.001$). Correlation analysis showed large negative correlations between average weekly internal training intensity and fatigue ($r = -0.63, p = 0.002$), DOMS ($r = -0.61, p = 0.003$), and WBI ($r = -0.53, p = 0.011$). Additionally, fatigue was significantly associated (large negative correlation) with accumulated weekly internal training intensity ($r = -0.51, p = 0.014$) and training strain ($r = -0.61, p = 0.003$). Small, but non-significant, correlations were found between CMJ performance and wellness status measures. These findings highlight the utility and simplicity of monitoring tools to improve athletes' performance.

Keywords: professional soccer; training intensity; well-being.

4.1.1. Introduction

It is commonly known that the prescription for a successful training program requires the application of different training principles, including individualization, training intensity progression, and recovery to bring an equilibrium between training and rest periods to induce positive adaptations (Kasper, 2019). This fact requires that coaches not only concentrate on varying intensities and exercise modalities, but also that they constantly monitor the internal training intensities (ITI) to better understand this state of adaptation to avoid possible chronic fatigue (Selmi, Ouergui, Levitt, et al., 2022). While using several ITI monitoring tools to record data such as heart rate indices, blood lactate, oxygen uptake, and hormone levels is expensive and not available for all players and teams, the subjective measures of ITI-like scales and questionnaires are of great importance (Mujika, 2017). These scales and questionnaires have shown their effectiveness as quick and easy methods for detecting early signs of tiredness and monitoring well-being to optimize training and achieve high-level performance (Selmi et al., 2021). This may include the use of the rating of perceived exertion (RPE), developed by Borg (Borg, 1970) and adopted by Foster et al. (Foster et al., 2001) as s-RPE well-being indices including fatigue, stress, delayed onset muscle soreness, and sleep, which have shown significant interactions among these items (Moalla et al., 2016; R. M. Silva et al., 2022) and that they were sensitive to increased training intensities, being factors that influence the technical-tactical performances of soccer players (Selmi et al., 2021). Moreover, in addition to

these tools and to the aim to identify fatigue and adequate recovery during different training phases, several previous studies have examined the countermovement jump performance (CMJ) as a measure of neuromuscular fatigue (Freitas et al., 2014; Johnston et al., 2013; Selmi, Ouergui, Levitt, et al., 2022).

Additionally, training intensities may vary according to the objectives of different phases of an entire annual training season, including the pre-season, during which coaches are striving to recondition players to attain the fitness levels of the past season, while during the in-season, maintaining the fitness levels achieved during the pre-season is the main objective (Jeong et al., 2011). This could apply to soccer players' specific intensities in accordance with each distinct phase (Nobari, Ramachandran, et al., 2022), which could therefore have a different impact on the players' abilities to adapt, recover, and maintain their well-being. Specifically, previous researchers have assessed these variables in the pre-season (Buchheit et al., 2013; Fessi, Nouria, et al., 2016; Manzi et al., 2013) and the in-season (S. Malone et al., 2018; Oliveira et al., 2019; Thorpe et al., 2015), comparing both training periods (Fessi, Nouria, et al., 2016; Jeong et al., 2011; Nobari, Ramachandran, et al., 2022). Regarding the pre-season phase, it has been previously reported by Buchheit et al. (Buchheit et al., 2013) that during the 2 weeks of pre-season camp, there were significant day-to-day variations in training intensity (coefficient of variation [CV] = 66%) and wellness measures (6–18%), while the overall well-being did not change substantially throughout the camp, and that all well-being measures were related to delta training intensity. Furthermore, Selmi et al. (Selmi et al., 2018) showed that 4 weeks of intense training during an early preparation period increased the training intensity and altered the technical performance, and that the well-being state was related to successful passes, interceptions, and ball losses during small-sided games.

Due to the specificity of the pre-season training phase and its role in preparing players to handle the demands of the matches, and due to its specificity in terms of higher intensities compared to those in the in-season period (Fessi, Nouria, et al., 2016; Jeong et al., 2011; Nobari, Ramachandran, et al., 2022), tracking players adaptations to this training period is of great interest, as it determines the success of the entire competitive season. Moreover, variations in well-being and training intensity outcomes, as well as relationships between them, must be determined when designing a training program for different season phases. Special consideration should be given to the effects of previously accumulated training intensity or neuromuscular fatigue on the fluctuations of the well-being status. Furthermore, investigations conducted under real-world conditions, and not simulations, are beneficial to coaches and team personnel because they provide a direct assessment of the effects of various training intensities.

Considering all the aforementioned facts, the present study aimed to (a) investigate the changes of ITI, well-being status, and CMJ performance across 5 weeks of the pre-season training phase in professional soccer players and (b) examine the dose–response relationship between ITI and CMJ performance with the variations in well-being status measures.

4.1.2. Materials and Methods

Study Design

This was a 5-week longitudinal study that aimed to investigate the ITI, well-being, and CMJ responses of Croatian professional soccer players during the pre-season phase. In a consensus statement released by intensity monitoring experts, these variables were rated as practically useful and having medium to high reliability and validity (Bourdon et al., 2017). After players returned from an off-season break, the study began at the beginning of July and ended in the first week of August. The players spent 5 weeks of the study in a controlled environment (training center). The team’s technical staff planned the entire training program during the pre-season phase. Training characteristics during this period are presented in Table 1. During the investigation, a total of 1764 observations were collected from training sessions and matches.

Table 1. Description of the training program over the 5 weeks of the pre-season phase.

measure		Week 1	Week 2	Week 3	Week 4	Week 5
TE-TA sessions (n)		5	4	5	4	5
	Σ	430	320	320	275	330
time	mean	86	80	80	68.75	66
	SD	14.7	22.7	17.3	6.3	15,6
S&C sessions (n)		3	3	2	1	/
	Σ	175	200	120	60	/
time	mean	58.3	66.7	60	60	/
	SD	2.9	2.9	/	/	/
Matches (n)		1	1	2	2	2

Participants

A total of 22 male professional soccer players (age = 21.7 ± 4 years, body height = 185.9 ± 6.3 cm, body weight = 79 ± 6.3 kg, BMI = 22.8 ± 1.4 kg·m²; VO₂max = 52.9 ± 3.2 mL kg⁻¹ min⁻¹) from the same team competing in the Croatian Second League participated in this study. Goal-keepers were excluded from the study due to their specific role on the team and their differing physical demands. Inclusion criteria to participate in the study were: (i) participation in at least 85% of the training sessions, and (ii) being healthy (no pain or injury) at the beginning of the pre-season phase. Participants provided their signed consent after being fully informed of the experimental procedures.

Procedures

The team staff specified the training intensity, and the investigators had no influence on this. All training sessions began with a 30 min general warm-up composed of 5–10 min of jogging, 10–15 min of stretching, and 10–15 min of core exercises. The technical-tactical (TE-TA) training included game-based training drills and technical exercises that lasted 60 to 90 min per session. All training sessions were conducted in a controlled environment on the same regulation court. During the sessions, regular verbal support from the head coach and staff was provided. The training intensity was manipulated by changes in rules (e.g., number of players engaging in small-side games, court size etc.) and the work-rest ratio within and between exercises. Strength and conditioning (S&C) training sessions consisted of strength exercises with light to moderate intensity, plyometric drills, and specific repeated sprint bouts. The S&C sessions mainly targeted lower-body segments with some upper-body (e.g., bench press) exercises. The primary objective was to increase players' strength and capacity for speed, agility, and endurance, as well as to enhance recovery between training sessions. Additionally, over the 5-week period, players participated in eight friendly matches. On each training day, daily subjective assessments of session rating of perceived exertion (sRPE) and well-being questionnaire were completed to assess ITI and well-being status, respectively. The sRPE assessment was previously introduced to all players during regular training sessions (in-season phase). The CMJ height was determined once a week prior to the first training session of the week. Additionally, the 30-15 Intermittent Fitness Test (30-15 IFT) was used to assess the ability to recover and repeat intermittent activity to calculate players' maximum oxygen uptake (VO₂max).

Internal Training Intensity. The sRPE was quantified by using the Borg CR10 scale (1 = very, very easy and 10 = extremely hard) (Borg, 1998). This method has been widely used in soccer for the calculation of training intensity (Nobari et al., 2021; Pereira et al., 2022). Approximately 30 min following the completion of every training session and match, players were given a full view of the scale and were required to rate their perceived exertion by asking them: “How hard was your training session?” The questionnaire was administered by the same researcher throughout the whole period of investigation. To reduce the impact of hearing the ratings provided by other players, the scores were given individually to each player. To calculate ITI, the sRPE value reported by players was multiplied by the training duration (minutes). On days with two training sessions, the ITIs were summed. For further analyses, the following variables were calculated for each week: (a) meanITI—average ITI during each week, (b) sumITI—the accumulated ITI calculated as the summation of the training intensities of all training sessions during each week, (c) TM—training monotony calculated from the relation of meanITI to SD and the corresponding week, and (d) TS—training strain calculated by the multiplication of meanITI and TM. Moreover, the training sessions were divided into three intensity zones according to RPE data: low-intensity zone ($Z1 \leq 4$ A.U.); moderate intensity zone ($Z2 < 7$ A.U.); and ≥ 7 high-intensity zone ($Z3$) (Seiler & Kjellerand, 2006).

Well-Being Status. To assess the daily well-being status of the players, a psychological questionnaire (WB) (McLean et al., 2010) consisting of five cognitive perceptions of fatigue, sleep, delayed onset of muscle soreness (DOMS), stress, and mood was applied. Players were required to rate each domain using a five-point Likert Scale (1—worst quality to 5—best quality) by asking them: “Please rate your level of fatigue, sleep quality, muscle soreness, mental stress, and mood.” The questionnaire was administered by the same researcher, and the responses were recorded individually to reduce the influence of other players on the scores. The well-being status index (WBI) represents the sum of all five domains (scores ranging from 5 to 25).

Countermovement Jump. The CMJ was used to determine vertical jump height using a reliable and validated photoelectric cell system Optojump (Microgate srl, Bolzano, Italy). The players were instructed to conduct a downward movement followed by a full extension of the legs. With their hands fixed to their hips, players were verbally encouraged to jump as high as possible during each trial. Each player performed three jumps in a row, with a 15 s interval between the jumps. The highest jump of three attempts was used for further analysis. Two

familiarization sessions were held seven days prior to the first week of the pre-season phase. The session started with a standard warm-up, after which participants practiced the jumps until they demonstrated consistent technique. The same experienced researcher performed all measurements.

Aerobic Power Test. The 30-15IFT was used to calculate the VO₂max of the players. On a 40 m straight runway, the test includes 30 s shuttle run alternated with 15 s passive rest periods. The running speed increases by 0.5 km/h every 45 s after the initial 8 km/h stage. An audible signal beeped at appropriate intervals to control the speed of the test, with players required to be within a 3 m tolerance zone at either end or the middle of the 40 m shuttle. Players were directed to go forward to the closest line at each extremity and the center of the shuttle at 20 m after successfully completing a level. Participants stopped voluntarily if they were completely worn out or if they were unable to complete the 2 m lines three times in a row. The speed of the last successfully completed stage was recorded as the maximum running speed (VIFT). The VO₂max was calculated by the following equation (Buchheit, 2008):

$$\text{VO}_2\text{max (mL kg}^{-1}\text{ min}^{-1}) = 28.3 - (2.15 \times 1) - (0.741 \times \text{age}) - (0.0357 \times \text{weight}) + (0.058 \times \text{age} \times \text{VIFT}) + (1.03 \times \text{VIFT})$$

The test was performed in the week preceding the first week of the pre-season phase.

Anthropometric Measures. Body height was measured with Harpenden Portable Stadiometer 603 VR (Holtain LTD, Crosswell, UK). Body mass and BMI (body mass in kg/height in m²) were assessed by the Tanita diagnostic scale (BC 418). Standardized conditions were followed in terms of previous exercise, dietary intake, and skin temperature (Kyle et al., 2004). All measurements were taken by the same experienced researcher.

Statistical Analysis

Descriptive statistics were presented in the form of mean, standard deviation (SD), 90% confidence limits (90% CL), or the coefficient of variation (CV%). The normality and homogeneity of the data were analyzed using the Shapiro–Wilk test and the Levene test. After confirming normality and sphericity assumptions, a one-way repeated measures ANOVA was used to compare variables across the weeks. A Bonferroni post hoc test was conducted and Cohen’s d was calculated for pairwise comparisons. The magnitude of d was qualitatively

interpreted using the following thresholds: <0.2, trivial; 0.2 to 0.6, small; 0.6 to 1.2, moderate; 1.2 to 2.0, large; and 2.0 to 4.0, very large (Cohen, 1992). Additionally, the magnitude-based inference was used to compare the differences in CMJ performance (Batterham & Hopkins, 2006). The chances of meaningful negative, trivial, or positive changes were determined qualitatively as follows: 1%, almost certainly not; 1–5%, very unlikely; 5–25%, unlikely; 25–75%, possible; 75–95%, likely; 95–99%, very likely; 99%, almost certainly. The true difference was deemed unclear if the chances of having poorer and better results were greater than 5%. To analyze the daily variations in ITI, WB scores, and weekly CMJ performance, terms such as “possibly” and “unclear” were used if the 90% confidence limits (CL) crossed one or both smallest worthwhile change boundaries (SWC; calculated by using 0.3 coefficient of variation), respectively. If the CL did not cross SWC boundaries, the effect was inferred a probable [30]. Pearson’s correlation coefficients were calculated to establish the correlations between internal ITI indices and well-being status measures. The threshold used to qualitatively assess the correlations was based on the following criteria (Hopkins et al., 2009): 0.1, trivial; 0.1–0.3, small; 0.3–0.5, moderate; 0.5–0.7, large; 0.7–0.9, very large; 0.9, nearly perfect. The post hoc analysis to compute achieved power was conducted for a single within-subjects factor assessed over five time points and correlations using Power Analysis and Sample Size (PASS) software (version 15 LLC, Kaysville, UT, USA) and previously published recommendations (Sim & Wright, 2005). The calculated power analyses (1- β) values were between 0.73 and 1 for all analyses with the sample size of twenty-two participants. The significance level was set at $p < 0.05$. All data were analyzed using SPSS 28.0 statistical software (SPSS, Chicago, IL, USA) and GraphPad Prism 9 (GraphPad Software, Inc., San Diego, CA, USA).

4.1.3. Results

In total, players spent 2230 ± 117 min in 32 training sessions, of which 23 were TE-TA and 9 were S&C. The percentages of the number of training sessions and matches carried out in the three intensity zones are presented in Figure 1. The highest percentage of Z3 was determined during the matches, where Z1 and Z2 were lower than Z3. For TE-TA training session, the significant difference in training session distribution across intensity was also determined, in which Z2 and Z3 were lower than Z1. The players did not spend any of the S&C in Z3, but a significant number of sessions were performed in Z1. According to the distribution observed for the combined TE-TA and S&C training sessions, players performed approximately 61, 25, and 14% in low, moderate, and high intensity, respectively.

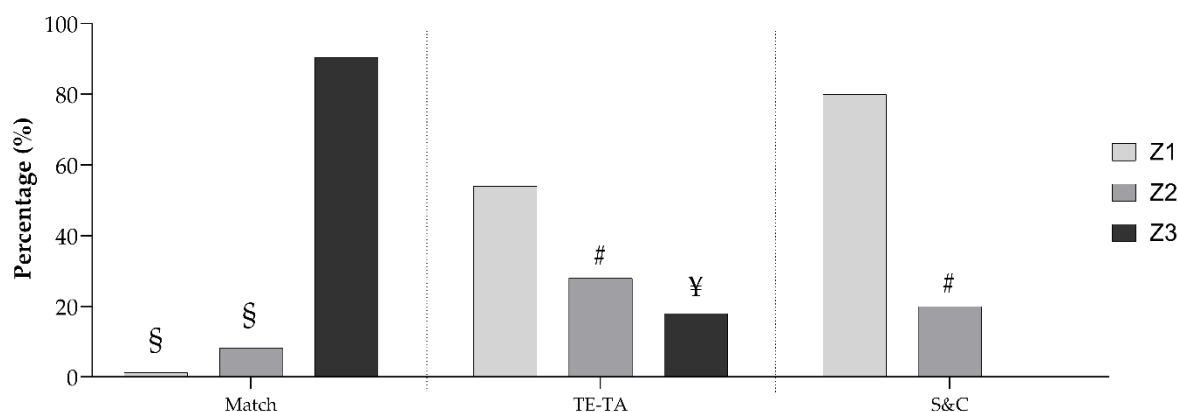


Figure 1. Percentage of the number of training sessions and matches carried out in the three intensity zones. Z1—low intensity zone; Z2—moderate intensity zone; Z3—high intensity zone; ¥—significantly lower than Z1 and Z2 at $p < 0.001$; #—significantly lower than Z1 at $p < 0.001$; §—significantly lower than Z3 at $p < 0.001$.

The daily internal training intensity well-being status measures observed over the 35 days of the pre-season phase are presented in Figures 2. and 3. The highest ITI was observed on day 3 and between days 12 to 17. Lower values were observed after training matches (2nd, 5th, and 6th match). Higher CVs were also noticed after the 6th, 7th, and 8th matches, with values ranging from 35.7 to 45.9%. The greatest positive change happened between days 11 and 12 (655.3%), while the greatest negative change appeared between days 17 and 18 (-81.7%). For the well-being status index, the highest values were observed in the first week of the investigation period (WBI: 18 to 20.3 a.u.). The highest CVs are found on days 24 and 25, while the daily changes are lower (values ranging from -22.1 to 19.6%) when compared with changes in ITI. Moreover, lower WBI values are noticeable after days of higher ITI (e.g., days 3, 17, 25).

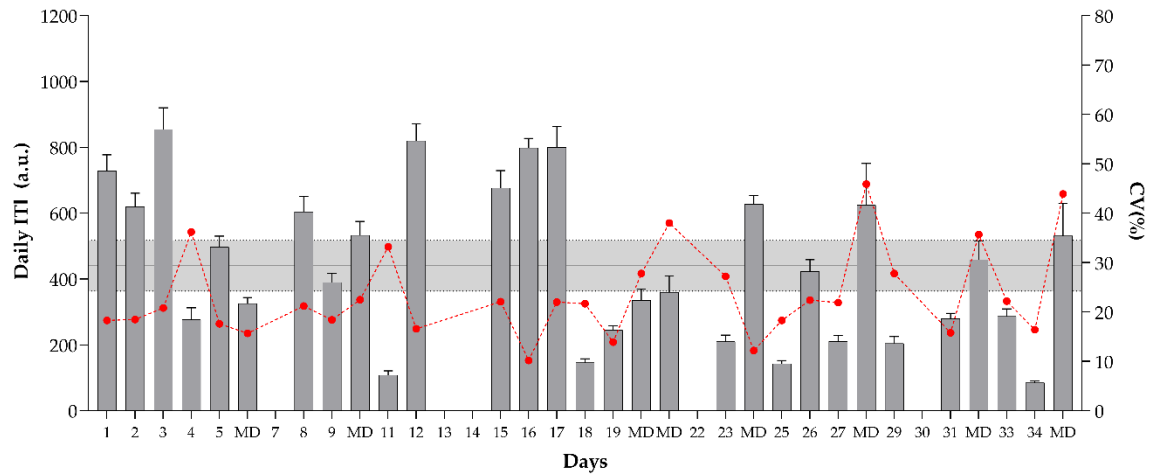


Figure 2. Daily internal training intensity (ITI) observed over the 35 days of the pre-season phase (5 weeks). The grey area represents the smallest worthwhile change (SWC = coefficient of variation \times 0.3), and the error bars show 90% confidence limits (CL). If the CL crossed one or both SWC boundaries, the terms “possibly” and “unclear” were used, respectively. The red line represents within-days intensity variations (CV%). MD—match day.

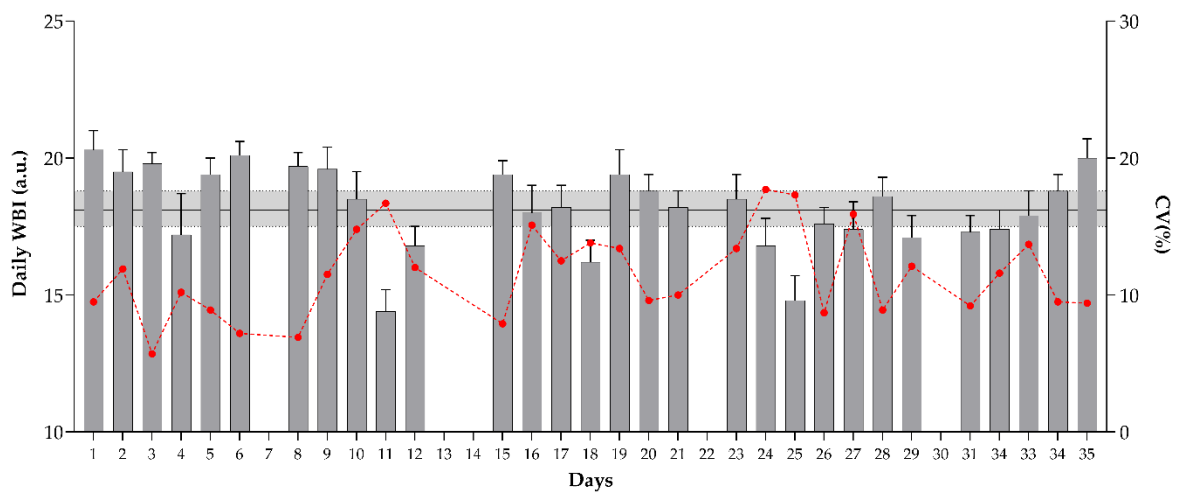


Figure 4.3. Daily well-being status index (WBI) observed over the 35 days of the pre-season (5 weeks). The grey area represents the smallest worthwhile change (SWC = coefficient of variation \times 0.3), and the error bars show 90% confidence limits (CL). If the CL crossed one or both SWC boundaries, the terms “possibly” and “unclear” were used, respectively. The red line represents within-days well-being status variations (CV%).

Values of countermovement jump (CMJ) height over the five measurement points are presented in Figure 4.4. One-way repeated measures ANOVA revealed a significant difference between testing occasions ($F(1,22) = 11.8, p < 0.001$). Additionally, compared with week 1 (baseline), CMJ height in weeks 4 and 5 were likely to be higher, respectively. Cohen d values ranged from 0.42 to 0.47, representing a small effect.

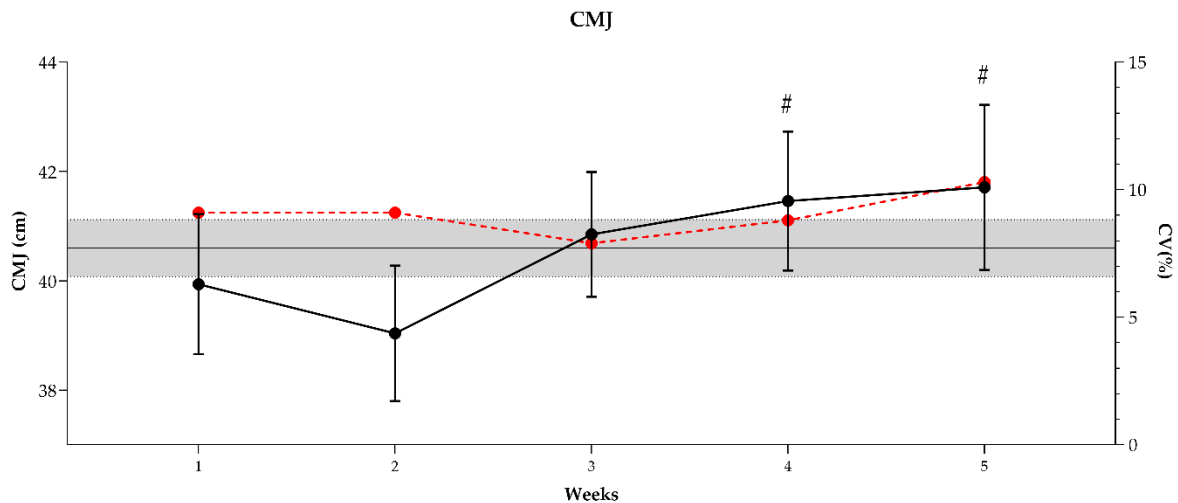


Figure 4. Countermovement jump (CMJ) height observed over the 5 weeks of the pre-season phase. The grey area represents the smallest worthwhile change (SWC = coefficient of variation $\times 0.3$), and the error bars show 90% confidence limits (CL). If the CL crossed one or both SWC boundaries, the terms “possibly” and “unclear” were used, respectively. The red line represents within-weeks CMJ variations (CV%); #—significantly higher than W1.

Table 2. represents ITI and well-being status measures across 5 weeks of investigation. Significant differences between weeks were found in all ITI measures (meanITI [$F(1,22) = 74.8, p < 0.001$], sumITI [$F(1,22) = 55.4, p < 0.001$], TM [$F(1,22) = 23.9, p < 0.001$], and TS [$F(1,22) = 34.5, p < 0.001$]). Post hoc analysis revealed that for meanITI, week 1 was statistically different from all other weeks. Almost similar was the result for sumITI, where week 1 was statistically different from all weeks, except week 3. For well-being status measures, one-way repeated measures ANOVA revealed a significant difference between weeks in all domains (fatigue [$F(1,22) = 4.3, p = 0.003$], sleep [$F(1,22) = 7.1, p < 0.001$], DOMS [$F(1,22) = 5.7, p < 0.001$], stress [$F(1,22) = 15.6, p < 0.001$]), and (mood [$F(1,22) = 12.7, p < 0.001$]), as well as overall WBI score ($F(1,22) = 13.2, p < 0.001$). Post hoc analysis revealed that greatest differences between weeks were found for WBI.

Measures of magnitude for multiple comparisons between weeks in ITI and well-being status measures are presented in Figure 5. Large to very large effects are found for both meanITI and sumITI for the week 1 vs. week 5 and week 3 vs. week 5 pairwise comparisons. Lower values (trivial to moderate effect) were found for the well-being status domains sleep and DOMS.

Table 2. Internal training intensity and well-being status measures of soccer players over the 5 weeks of the pre-season phase.

measure		W1	W2	W3	W4	W5
meanITI	mean	549.3	483.2 ¹	485.6 ¹	356.1 ^{1,2,3}	294.3 ^{1,2,3,4}
	SD	52.4	84.1	50.3	57.2	44.7
sumITI	mean	3035.7	2259.1 ¹	3310.9 ²	1946.4 ^{1,2,3}	1647.3 ^{1,3}
	SD	409.9	536.0	416.6	537.9	367.9
TM	mean	2.2	1.8 ¹	1.7 ^{1,2}	1.5 ^{1,3}	1.6 ^{1,3}
	SD	0.3	0.3	0.2	0.3	0.2
TS	mean	6656.3	4104.4 ¹	5565.9 ^{1,2}	3022.8 ^{1,3}	2599.9 ^{1,2,3}
	SD	1093.3	1322.3	1046.4	982.7	622.2
fatigue	mean	3.3	3.1	3.2	2.9 ³	3.3
	SD	0.4	0.4	0.5	0.4	0.4
sleep	mean	4.1	3.7 ¹	3.9 ²	3.7 ¹	3.8
	SD	0.3	0.4	0.3	0.4	0.4
DOMS	mean	3.6	3.2 ¹	3.4	3.2 ¹	3.3
	SD	0.4	0.4	0.4	0.4	0.3
stress	mean	4.2	3.8 ¹	3.8 ¹	3.5 ^{1,4}	3.7 ¹
	SD	0.4	0.4	0.4	0.6	0.4
mood	mean	4.3	4. ¹	4.	3.7 ^{1,4}	4.0 ¹
	SD	0.4	0.4	0.4	0.4	0.3
WBI	mean	19.3	17.7 ¹	18.3	17.1 ^{1,3}	18.1 ^{1,5}
	SD	1.4	1.7	1.4	1.7	1.2

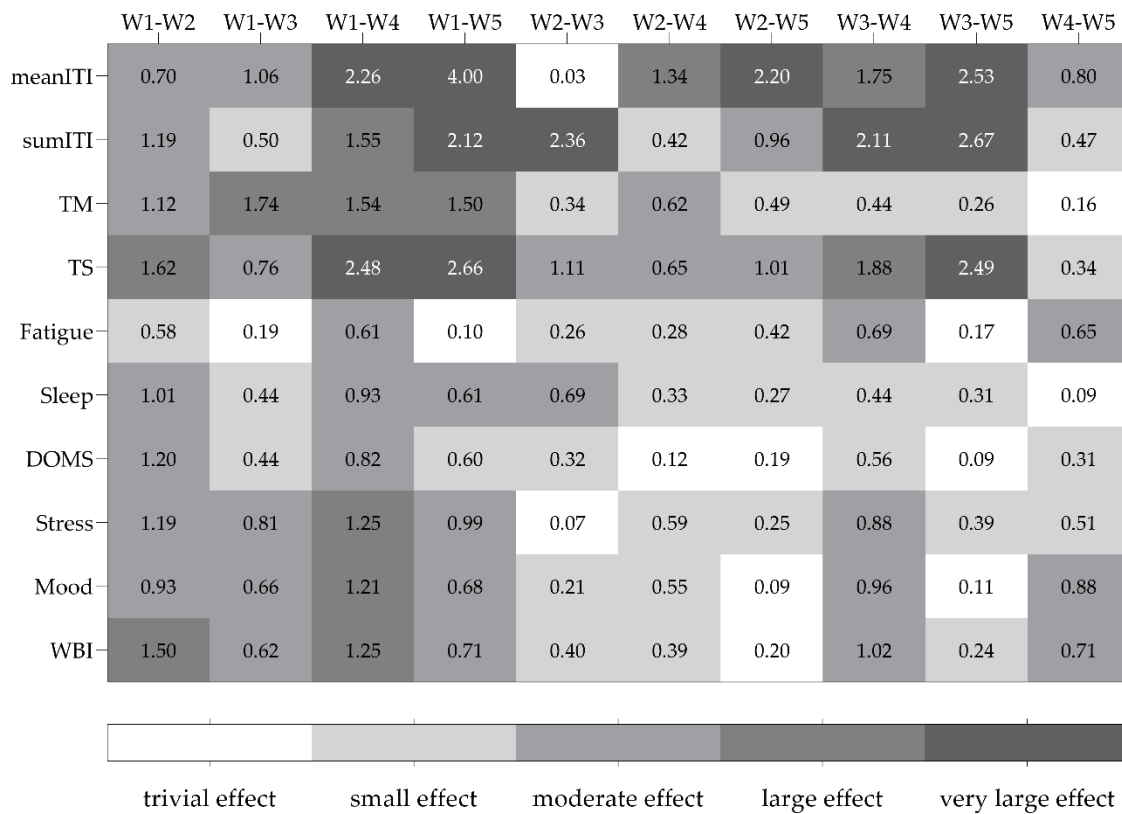


Figure 5. Multiple comparisons between weeks in internal training intensity and well-being status measures expressed as the magnitude of effect size; meanITI—average weekly internal intensity; sumITI—accumulated weekly internal intensity; TM—training monotony; TS—training strain; DOMS—delayed onset of muscle soreness; WBI—well-being status index; W—week.

Pearson’s correlation coefficients between ITI and well-being status measures are presented in Figure 6. Large negative correlations between mean ITI and fatigue ($r = -0.63$, $p = 0.002$), DOMS ($r = -0.61$, $p = 0.003$), and WB ($r = -0.53$, $p = 0.011$), sumITI, and fatigue ($r = -0.51$, $p = 0.014$), and TS and fatigue ($r = -0.61$, $p = 0.003$) were found. Moderate to small correlations were found between TM and TS with well-being measures, but without statistical significance. Moreover, small but non-significant correlations were found between CMJ performance and well-being status measures.

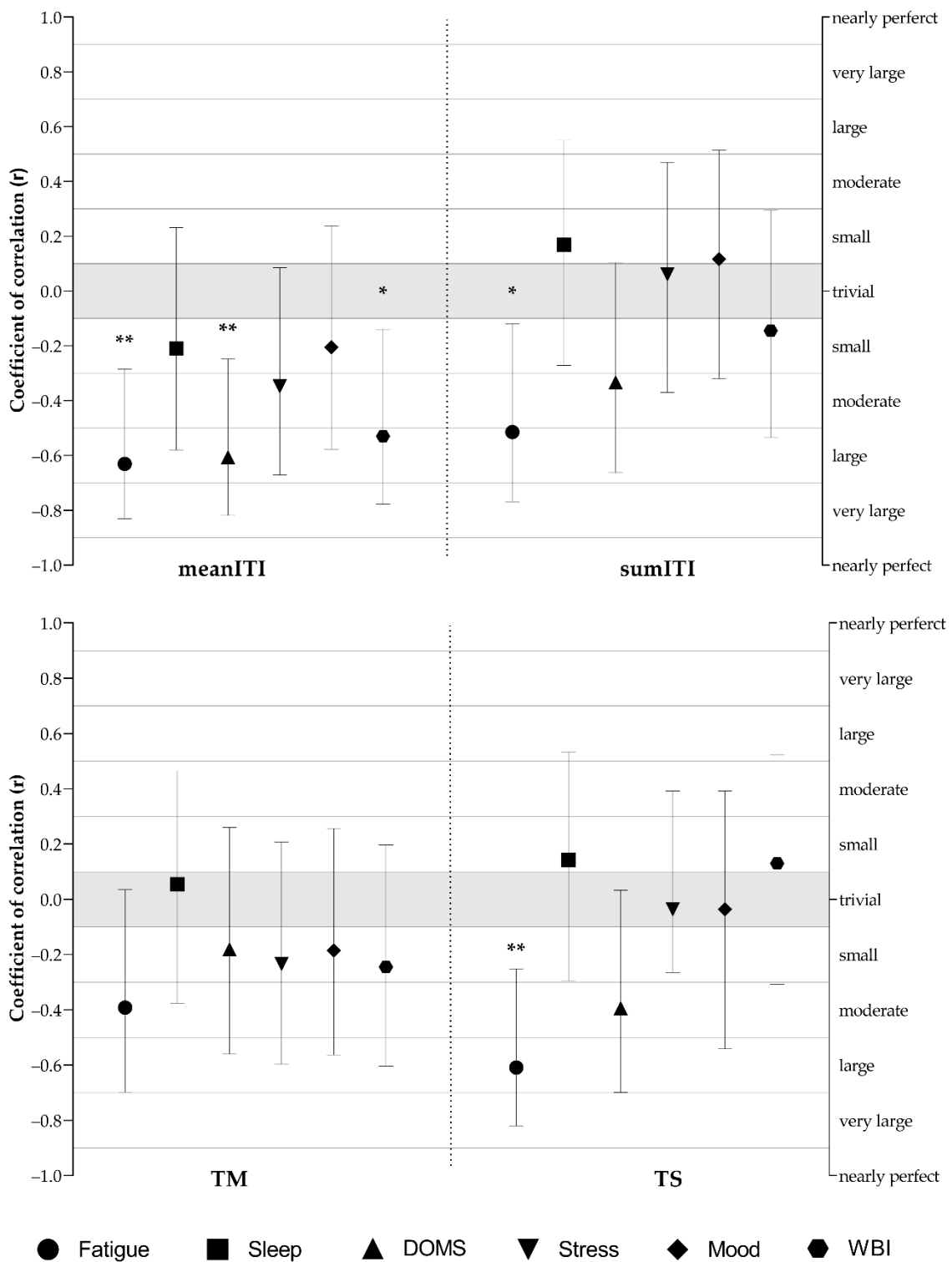


Figure 6. Coefficients of correlation (r) determined between internal intensity and well-being status measures; meanITI—average weekly internal intensity; sumITI—accumulated weekly internal intensity; TM—training monotony, TS—training strain; DOMS—delayed onset of

muscle soreness; WBI—well-being status index. Error bars represent 90% confidence limits (CL); *—significance at $p < 0.05$; **—significance at $p < 0.01$.

4.1.4. Discussion

This study aimed to assess the ITI, well-being status, and jumping performance in professional soccer players during the five weeks of the pre-season phase preceding the national league season. Additionally, the study aimed to determine the relationship between ITI indices, CMJ performance, and well-being status measures. The main findings of this study were as follows: (i) most TE-TA and S&C training sessions were performed at low intensity, while the proportion of matches played at high intensity was over 90%; (ii) lower daily WBI values were observed after days of higher ITI; (iii) CMJ performance progressively increased over five weeks; (iv) in weeks with lower values of ITI, higher CMJ performance was observed; (v) significant differences were found for all ITI and well-being status measures across the weeks, with TM and TS being lowest in the final week of the pre-season phase; (vi) large negative association was observed between average ITI and the well-being status domains of fatigue, DOMS, and WB, as well as between accumulated ITI and TS and fatigue.

Players spent the majority of their TE-TA and S&C sessions in the low intensity zone, with a proportion of approximately 53% and 80%, respectively. Sessions at moderate intensity accounted for approximately 28% of the time for TE-TA trainings and 20% of the time for S&C trainings, while high intensity was determined only for the TE-TA trainings (approximately 20%) (Figure 1). Players' performances in the combined TE-TA and S&C training sessions occurred at approximately 61, 25, and 14% in the low, moderate, and high intensity ranges, respectively. Training intensity distribution in this study across the five weeks was almost identical to those reported by (Borges et al., 2019), in which U20 soccer players completed over 60% of their training sessions at low intensity, while moderate and high intensity constituted 25% and 15% of their total trainings, respectively. A more balanced distribution was reported for Norwegian soccer (Algrøy et al., 2011) and Australian rugby (Lovell et al., 2013) players; however, these investigations included the in-season (competition) phase, in which official games took place. Furthermore, the high proportion of Z1 could be explained by the fact that all training sessions were computed for analysis in this real-world scenario (including recovery sessions with low training intensity).

During the five weeks of the pre-season phase, the accumulated ITI (average accumulated weekly ITI: 2439.9 ± 224.7 a.u.) were similar to those reported for professional

senior soccer players (Arcos et al., 2015; Clemente et al., 2019), but higher than those reported for junior soccer players (Nobari, Ceylan, et al., 2022; Nobari et al., 2021). Significant week-to-week changes in average weekly ITI (0.5 to 26%) were determined between weeks (Table 2), indicating that there was progression in the stimulus, as well as inter-week variability. Lack of progression is associated with injury risk and poor athlete performance (Gabbett, 2016). Moreover, stabilization of the intensity may be one factor contributing to a performance plateau. Athletes should not adopt the variability and progression of the intensity based on the general absence of changes in the training intensity throughout the week (Cruz et al., 2018; Matos et al., 2019). Similarly, significant week-to-week changes found in well-being status measures (Table 2) clearly show that well-being and physical adaptations to training appear to be significantly influenced by absolute training intensities collected over time and their distribution over the weeks (Cruz et al., 2018). It is well known that subjective well-being commonly deteriorates with an acute increase in training intensity and improves with an acute reduction in training intensity (Saw et al., 2016). The TM and TS parameters (derived from sRPE) are important factors related to negative adaptations to training (Foster, 1998)[42]. In this study, the TM and TS showed a significant decrease over the weeks (Table 2), with the highest values of 2.2 and 6656.3 in the first week, respectively. A similar TM pattern was observed in senior (Fessi, Nouria, et al., 2016) and junior soccer players (Borges et al., 2019; Clemente et al., 2019) during the same period. A decrease in TM during tapering is associated with improvement in physical match activity and therefore, represents a good indicator of the state and readiness of the players (Fessi, Zarrouk, Di Salvo, et al., 2016). However, recent systematic review reflected that acute:chronic workload ratio (ACWR), along with TM, should be used to better explain the physical capacities of players (Rico-González et al., 2022). Given that the study period was five weeks, the ACWR was not considered. Within-week variations for the TM (CV% from 13.2 to 16.8) and TS (CV% from 16.4 to 32.5) indicate individualized ITI responses, although the training program was similar for all players; however, this can be related to the different physical demands of each playing position (Borges et al., 2019).

CMJ performance over the period of investigation showed a progressive increasing trend (Figure 4). CMJ height in weeks 4 and 5 was most likely to very likely higher when compared to week 1 (baseline). In week 2, athletes showed a slight decrease in CMJ performance, but these changes were not meaningful. The progressive increase was probably induced by the reduction of the training intensity in the following weeks of the training program. In a study by Cruz et al. (Cruz et al., 2018), CMJ performance progressively increased when the training intensities were reduced over the nine weeks of the pre-season phase in

basketball. Moreover, similar observations were also reported for soccer (J. R. Silva et al., 2011), rugby (Johnston et al., 2013), volleyball (Aoki et al., 2016) and futsal (Miloski et al., 2016).

The secondary aim of this study was to examine the dose–response relationship between ITI and the variations in well-being status measures (Figure 6). Results revealed that fatigue largely correlated with average and accumulated weekly ITI and TS. Moreover, DOMS and overall WB score were largely correlated with average ITI. Interestingly, non-significant negative small to moderate correlations were observed between TM and all well-being status measures. Similar results were found for soccer (Clemente et al., 2017) and basketball players (Clemente, Bredt, et al., 2020), where fatigue and DOMS had higher correlations with ITI compared with other well-being categories. No relationships with ITI are specifically confirmed for sleep, where the authors found significant correlations with fatigue, DOMS, and overall well-being score, but not with athletes' sleep quality (Moalla et al., 2016; Thorpe et al., 2015). Additionally, variations in sleep quality, fatigue, and DOMS were more sensitive to acute rather than chronic training intensity or TM (Clemente, Silva, Clark, et al., 2020). DOMS and perceived fatigue may be related to each other and are associated with the physical strain players experience during training sessions, therefore presenting high sensitivity to variations in ITI (Clemente, Bredt, et al., 2020). However, deeper analysis is required, as perceived well-being indices can be influenced by other environmental factors, such as high altitude, religious practices, league ranking, and match importance (Armstrong & VanHeest, 2002), which are not controlled in this study. This is especially true for sleep, stress, and mood, which represent the psycho-cognitive component of the well-being status and directly influence each other. Reducing stress may enhance sleep quality, whereas sleep issues may have a negative impact on the stress system and attenuate endocrine stress responses (Hu et al., 2020). Moreover, the main contextual factors to consider when identifying stress sources include negative organizational systems and cultures, concerns about performance expectations and standards, career development issues, negative aspects of interpersonal relationships, the demanding nature of work itself, and issues regarding the work/non-work interface (Noblet & Gifford, 2002).

Since the CMJ test is reliable and well-accepted by professional athletes, it is useful for identifying and quantifying fatigue in field conditions (Marrier et al., 2017). Despite the fact that the CMJ height and well-being scores varied with training intensities, there was only a weak, non-significant association between the two. This is in contrast with the previous studies in which a significant relationship was determined between the two (Hills & Rogerson, 2018;

Tavares et al., 2018). Similar findings were reported in a study regarding wrestlers, in which the authors suggest that coaches should analyze WBI instead of single well-being variables (Nobari, Silva, et al., 2022). Another study conducted on baseball players reports that a five-item well-being questionnaire demonstrated consistency and efficiency; however, it did not reflect positive or negative changes in CMJ performance (Brasch et al., 2019). Subjective and objective measures assess different aspects of fatigue. This demonstrates that several subjective and objective factors need to be monitored for making informed judgments, instead of concentrating on either subjective or objective measurements alone, which has crucial implications for monitoring fitness and fatigue.

Study Limitations

Although conducted in a real-world scenario, this study has some limitations. The observations were conducted during a professional pre-season phase; therefore, it was impossible to form a control group or evaluate as many parameters as would have been desirable. There were no objective internal or external intensity measurements applied and sRPE was the sole internal training intensity indicator, which may have inhibited a more accurate measurement of the training's physiological effects. As perceived effort scales have been found to be highly linked with heart rate measurements and GPS information, it would be interesting to include these variables to assess players' responses to the training stimulus. Moreover, the integrations of s-RPE with GPS data provide a better approach to obtaining knowledge about TM (J. Afonso et al., 2021). Additionally, it is known that poor sleep and nutritional habits can have negative effects on players' performance (Halson, 2019; Vázquez-Espino et al., 2020); however, due to the nature of the study, these parameters could not be monitored.

Practical Applications

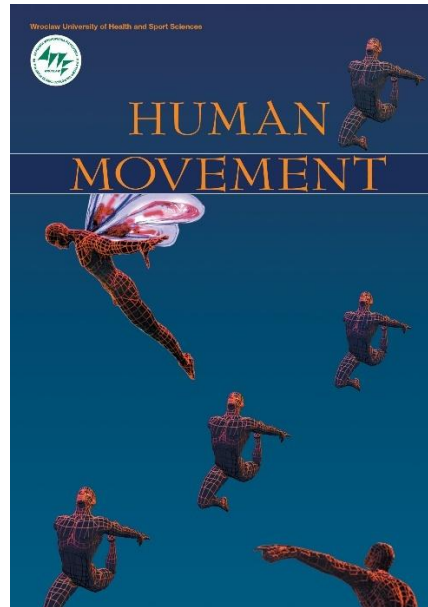
While some limitations were disclosed, this study possesses good ecological validity, as it was conducted with professional soccer players during the pre-season phase before the competitive season. Complementary research should be conducted to close the gap between the theory and practice of training periodization. Coaches and others involved in developing training programs should be aware of the significance of perceived exertion in effectively monitoring soccer players' well-being. Assessing relative training intensities after a training session could be critical in determining whether neuromuscular fatigue and DOMS, rather than disturbances in sleep, stress, and mood, will occur in players within 24 h. Although it is

challenging to apply an individual approach, it is recommended that different modalities should be used because each player responds differently to training stimuli. Monitoring these measures during the pre-season assists coaches in preparing players for the demands of matches during the in-season phase.

4.1.5. Conclusions

Lower daily WB values were observed after days of higher ITI; likewise, decrements in weekly ITI induced positive CMJ performances, with a progressive trend over the weeks. Significant week-to-week changes in ITI measures indicated that there was progression in the stimulus and inter-week variability, which possibly reduced injury risk. Moreover, inter-week variability in WB components clearly showed that well-being and physical adaptations to training appeared to be significantly influenced by absolute training intensities. Only the meaningful correlations found between ITI and fatigue and DOMS support previous findings of reduced sensitivity for psycho-cognitive perceptions of sleep, stress, and mood. Neuromuscular fatigue and its relationship with well-being should be used as a complementary analysis, with an increased number of objective and subjective measures included in training monitoring. Overall, this study highlights the utility and simplicity of monitoring tools to improve athletes' performance. Coaches and sports scientists can more effectively create and modify their training programs by using descriptions of the typical ITI experienced by professional soccer players during preparation for the competitive season. Lastly, a balanced training response/recovery ratio is important to effectively increase players' physical performance.

4.2. Izvorni znanstveni rad 2: Relationships between internal training intensity, heart rate variability, sleep duration, and neuromuscular performance in professional soccer players.



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Relationships between internal training intensity, heart rate variability, sleep duration, and neuromuscular performance in professional soccer players

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Abstract

Purpose: This study examined the relationship between internal training intensity and physiological and performance markers, including heart rate variability, resting heart rate, sleep duration, and countermovement jump performance in professional soccer players during a five-week preseason. **Methods:** This longitudinal design included 10 professional soccer players (age: 20.8 ± 2.3 years) with the following variables measured weekly: ITI, heart rate variability (HRV), resting heart rate (RHR), sleep duration, and countermovement jump (CMJ) performance. **Results:** Results showed a significant reduction in ITI ($p < 0.001$) across the preseason, reflecting effective intensity management. CMJ performance showed an initial decline before significantly increasing after week 2 ($p < 0.001$), while no significant changes were observed in RHRmean ($p = 0.25$) or lnRMSSDmean ($p = 0.27$). However, lnRMSSDCV decreased by 39.9%, indicating improved autonomic stability. A moderate negative correlation was observed between lnRMSSDmean and lnRMSSDCV ($r = -0.54$, $p <$

0.001), suggesting that greater parasympathetic tone is associated with reduced daily HRV fluctuations. ITI showed moderate negative correlations with Sleepmean ($r = -0.32$, $p = 0.045$) and CMJ performance ($r = -0.43$, $p = 0.005$) and a positive correlation with lnRMSSDCV ($r = 0.35$, $p = 0.03$). Conclusions: Higher ITI is associated with reduced CMJ performance, likely due to fatigue, emphasising the need to monitor CMJ for optimising training loads and preventing overtraining. Similarly, its link to shorter sleep duration highlights the importance of tracking sleep for effective recovery management. Additionally, the inverse relationship between lnRMSSDmean and lnRMSSDCV suggests that greater parasympathetic activity stabilises HRV fluctuations, reflecting improved autonomic balance and aiding in training adjustments. This study highlights the importance of integrating HRV, sleep, and CMJ into preseason training programs for professional soccer players. A tailored training approach emphasising reduced ITI and monitoring autonomic stability and recovery effectively improves physiological resilience and neuromuscular performance, ensuring players' readiness for the competitive season.

Keywords: cardiovascular, adaptation, team sports, autonomic nervous system

4.2.1. Introduction

The implementation and quality optimisation of a training program depend on the application of several training principles, including an individualised approach (in team sports), the progression of training volume and intensity, and the incorporation of recovery phases through the use of various strategies (Bucher Sandbakk et al., 2023). To adequately achieve their planned goals, the coaching staff must continuously measure and monitor internal training intensity (ITI) which reflects an athlete's physiological and perceptual response to a given training stimulus (Halson, 2014; Macedo et al., 2024). ITI is usually assessed with the use of internal intensity measures such as subjective scales, heart rate levels, and biochemical markers (Foster et al., 2017; Impellizzeri et al., 2019). It provides valuable insights to coaches about how an athlete's body reacts and adapts to external training stimuli. ITI allows coaches to make adjustments to the training program by considering the current state of their athletes (Impellizzeri et al., 2019). This helps prevent overtraining caused by non-functional training intensities, thereby reducing the risk of injuries (Impellizzeri et al., 2020; West et al., 2021), making it one of the most important tools for injury prevention (Halson, 2014). Although there

are various methods to monitor ITI, such as hormonal and lactate level analysers, and portable maximum oxygen consumption (VO₂max) analysers, they can be costly and inaccessible to a large number of clubs. Therefore, the assessment of ITI using subjective measures, such as scales and questionnaires, is of utmost importance because of their accessibility and low cost, in addition to their effectiveness in simply and quickly measuring what they are intended to measure (J. O. C. Coyne et al., 2022). However, in addition to subjective measures of ITI (such as RPE [Foster, 1998]), objective physiological markers like heart rate variability (HRV) and sleep duration are crucial in understanding the impact of training intensity on athletes' recovery and training outcomes. Subjective measures alone are not sufficient, as psychological factors, motivation, and external stressors can influence them. Therefore, incorporating objective physiological data provides a more accurate and comprehensive assessment of an athlete's internal training intensity. A decline in HRV values and poor sleep duration can signal to coaches that an athlete is fatigued and has not recovered adequately for their next training session (Mishica et al., 2022). Given that sleep duration reflects an athlete's ability to recover, it stands as a key factor in influencing not just athletes' recovery but also athlete's ability to adapt to stress and maintain overall well-being levels (Fullagar et al., 2015; Nobari et al., 2023). Therefore, ensuring sufficient sleep duration is essential for their overall performance. With the availability of various modern monitors (such as smartwatches and fitness bracelets), integrating this parameter into the monitoring toolkit provides coaching staff with a simple way to measure and track athletes' performance. Better sleep patterns and sufficient duration positively affect recovery and overall athlete performance, highlighting the importance of adequate monitoring (Cunha et al., 2023; Hamlin et al., 2021). Moreover, in addition to the importance of sleep duration and rest monitoring, cardiac autonomic activity, as derived from the measure of HRV, is likely to play an important role in understanding functional adaptations to training stimuli and individual responses (Hautala et al., 2009).

Research into cardiac responses to training reported that disrupted levels of HRV can contribute to an increase in the occurrence of injuries and poor adaptation to training intensities (Gisselman et al., 2016). In contrast, optimal and better levels of HRV allow the coaching staff to manage training intensities by increasing the intensity and volume of work, enabling athletes to optimise their performance and prevent stagnation (Carrasco-Poyatos et al., 2020; Lundstrom et al., 2023). Furthermore, aiming to identify both fatigue and adequate recovery during training, previous research highlighted that the countermovement jump (CMJ) test is a simple, easy, and non-invasive tool to assess levels of neuromuscular fatigue (Maleš et al., 2022). This makes CMJ of particular interest to coaches during the preseason, as that is a period

characterised by increases in training volume and intensity, as athletes experience a rapid increase in their workloads (Maleš et al., 2022). Regularly monitoring CMJ values in athletes during that period provides insight into their neuromuscular readiness (accumulated fatigue levels).

The coaching staff set different goals for themselves and athletes depending on the phase of the season (Curtis et al., 2020). In fact, while the focus is on achieving optimal preparation levels during the preseason period, which reduces the risk of injury during the season, maintaining the fitness level achieved is the main objective of the in-season period (Eliakim et al., 2018; Yu et al., 2021). Achieving these goals can give the athletes the ability to recover, depending on the phase. Previous research has shown significant variations in intensity depending on whether it is the preseason period or during the soccer season (Clemente, Silva, Castillo, et al., 2020). Although metrics such as HRV, sleep duration, and neuromuscular fatigue have been previously investigated, they were mostly examined as isolated factors, leaving a gap in the research that integrates them into a comprehensive monitoring strategy specifically for soccer players during preseason. Considering the importance of conducting an adequate preseason period to prepare players for the demands of the new season, integrating these metrics (i.e., HRV, sleep, neuromuscular fatigue) into the daily monitoring routines of the preseason phase is of utmost importance as it can allow athletes to achieve a harmonious balance between effort and recovery, maximising their performance (Maleš et al., 2022). Therefore, the current study aimed to investigate the relationships between internal training intensity (ITI) and key recovery and performance metrics, including HRV, sleep duration, and CMJ performance, over a five-week preseason in professional soccer players. This study tried to provide a more comprehensive approach to soccer player monitoring, offering new insights to enhance existing data, and supporting evidence-based decision-making for coaches.

4.2.2. Materials and Methods

Study design

This longitudinal study is part of a broader research effort exploring physiological adaptations and performance in professional soccer players during preseason. The initial study (Maleš et al., 2022) focused on examining the relationships between ITI and well-being, alongside the progression of these variables over a five-week period in a sample of 22 soccer players. While that work highlighted significant changes in ITI and well-being during preseason training, no other comparisons were observed, such as cardiac markers and sleep

duration. The current study builds on these findings by incorporating additional physiological and recovery metrics such as HRV and sleep duration, within a subsample of the original cohort, providing a more comprehensive understanding of recovery and adaptation processes during the preseason. This subsample was selected due to the inclusion of advanced physiological monitoring tools, specifically HRV and sleep-tracking sensors. These tools require consistent and accurate daily measurements, which were logistically feasible only for a smaller group of players. Therefore, the current study focuses on how the HRV metric, sleep duration, and CMJ interact with ITI, offering novel perspectives on the role of autonomic stability and recovery in training adaptations. This approach aligns with best-practice guidelines (Kirkman & Chen, 2011) for leveraging rich datasets to address distinct research questions and theoretical frameworks. By expanding on the findings of the earlier study, the current investigation offers complementary insights into preseason training strategies, emphasising the importance of integrating HRV and sleep monitoring to enhance player performance and recovery. The study began after the return of all players from the summer break and lasted from the beginning of July until the end of the preseason period (first week of August). Throughout the five weeks, the players were in controlled conditions within the football club. The coaching staff were responsible for planning and programming the entire preseason training plan. The training volumes and the number of training units per week are shown in Table 1.

Table 1. Weekly training description during 5 weeks.

Week number	Weekly sessions (n)	Double sessions (n)	Rest days (n)	Training volume (n)	Number of matches (n)
1	8	3	1	605	1
2	7	3	2	520	1
3	7	2	0	440	2
4	5	1	1	335	2
5	5	1	1	330	2

5.2.2 Participants

This study involved 10 professional soccer players, all members of the same team in the Second Croatian Football League. Player characteristics are shown in Table 2. The sample size was not determined a priori, as it was based on convenience sampling. A post hoc power analysis conducted using the G*Power software (ver. 3.1.9.4 Düsseldorf, Germany; [Faul et al., 2007]) revealed power values ranging from 0.89 to 1.00. To be eligible, soccer players had

to fulfil the following inclusion criteria: (i) participation in at least 85% of the training sessions, and (ii) medical clearance given by a sports medicine doctor (no pain or injury) at the beginning of the pre-season phase. Players were excluded if they met any of the following criteria: (i) sustained a musculoskeletal injury prior to the preseason that could impair training participation and performance outcomes, or (ii) were undergoing pharmacological treatments (e.g., betablockers, anti-inflammatory drugs) that influence autonomic function or fatigue perception. Players provided their signed consent after being fully informed of the experimental procedures.

Table 2. Player characteristics (n = 10).

	Mean ± SD
Age (years)	20.8 ± 2.3
Body height (cm)	186.4 ± 5.4
Body mass (kg)	79.0 ± 5
BMI (kg/m ²)	22.8 ± 1.4
VO ₂ max (ml · kg ⁻¹ · min ⁻¹)	53.4 ± 2.7

Procedures

The coaching staff planned and programmed the preseason period without the research team's involvement. All training sessions were performed in a controlled environment and were directly supervised by the coaching staff. The training program consisted of (a) technical-tactical sessions (TE-TA), (b) strength and conditioning sessions (S&C), and (c) friendly matches. TE-TA sessions began with a 30-minute general warm-up conducted by the strength and conditioning coach. The warm-up included 10 to 15 min of individual stretching, 5 to 10 min of jogging or passing drills with light jogging, and 10 to 15 min of speed, agility, and quickness (SAQ [Azmi & Kusnanik, 2018]) and specific football movement protocols. Following the warm-up, TE-TA sessions were taken over by the main coach and assistant coach, focusing on specific technical-tactical aspects of football. Training intensity and volume were systematically adjusted based on specific task and rule modifications to ensure progressive intensity management across sessions. In the technical-tactical (TE-TA) sessions, the intensity was modified through small-sided game (SSG) variations (e.g., altering player numbers, implementing one-touch passing rules, and incorporating 'joker' players to facilitate transitions), as well as integrating high-intensity interval training (HIIT [Manuel Clemente et al., 2021]) running protocols to target metabolic demands. Task duration and recovery periods were also manipulated to standardise the training intensity while maintaining session

objectives. Strength and conditioning (S&C) sessions focused on moderate-intensity strength and power training, primarily targeting lower-body power, agility, and endurance, with an emphasis on injury prevention and recovery support between training sessions. Friendly matches followed standard competitive rules and durations, serving as high-intensity exposure within the training plan. Each training day involved assessing session ratings of perceived exertion (sRPE). CMJ performance was measured weekly before the first training session, while sleep duration and HRV were tracked daily until the study's conclusion. Participants underwent at least two familiarisation sessions before the study started to ensure they were accustomed to the training routines, warm-up protocols, and performance assessments outlined in the preseason program.

Internal training intensity. sRPE was evaluated using the widely used method: the Borg CR10 Scale (Foster et al., 2001). Players were asked to answer the researcher's question, 'How difficult was this training session for you?' They rated their responses on a scale from 1 to 10, where 1 = very, very light, and 10 = extremely difficult. The answers were collected 30 min after the end of the training session during team meetings. The players provided their answers privately and always to the same researcher to avoid potential external influence. ITI was calculated using the formula: $\text{Internal Training Intensity} = \text{sRPE (a.u.)} \times \text{session duration (min)}$. If there were multiple training sessions on the same day, the sum of both sessions represented the ITI for that day. For further analyses, the weekly mean internal intensity (ITImean) was calculated for each week.

Countermovement jump. The CMJ test used a reliable and validated OptoJump photoelectric platform (Microgate srl, Bolzano, Italy) to assess neuromuscular performance. The test was conducted 30 min before the week's first training session, following a standard warm-up period. Players had to perform three jumps, all of them barefoot [19]. They were instructed to place the palms of their hands on their hips and to perform a downward movement (into a squat position), followed by full knee extension and a jump. After each jump, players had 15 s of rest, and the best value out of three jumps was used in the research. The same experienced researcher performed all the measurements. The intraclass correlation coefficient (ICC) values for the CMJ test ranged from 0.93 to 0.97, indicating excellent reliability.

HRV data. Players were instructed to record their resting HRV (R-R intervals) for 2 min immediately upon waking, following these instructions: (1) remain motionless while recording;

(2) perform the measurement prior to consuming any food or fluids; and (3) empty the urinary bladder beforehand; (4) breathe spontaneously and maintain a neutral state of mind during data collection (Bloomfield et al., 2001). The R-R interval recordings were obtained using a Polar H10 sensor chest strap (Polar Electro Oy, Kempele, Finland; sampling rate: 1000 Hz) and were downloaded using the Elite HRV App (version 5.3.2), which demonstrates near-perfect agreement with ECG ($r = 0.99$) for HRV measurements across supine, seated, and standing positions, indicating high validity (Flatt & Howells, 2019). Subsequently, the R-R interval recordings were analysed using the HRV analysis software Kubios HRV Premium (version 3.5.0., Biosignal Analysis and Medical Imaging Group, Kuopio, Finland). Ectopic beats were corrected using the automatic artifact correction algorithm, replacing them with interpolated adjacent interbeat intervals (IBI). The software's automatic noise detection feature was utilised to identify and mark distorted IBIs, such as those caused by movement (Tarvainen et al., 2014). The vagally-mediated HRV parameter analysed was the logarithm of the root-mean-square of successive differences (lnRMSSD), a reliable marker of parasympathetic (vagal) activity for monitoring in sports field settings (Medeiros et al., 2021; Muñoz-López et al., 2021). For analysis, the weekly mean of lnRMSSD (lnRMSSDmean, expressed in milliseconds [ms]) and its coefficient of variation (lnRMSSDCV, expressed as a percentage) were calculated individually. All HRV measurements were consistently recorded between 07:00 and 08:00 AM.

Sleep duration and resting heart rate. A Mi Band 4 actigraphy device (Foxconn, Xiaomi, China) was used to determine the player's sleep duration and RHR during the preseason period. This device has been previously validated (Concheiro-Moscoso et al., 2023; Xie et al., 2018) and is widely used to assess the sleep duration of various populations (Atkins et al., 2020; Concheiro-Moscoso et al., 2022). A third-party script (XDA developers, 2015) was utilised to retrieve data through an Android backup since Mi Band lacks a built-in function for data extraction. The accuracy of wrist-worn devices may vary across individuals due to factors such as wrist movement, device positioning, and individual sleep patterns, potentially introducing some measurement error. To minimise inconsistencies, participants were familiarised with the device before data collection, provided with standardised wear and use instructions, and data analysis focused on trends over time rather than isolated values. Once the research started, players would wear the Xiaomi band on their left wrist when going to sleep and keep it on until they wake up. Players were not asked to change their sleep schedule for this study but to act as they usually do during the observed period. For further analysis, the weekly mean of the total

time spent sleeping (Sleepmean, expressed in minutes) and weekly mean of the resting heart rate (RHRmean, expressed in beats per minute) were calculated.

Statistical analysis

Descriptive statistics are reported as mean, standard deviation (SD), and coefficients of variation (CV%). The normality of the data was assessed using the Shapiro–Wilk test, while sphericity was tested via Mauchly’s test. When the assumption of sphericity was violated, Greenhouse–Geisser corrections were applied. A one-way repeated measures ANOVA was conducted to compare variables across the five weeks of the pre- season phase. A Bonferroni post-hoc test was used to identify the magnitude of differences between means with Cohen’s *d* as a measure of effect size (ES) and interpreted using the following qualitative thresholds:

< 0.2, trivial; 0.2–0.6, small; 0.6–1.2, moderate; 1.2–2.0, large; 2.0–4.0, very large; and > 4.0, extremely large (Hopkins et al., 2009). The repeated-measures correlation analysis using the rmcrrShiny app was performed to determine the relationship between variables (Bakdash & Marusich, 2017; Marusich & Bakdash, 2021). This correlation analysis is appropriate for paired, repeated-measures data, as it accounts for the non-independence of data points from the same participant and identifies common intra-individual changes. The magnitude of the repeated-measures correlation coefficient (rrm) with 95% confidence intervals (95%CI) estimated using parametric bootstrapping (1,000 samples) was interpreted conservatively using the following ranges: 0.1, trivial; 0.1–0.3, small; 0.3–0.5, moderate; 0.5–0.7, large; 0.7–0.9, very large; and 0.9–1.0, almost perfect (Hopkins et al., 2009). A *p*-value of < 0.05 was considered statistically significant. All data were analysed using the SPSS 29.0 statistical software (SPSS, Chicago, IL, USA) and GraphPad Prism 9 (GraphPad Software, Inc., San Diego, CA, USA).

4.2.3. Results

Figure 1 displays changes in ITImean between weeks over the preseason phase. There was a significant time effect ($F(4,36) = 29.83$, $p < 0.001$) with the end of the preseason phase (week 5) being lower than in week 1 (ES = 3.91 [very large]), 2 (ES = 3.69 [very large]), 3 (ES = 3.68 [very large]), and 4 (ES = 1.53 [large]). Moreover, week 4 was lower than week 1 (ES = 2.28 [very large]) and 2 (ES = 2.1 [very large]).

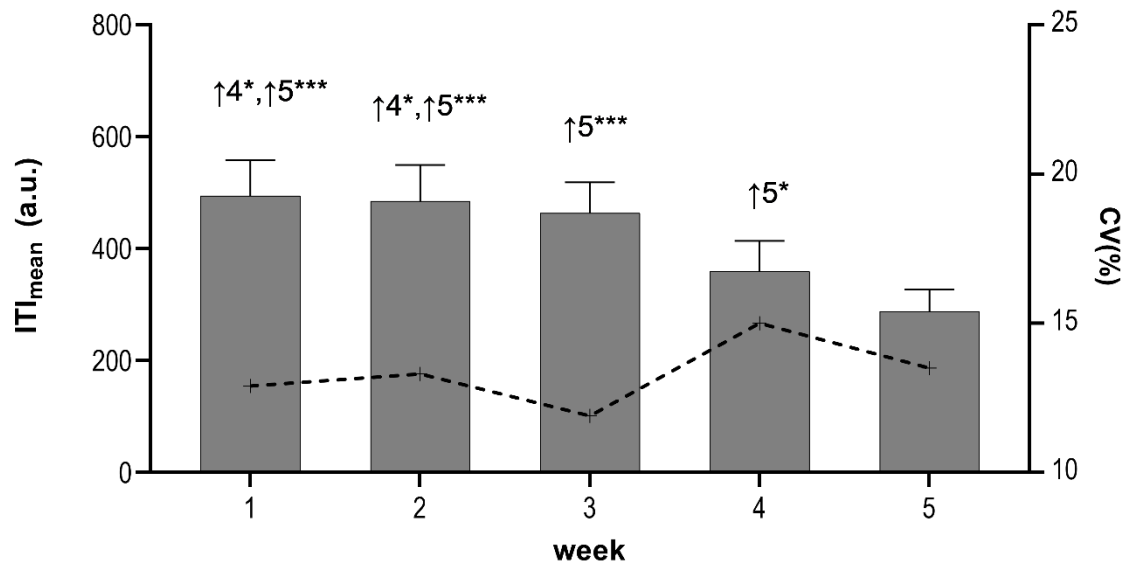


Figure 1. Internal training intensity values over the 5 weeks during the preseason in professional soccer players ($n = 10$). ITI_{mean} – weekly mean internal intensity, ↑ – positive direction of difference, ↓ – negative direction of difference, statistically different: 4 – from week 4, 5 – from week 5; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Figures 2 and 3 show changes in lnRMSSD_{mean} and lnRMSSDCV during the weeks in the observed period. Although there was a 39.9% decrease in lnRMSSDCV from week 1 to week 5 ($\Delta = -2.11$, ES = 1.32 [large]), no significant time effect was determined ($F(4,36) = 2.12$, $p = 0.1$). Also, there were no significant changes in lnRMSSD_{mean} between the weeks of the observed period ($F(4,36) = 1.37$, $p = 0.27$).

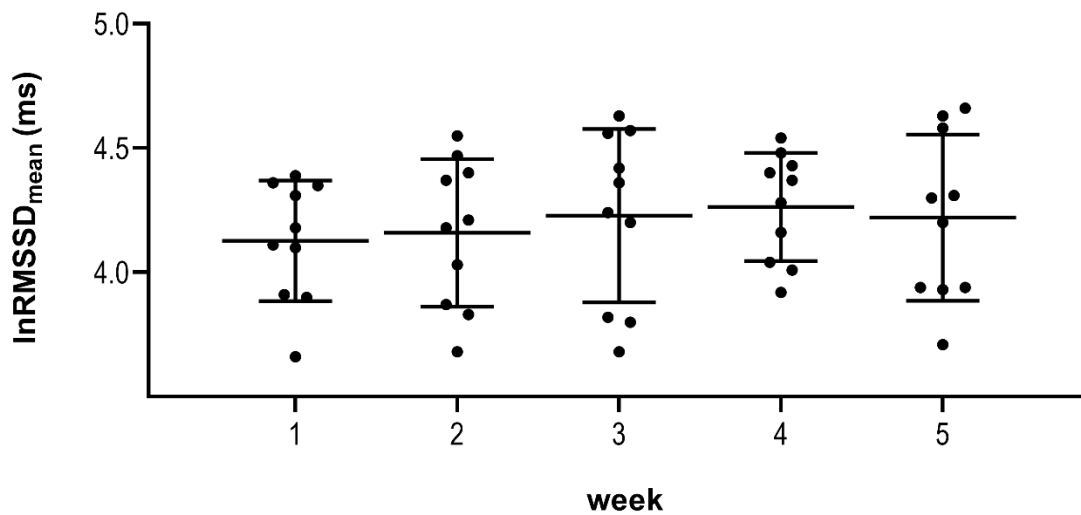


Figure 2. Individual and group heart rate variability values over the 5 weeks during the preseason in professional soccer players ($n = 10$). $\ln\text{RMSSD}_{\text{mean}}$ – weekly mean log-transformed root-mean-square difference of successive R-R intervals.

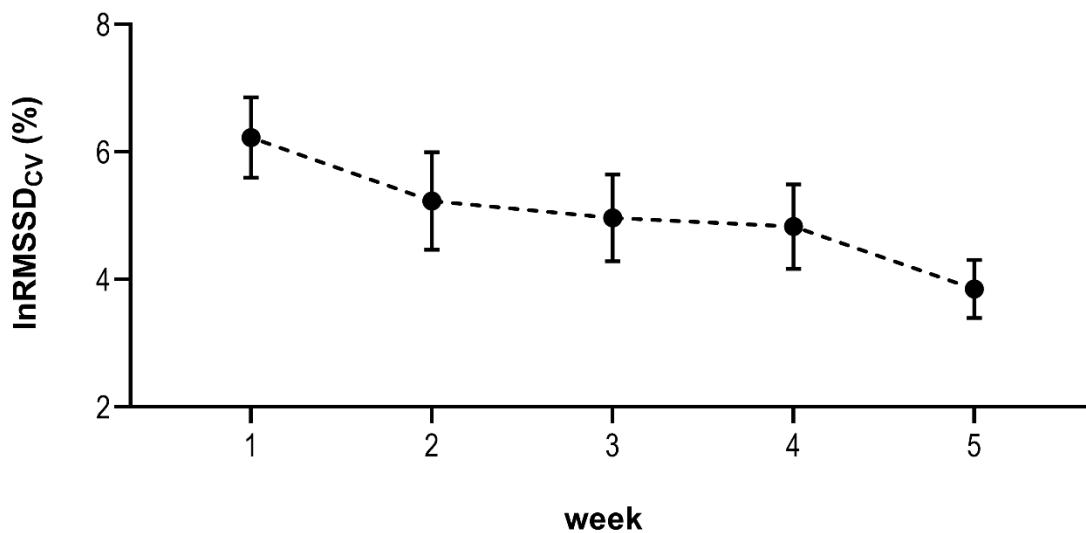


Figure 3. Group heart rate variability values expressed as percentages over the 5 weeks during the preseason in professional soccer players ($n = 10$). $\ln\text{RMSSD}_{\text{cv}}$ – coefficient of variation of weekly log-transformed root-mean-square difference of successive R-R intervals.

Table 3 demonstrates changes between weeks in RHR_{mean} , $\text{Sleep}_{\text{mean}}$ and CMJ. A significant time effect was determined for CMJ ($F(4,36) = 10.42$, $p < 0.001$), where

performances were lower in week 2 than in week 1 (ES = 0.63 [moderate], week 4 (ES = 0.8 [moderate], and week 5 (ES = 0.82 [moderate]. There were no significant changes in RHR_{mean} (F(4,36) = 1.51, p = 0.25) and Sleep_{mean} (F(4,36) = 0.95, p = 0.45).

Table 3. Variables of resting heart rate, sleep duration, and CMJ performance over the 5 weeks during the preseason in professional soccer players (n = 10)

Week	RHR _{mean} (beats · min ⁻¹)		Sleep _{mean} (min)		CMJ (cm)	
	1	54.7	(3.8)	441.2	(32.5)	42.2
2	53.1	(3.1)	433.6	(49.9)	39.7	(4.1) [↓] 4**
3	53.8	(3.6)	449.1	(34.7)	41.3	(2.8)
4	52.6	(2.6)	448.2	(39)	42.7	(3.4)
5	53.5	(2.7)	460.6	(39.1)	43.1	(4.3) [↑] 2*

All data is presented as mean (SD), RHR_{mean} – weekly mean of resting heart rate, Sleep_{mean} – weekly mean of total time spent sleeping, CMJ – countermovement jump, ↑ – positive direction of difference, ↓ – negative direction of difference, statistically different: 2 – from week 2, 4 – from week 4, * p < 0.05, ** p < 0.01

With the repeated-measures correlation analysis approach (Table 4 and Figure 4), the results showed that ITI_{mean} had a positive correlation with lnRMSSDCV (p = 0.03, r_{rm} [moderate]) and a negative correlation with CMJ (p = 0.005, r_{rm} [moderate]) and Sleep_{mean} (p = 0.045, r_{rm} [moderate]). There was also a negative correlation between lnRMSSD_{mean} and lnRMSSDCV (r_{rm} = -0.54 [moderate], p < 0.001, 95%CI [-0.73 to -0.28]) (Figure 4).

Table 4. Repeated measures correlation between internal training intensity and cardiac autonomic markers, sleep duration, and neuromuscular performance (n = 10)

Variable	r _{mr}	ITI _{mean}	
		df	95%CI
CMJ (cm)	-0.43**	39	-0.65 to -0.14
RHR _{mean} (beat · min ⁻¹)	0.14	39	-0.18 to 0.42
lnRMSSD _{mean} (ms)	-0.27	39	-0.54 to 0.04
lnRMSSD _{CV} (%)	0.35*	39	-0.05 to -0.6
Sleep _{mean} (min)	-0.32*	39	-0.57 to -0.01

ITI_{mean} – weekly mean internal intensity, CMJ – countermovement jump, RHR_{mean} – weekly mean resting heart rate, lnRMSSD_{mean} – weekly mean log-transformed root-mean-square

difference of successive R-R intervals, $\ln\text{RMSSD}_{\text{CV}}$ – weekly coefficient of variation of log-transformed root-mean-square, $\text{Sleep}_{\text{mean}}$ – weekly mean of total time spent sleeping, r_{mr} – repeated-measures correlation coefficient, 95%CI – 95% confidence intervals for r_{mr} , * $p < 0.05$, ** $p < 0.01$

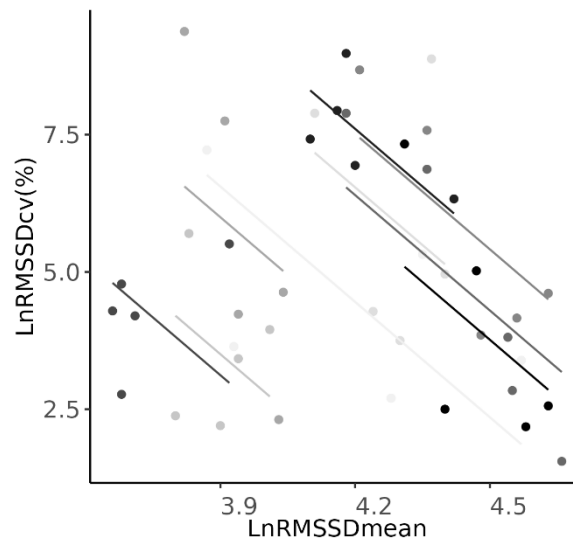


Figure 4. Repeated-measures correlation plots between $\ln\text{RMSSD}_{\text{mean}}$ and $\ln\text{RMSSD}_{\text{CV}}$. Each shade of grey represents a unique participant, with points indicating their performance on both measures at specific time points, and the corresponding lines illustrate the rrm fit for each participant

4.2.4. Discussion

This study explored the relationship between ITI and physiological and performance markers during a five-week preseason in professional soccer players. The results showed significant changes during the pre-competition phase, with ITI_{mean} decreasing, while CMJ increased over the observed period. No significant changes were observed in RHR_{mean} , $\ln\text{RMSSD}_{\text{mean}}$, or sleep duration, though $\ln\text{RMSSD}_{\text{CV}}$ showed a notable 39.9% reduction from week 1 to 5. Repeated correlation analysis revealed that ITI_{mean} was positively

correlated with $\ln\text{RMSSDCV}$, and negatively correlated with Sleepmean and CMJ , while $\ln\text{RMSSDmean}$ correlated negatively with $\ln\text{RMSSDCV}$. The results of the present study offer essential insights into how meticulously implemented training programs in the preseason phase can affect physiological and autonomic adaptations and neuromuscular performances in professional soccer players.

The ITI_{mean} showed a significant decrease, with values ranging from 288 to 494 a.u., which is comparable to those observed in professional senior soccer players during preseason (Pereira et al., 2022). However, they were higher than those reported for youth soccer players (Lechner et al., 2023), with both preseason periods lasting 4 to 6 weeks. A reduction in ITI was linked to improvements in physical match performance, making it a reliable indicator of players' condition and readiness. Research shows that a decrease in ITI during the tapering in the preseason phase can improve players' readiness for matches (Guridi Lopategui et al., 2021). Achieving balance in ITI is crucial for athletes to avoid overtraining and to maximise performance (Kellmann et al., 2018). CMJ showed a progressive increase during the weeks despite a single decrease of 6% from week 1 to week 2. This initial drop likely reflects accumulated neuromuscular fatigue from the increased training intensity at the start of the preseason (highest ITI in week 1). Similar patterns have been observed in soccer, where early-phase training stress temporarily suppresses power output before adaptation occurs (Los Arcos et al., 2015). By Weeks 3–5, as players adapted and fatigue levels decreased, CMJ performance improved, indicating positive neuromuscular adaptation to the training stimulus. The findings of this study support the importance of considering early-phase fatigue effects when interpreting short-term CMJ fluctuations. However, studies of CMJ during preseason show mixed findings, with some studies showing that CMJ changes are trivial (Los Arcos et al., 2020; J. J. Malone et al., 2015), while these changes are significant in others (Fessi, Zarrouk, Filetti, et al., 2016; Kobal et al., 2022). These differences may be influenced by training volume, load distribution, and individual adaptation rates. While CMJ is an indicator of neuromuscular function, it does not fully capture the complexity of performance adaptations during preseason. Soccer performance relies not only on lower-body power but also on endurance, agility, tactical skills, and psychological readiness (Kovacevic et al., 2018; Rađa et al., 2019). Consequently, CMJ should be interpreted alongside other performance metrics, such as sprint tests and technical-tactical assessments, to obtain a comprehensive view of player readiness. $\ln\text{RMSSDCV}$ decreased by 39.88% (95% CI: -57.14% to -22.63% , $p = 0.1$), indicating a substantial physiological adaptation despite statistical non-significance. This finding may suggest that there was a meaningful physiological adaptation in soccer players and

is in alignment with previous research where a reduction in $\ln\text{RMSSDCV}$ was reported (Figueiredo et al., 2019; Nakamura et al., 2016). Moreover, reduced $\ln\text{RMSSDCV}$ has been correlated with fewer daily fluctuations, indicating autonomic stability during well managed training intensities (Figueiredo et al., 2019). Therefore, reduced $\ln\text{RMSSDCV}$ may indicate the stability of the functioning of the autonomic nervous system (ANS), implying that athletes have adjusted to the imposed training intensities. On the other hand, $\ln\text{RMSSDmean}$ stabilisation over the weeks suggests that the average vagal tone remained consistent despite changes in day-to-day variability. The lack of significant changes in RHRmean may reflect a good balance of autonomic nervous system (ANS) and cardiovascular fitness (Schneider et al., 2018). Therefore, the non-significant time effect in both indicators of autonomic regulation is not surprising, indicating that players had a well-balanced training intensity and maintained parasympathetic balance during the observed period.

The sleep duration remained unchanged over the weeks, with an average of 7.5 hours, which aligns with recommendations for professional athletes (Walsh et al., 2021). The consistent Sleepmean values suggest that the players maintained relatively stable sleep durations across the weeks ($p = 0.45$). Sleep patterns in athletes often remain stable during different training phases, suggesting that external stressors or training load variations may not always disrupt sleep duration (Halson et al., 2022; Sargent et al., 2021). The stability observed may reflect effective recovery practices or the athletes' adherence to good sleep hygiene strategies (Vachon et al., 2023).

The repeated-measures correlation analysis showed a moderate, positive correlation between ITImean and $\ln\text{RMSSDCV}$ ($r = 0.35$, $p = 0.03$), suggesting that increased training intensity is associated with greater daily fluctuations in HRV. The moderate strength of the correlation suggests that any fluctuations remained within a manageable range, indicating that training adaptations were largely appropriate. Previous studies in soccer (Flatt & Esco, 2016), rugby (Flatt & Howells, 2019) and futsal (Nakamura et al., 2023) have shown similar findings, where a reduction in $\ln\text{RMSSDCV}$ is considered an indicator of physiological adaptability to training stress. Inter-day variability in parasympathetic activity, as reflected by $\ln\text{RMSSDCV}$, may indicate a dynamic autonomic response to fluctuating training intensity, which is essential for maintaining performance and preventing overtraining (Nakamura et al., 2023)[62]. According to Nakamura and Flatt (Nakamura & Flatt, 2020), consistently high variability in $\ln\text{RMSSD}$ values within a week is generally considered undesirable. While $\ln\text{RMSSD}$ is a key indicator of parasympathetic activity, excessive fluctuations suggest irregular adaptations to training loads, potentially indicating inadequate recovery or excessive fatigue accumulation

(Nakamura & Flatt, 2020). Well-trained athletes typically exhibit lower lnRMSSDCV, as their autonomic nervous systems demonstrate greater stability in response to training stimuli, facilitating more consistent recovery and performance readiness (Flatt & Esco, 2016).

Previous research on the relationship between weekly lnRMSSD and ITI shows mixed results. A study in elite water polo players found low that correlations between internal training intensity and lnRMSSDmean were observed during preseason, and no correlation was found during in-season periods (Botonis et al., 2021). Its authors attribute this to the influence of non-training stressors during competition phases. Similarly, Nakamura et al. (Nakamura et al., 2016) reported that lnRMSSDmean remained unchanged across a 5-week preseason in futsal players, and no significant correlations were observed between weekly sRPE and lnRMSSD. On the other hand, some studies reported significant negative correlations between lnRMSSDmean and internal training intensity (Barrero et al., 2019; J. Coyne et al., 2021; Flatt et al., 2017). However, the coefficient of variation of ln- RMSSD has been suggested as a potentially more sensitive indicator to detect acute changes in training intensity (Holmes et al., 2018; Nakamura et al., 2023). lnRMSSDmean is more stable among elite or professional players than recreational athletes, potentially due to their higher baseline fitness levels and greater capacity to tolerate training stress. Thus, at the team level, lnRMSSDmean appears less sensitive to acute changes in internal training intensity, reflecting its role as a marker of long-term parasympathetic balance and chronic recovery (Buchheit, 2014). The observed discrepancy between lnRMSSDCV and lnRMSSDmean aligns with findings observed in futsal players, where lnRMSSDCV was shown to be a more responsive marker of training adaptations than the mean values [53,62]. This reinforces the idea that, while lnRMSSDmean reflects baseline parasympathetic function, lnRMSSDCV serves as a more dynamic indicator of training-induced stress. Finally, the observed moderate negative correlation between lnRMSSDmean and lnRMSSDCV aligns with previous findings, suggesting that greater parasympathetic activity reflects a higher resilience or capacity to training stress (Nakamura et al., 2016, 2023). During preparatory soccer training, an optimal weekly lnRMSSD pattern is characterised by a gradual rise in weekly average values and a decrease in daily variability (lnRMSSDCV)(Nakamura & Flatt, 2020). This relationship indicates that players with a well maintained autonomic balance are stronger at recovering from day-to-day training demands, minimising perturbations in HRV. Therefore, a negative correlation highlights the significance of maintaining stable and elevated lnRMSSDmean values, while a reduced ln- RMSSDCV may improve training adaptations by promoting increased resilience to cumulative training stress (Boullosa et al., 2013). These findings highlight the importance of routinely monitoring these

measures to modify training intensities and facilitate optimal recovery and performance improvement (Nakamura et al., 2016).

A moderate negative correlation was found between Sleepmean and ITImean. Increased ITI was associated with shorter sleep duration, potentially due to factors such as heightened autonomic arousal, increased physiological demands, and psychological stress resulting from rigorous training sessions or competitions (Halson et al., 2022; Vachon et al., 2023). For professional athletes, sleep is a crucial component of recovery and adaptation to training. It helps regulate hormones, restore energy levels, and support cognitive recovery, which are all vital for maintaining peak performance (Bender et al., 2018). Decreased sleep duration, as observed in athletes with increased ITI, may impair recovery mechanisms, resulting in reduced performance and higher fatigue. Studies have highlighted that enhancing sleep hygiene and obtaining adequate sleep is crucial for accommodating the requirements of intensive training programs (Halson et al., 2022; Sargent et al., 2021). Furthermore, variability in sleep patterns may intensify the adverse effects of increased ITI. Athletes with irregular sleep patterns or variable sleep lengths are more prone to sleep disruptions, which may intensify the stress of rigorous training and delay recovery (Driller et al., 2018). From a practical perspective, coaches and sports scientists should closely monitor sleep as a key recovery metric. If players exhibit consistently reduced sleep duration during periods of high ITI, adjustments to training intensity or recovery strategies may be necessary. Furthermore, educating athletes on sleep hygiene and optimising sleep schedules can enhance recovery and maintain performance across the season.

A moderate negative connection between ITImean and neuromuscular performance (CMJ) is consistent with prior research in soccer. Increased training exposure may cause fatigue, impairing neuromuscular function. Los Arcos et al. [46] found that increased training intensities were inversely correlated with physical performance, including CMJ, during prolonged training periods. The observed effects are likely attributable to functional or non-functional overreaching, where excessive workloads surpass recovery capability, resulting in brief reductions in muscular power (Thorpe et al., 2015). Therefore, training intensities were carefully planned and modified over the five-week preseason phase in this study. Consistent enhancements in physical performance, including CMJ performance, are essential for athletes over the latter phases of the season.

This study has a few limitations that should be acknowledged. The sample size of 10 players limits the generalisability of the findings and provides only a snapshot of short-term adaptations. A larger sample would allow for greater variability in individual responses and improve the robustness of the conclusions. Although the HRV stability over the five-week

preseason suggests that autonomic balance was maintained, metrics like $\ln\text{RMSSD}_{\text{mean}}$ and $\ln\text{RMSSD}_{\text{CV}}$ alone may not confirm full recovery. Laboratory-based measures of fitness or physiological responses, such as biochemical markers (e.g., cortisol, lactate) or muscle damage indicators, could have provided a more comprehensive understanding of training adaptations and recovery status. Moreover, the absence of specific performance tests also limits the ability to fully understand how $\ln\text{RMSSD}$ and other physiological markers relate to performance adaptations. Future research should explore these relationships over longer training periods and include a broader range of laboratory-based performance and physiological markers. This should include a combination of objective and subjective indicators, such as subjective fatigue scores, cortisol and lactate concentration, and muscle soreness tracking alongside HRV. A comprehensive, multidimensional approach would provide deeper insights into training adaptations, recovery status, and overall athlete readiness, ultimately optimising the intensity management strategy. Lastly, several potential confounding variables were not controlled for, including diet, training history, and psychological stress, all of which could influence HRV, CMJ, and sleep duration. Variability in nutritional intake, prior training intensity, or individual stress levels may have impacted physiological markers, making it difficult to isolate the effects of training intensity alone.

4.2.5. Practical applications

The results of this study provide significant insights for coaches and performance personnel. The decrease in ITI over the preseason demonstrates the advantages of progressively decreasing intensity, which enhanced neuromuscular performance, as indicated by the CMJ. This may reflect that players successfully recovered and transitioned training adaptations into enhanced physical performance. The reduction in $\ln\text{RMSSD}_{\text{CV}}$, an indicator of autonomic stability, implies that the participants adapted well to the training requirements, showing reduced day-to-day variability in autonomic function. This is a crucial indicator for coaches to assess, demonstrating players' ability to manage training intensities and recuperate effectively. To be specific, while $\ln\text{RMSSD}_{\text{mean}}$ remained constant, the decrease in variability suggests a shift towards a more stable and resilient autonomic system. The regular sleep duration of approximately 7.5 hours was an additional favourable observation. Despite the increased demands of playing two matches per week in the later weeks, the players maintained consistent sleep patterns, which likely supported their recovery and performance.

4.2.6. Conclusions

This study highlights that a carefully designed preseason program can lead to substantial improvements in performance and physiological stability in professional soccer players. In contrast to the original study, which centred on monitoring isolated variations in ITI and well-being measures throughout a five-week preseason, the present research adopts a more comprehensive approach by examining the interplay between ITI, HRV, sleep, and CMJ. This integrated perspective analyses each variable's temporal evolution and interactions, providing thorough knowledge of the relationship between training intensities, recovery, and performance. The incorporation of HRV markers (lnRMSSDmean and lnRMSSDCV) facilitates a detailed assessment of autonomic nervous system function, with lnRMSSDCV acting as a dynamic measure of autonomic stability and responsiveness to training intensities. The use of sleep duration as a recovery parameter underscores its potential impact on physiological recovery and neuromuscular function, introducing a vital aspect that was lacking in the original study. Through the analysis of all observed metrics, coaches can acquire insights into their players' reactions to training and recovery.

4.3. Izvorni znanstveni rad 3: Perceived recovery and muscle fatigue in professional soccer players during preseason.



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Perceived Recovery and Muscle Fatigue in Professional Soccer Players During Preseason

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Abstract

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 24.8 ± 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 ($r_{rm} = -0.72$), and between ITI and CMJ ($r_{rm} = -0.55$), 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

4.3.1. 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 (Colby et al., 2017). 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 (Rhini et al., 2025). 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 (S. Malone et al., 2017). 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 (Drew et al., 2017). Although professional sports are commonly associated with health, fitness, and overall well-being, the reality is often markedly different (Nuetzel, 2025). 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 (Chen et al., 2019). Indeed, abrupt increases in training intensity and frequency without adequate recovery can precipitate significant deficits in neuromuscular and perceptual readiness (Soligard et al., 2016). 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 (Schwellnus et al., 2016; Soligard et al., 2016).

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 (Impellizzeri et al., 2020). 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 (Bourdon et al., 2017), along with subjective indicators of fatigue, and objective assessments of neuromuscular performance (Halson, 2014; Maleš et al., 2022).

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 (Rago et al., 2020). 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 (Ouergui et al., 2020). 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 (Selmi, Ouergui, Muscella, et al., 2022).

Sansone et al.(2018) 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 (Thorpe et al., 2015). 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 (Selmi et al., 2021). 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 (McGuigan et al., 2020; Yang et al., 2024).

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 fatigue (Garrett et al., 2019) or signs of overreaching, thereby providing valuable insights to guide timely training adjustments and reduce the risk of progression toward overtraining syndrome (Bishop et al., 2023; Eggenberger et al., 2024). 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.

4.3.2. Materials and 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., (McKay et al., 2022) 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 (Navalta & Stone, 2019).

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 (rrm) using the rmcrr 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, (Maleš et al., 2022; S. Malone et al., 2018; Nobari et al., 2021; Sansone et al., 2018) a correlation of $rrm = 0.30$ 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 (Bakdash & Marusich, 2017) 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 ± SD
Age (years)	24.8 ± 4.4
Body height (cm)	182 ± 7
Body mass (kg)	74.6 ± 6.7
Muscle mass (kg)	64.9 ± 4.3
Body fat (%)	8.3 ± 3.7
BMI (kg/m ²)	22.6 ± 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 6.2. 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 6.2. 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

Internal Training Intensity (ITI). ITI was calculated using the sRPE method, as proposed by Foster et al. (Foster et al., 2001). 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 (ITIDs) were used to compute weekly internal training intensity (ITIs) 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) (Mandorino et al., 2022; Miranda-Mendoza et al., 2023). 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 (TQRpost), 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 TQRfw (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., $TS-\Delta = TQR - sRPE$). 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 (Ruf et al., 2024; Thorpe et al., 2015).

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 (Twist & Highton, 2013).

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) (Hopkins et al., 2009). 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 (rrm) 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 ($F(3,66) = 57.38$, $p < 0.001$, $\eta^2 = 0.73$ [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.

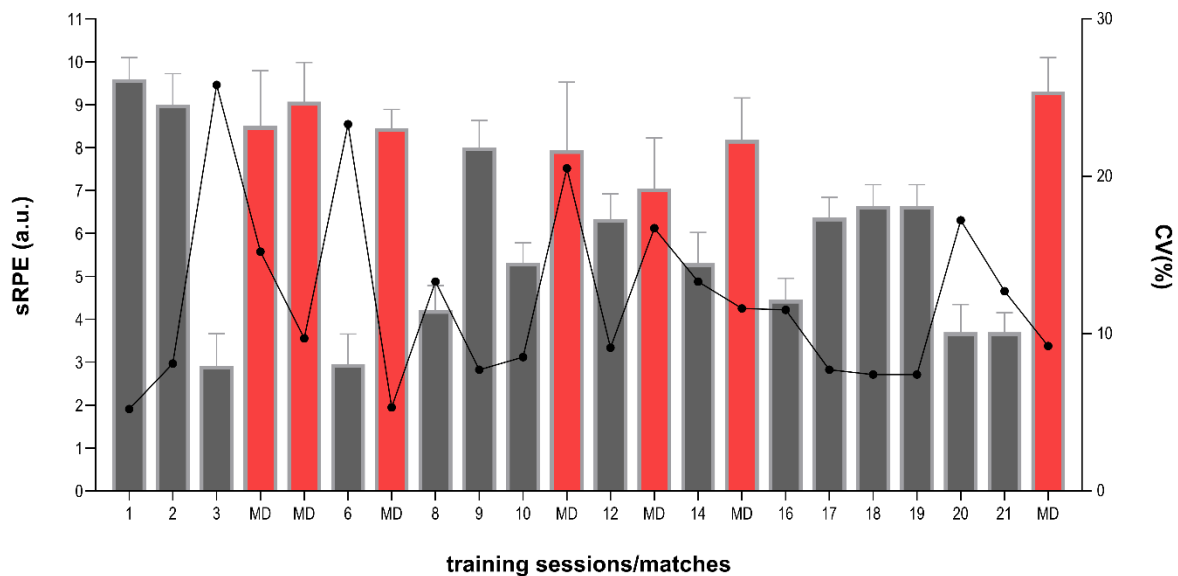


Figure 1. Daily variations in sRPE within included match days (MD) are highlighted in red. The bars represent sRPE values with standard deviation (SD). Coefficient of variation (CV%) is shown as a black line following the y- axis.

Figure 2 displays the weekly variations in mean ITI and TQR. The repeated measures ANOVA revealed a statistically significant time effect for the ITI ($F(3,66) = 138.29$ $p < 0.001$, $\eta^2 = 0.86$ [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 ($F(3,66) = 93.54$, $p < 0.001$, $\eta^2 = 0.81$ [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]).

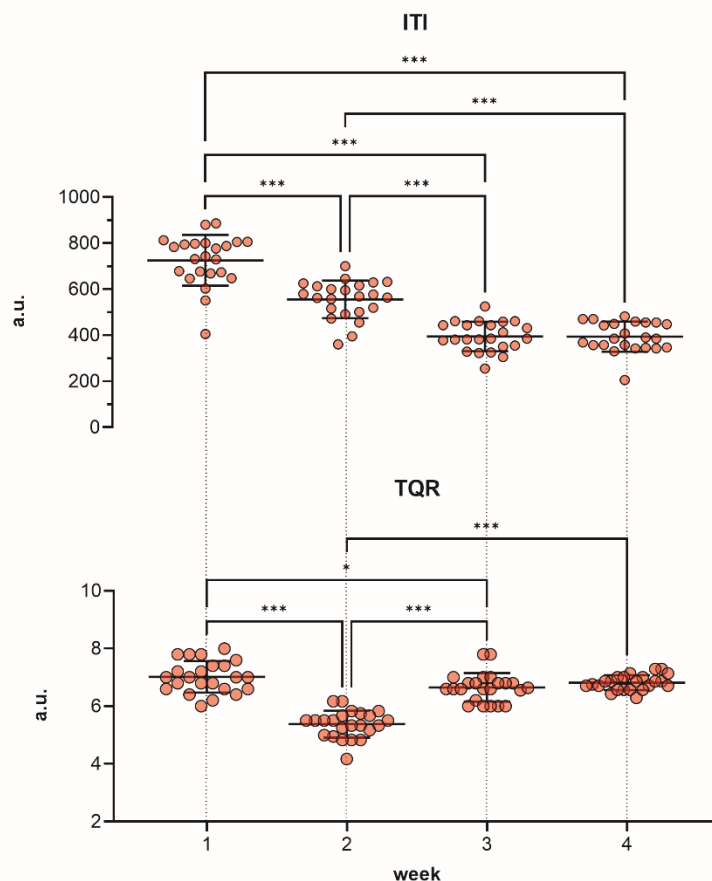


Figure 2. Weekly variations in ITI and TQR over a four-week period. Every dot represents an individual data point, and the black horizontal line indicates the mean value for every week. * $p < 0.05$, *** $p < 0.001$.

Weekly variations in CMJ and PMS are illustrated in Figure 3. CMJ performance significantly changed over time ($F(3,66) = 26.35$, $p < 0.001$, $\eta^2 = 0.55$ [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 ($F(3,66) = 8.06$, $p < 0.001$, $\eta^2 = 0.27$ [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]).

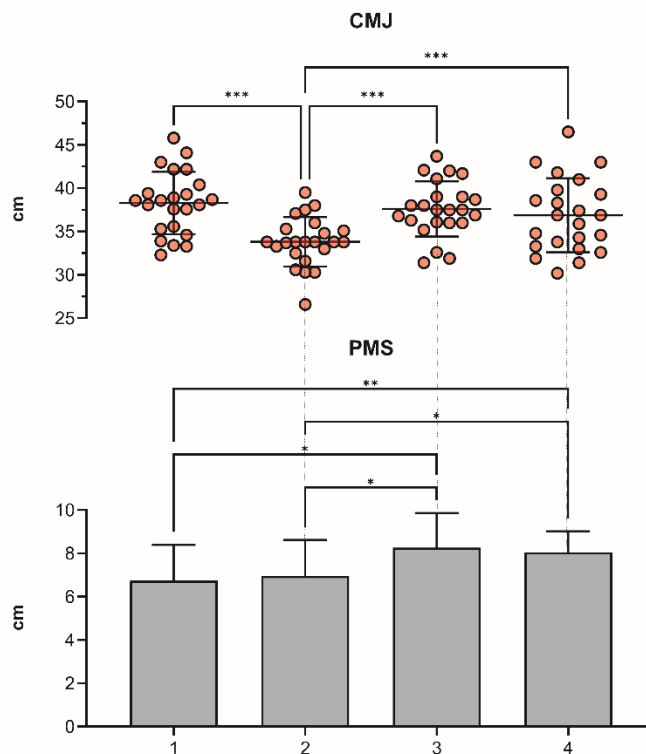


Figure 3. Weekly variations in neuromuscular performance (CMJ) and PMS over a 4-week period. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

The TS- Δ index and TQRfw 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.

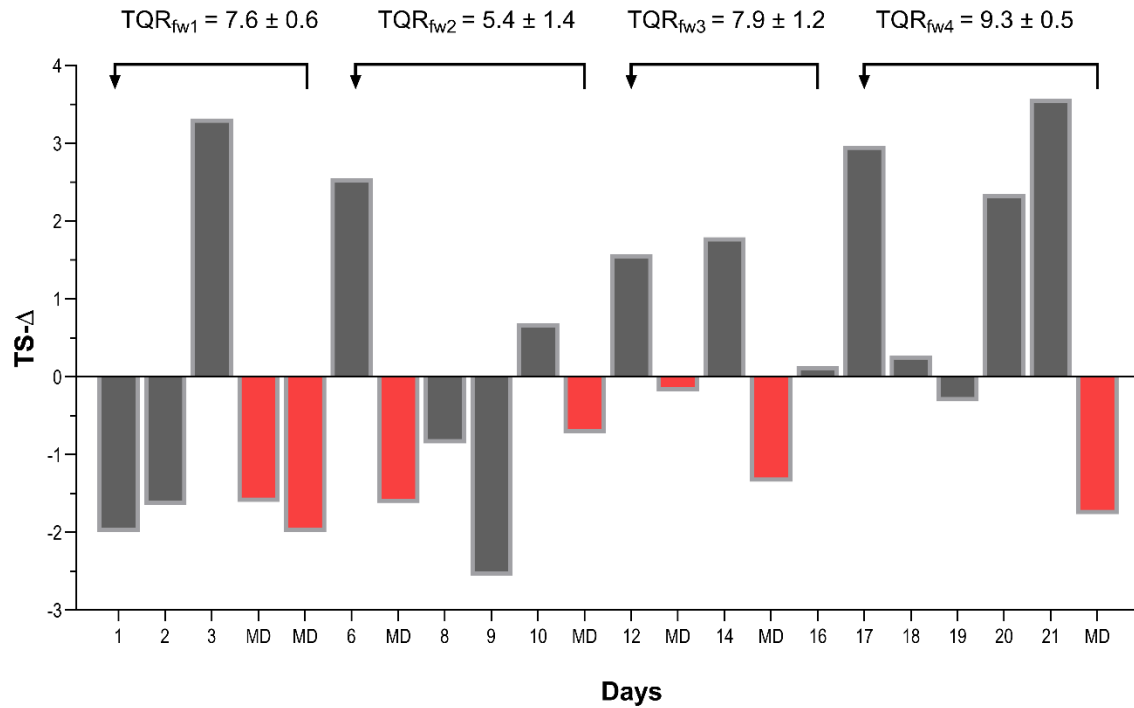


Figure 4. Daily variations in the TS-Δ index and TQRfw.

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

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

pair	rrm	p	95% CI
ITIDs vs. TQRpost	-0.23	< 0.001	-0.32 to -0.143
TS-Δ vs. TQRpost	0.28	< 0.001	0.192 to 0.369
ITIws vs. TQRfw	-0.72	< 0.001	-0.835 to -0.547

Legend: rrm – repeated-measures correlation coefficient; *p* – significance level; 95%CI – 95% confidence intervals for rrm

Multiple significant correlations between the training intensity, neuromuscular performance, and perceived muscle soreness are presented in Table 4. Specifically, ITIws showed a moderate negative correlation with PMS, indicating that higher ITI values were associated with lower PMS severity. Similarly, ITIws 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	rrm	p	95% CI
ITIws vs. PMS	-0.33	0.02	-0.566 to -0.051
ITIws vs. CMJ	-0.55	< 0.001	-0.725 to -0.317
CMJ vs. PMS	0.47	< 0.001	0.213 to 0.668

Legend: rrm – repeated-measures correlation coefficient; *p* – significance level; 95%CI – 95% confidence intervals for rrm

4.3.3. 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 (Fessi, Zarrouk, Di Salvo, et al., 2016). Furthermore, previous research highlights that early preseason is typically characterized by elevated training demands intended to provoke physiological adaptation (Jeong et al., 2011). 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 (Sansone et al., 2018).

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 (Marco-Contreras et al., 2021). 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 (Nobari et al., 2020) while fixture congestion with inadequate rest worsens PMS (Hattersley et al., 2018). 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 ($rrm = -0.72$), 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 (Sansone et al., 2018). 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 TQRpost ($rrm = -0.23$) further suggests that acute intensity is also reflected in perceptual recovery status, although to a lesser extent than accumulated weekly ITI. This aligns with Kenttä and Hassmén's model, (Kenttä & Hassmén, 1998) 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 ($rrm = -0.55$) suggests that greater training stress is linked to reduced neuromuscular performance, as reported by Gathercole et al. (Gathercole et al., 2015). 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 (Hody et al., 2019); 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 (Alba-Jiménez et al., 2022).

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 (de Araujo et al., 2022). Conceptually, TS- Δ may complement the acute:chronic workload ratio by capturing session-level mismatches between readiness and demand (Gabbett, 2016) and it builds on the recovery–training interaction framework of Kenttä and Hassmén (Kenttä & Hassmén, 1998).

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. (Sansone et al., 2018) 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.

5. GENERALNI ZAKLJUČAK

Glavni cilj ovog doktorskog rada bio je istražiti odnose između unutarnjeg trenažnog opterećenja, pokazatelja oporavka, dobrobiti i neuromišićne izvedbe tijekom pripremnog perioda kod profesionalnih nogometaša, primjenom integriranog sustava subjektivnih i objektivnih pokazatelj. Njegovo ostvarenje analizirano je kroz tri zasebna istraživanja, a osvrt na parcijalne ciljeve i pripadajuće hipoteze prikazan je u nastavku.

Prvi parcijalni cilj bio je istražiti tjedne promjene unutarnjeg trenažnog opterećenja, statusa dobrobiti i izvedbe vertikalnog skoka iz čučnja tijekom petotjednog pripremnog perioda kod profesionalnih nogometaša, te ispitati odnos doza–odgovor između unutarnjeg trenažnog opterećenja i izvedbe vertikalnog skoka iz čučnja u odnosu na varijacije mjera statusa dobrobiti. Rezultati prvog istraživanja pokazali su statistički značajne tjedne promjene u svim pokazateljima unutarnjeg trenažnog opterećenja, statusa dobrobiti i neuromišićne izvedbe. CMJ izvedba bila je značajno viša u četvrtom i petom tjednu u odnosu na prvi tjedan, dok su sve mjere unutarnjeg trenažnog opterećenja pokazale značajne razlike između tjedana. Također, značajne tjedne razlike utvrđene su i za sve ispitivane kategorije dobrobiti, uključujući umor, san, mišićnu bol, stres, raspoloženje i ukupni indeks dobrobiti. Korelacijska analiza pokazala je značajne negativne povezanosti između prosječnog tjednog unutarnjeg trenažnog opterećenja i umora, mišićne boli te ukupnog indeksa dobrobiti, dok su umor, akumulirano tjedno opterećenje i trenažni napor također bili značajno povezani. S druge strane, povezanosti između CMJ izvedbe i mjera dobrobiti bile su male i statistički neznačajne. Na temelju navedenoga može se zaključiti da je prvi parcijalni cilj ostvaren, a prva hipoteza potvrđena.

Drugi parcijalni cilj bio je analizirati odnos između unutarnjeg trenažnog opterećenja i ključnih pokazatelja oporavka i izvedbe, uključujući varijabilnost srčanog ritma, trajanje sna i izvedbu vertikalnog skoka iz čučnja, tijekom petotjednog pripremnog perioda kod profesionalnih nogometaša. Rezultati drugog istraživanja pokazali su da je unutarnje trenažno opterećenje značajno povezano s pojedinim objektivnim pokazateljima oporavka i izvedbe. Veće unutarnje trenažno opterećenje bilo je povezano s kraćim trajanjem sna, slabijom izvedbom vertikalnog skoka iz čučnja i većom varijabilnošću srčanog ritma izraženom kroz $\ln\text{RMSSDCV}$. Istodobno, prosječne vrijednosti $\ln\text{RMSSD}$ -a i srčane frekvencije u mirovanju nisu pokazale značajne tjedne promjene, što upućuje na to da svi fiziološki pokazatelji nisu jednako osjetljivi na promjene trenažnog opterećenja u kratkom pripremnom razdoblju. Unatoč tomu, dobiveni rezultati potvrđuju da povećano unutarnje trenažno opterećenje može biti

povezano s nepovoljnijim obrascima oporavka i smanjenom neuromišićnom izvedbom. Slijedom toga, drugi parcijalni cilj može se smatrati ostvarenim, a druga hipoteza potvrđenom.

Treći parcijalni cilj bio je ispitati tjedne varijacije i odnose u varijablama unutarnjeg trenažnog opterećenja, subjektivne percepcije oporavka, neuromišićne izvedbe i mišićnog umora tijekom četverotjednog pripremnog perioda, te dodatno procijeniti korisnost indeksa TS- Δ kao praktičnog alata za praćenje ravnoteže između trenažnog podražaja i oporavka. Rezultati trećeg istraživanja pokazali su značajne tjedne varijacije unutarnjeg trenažnog opterećenja, percipiranog oporavka, neuromišićne izvedbe i percipirane mišićne boli. Najveće opterećenje zabilježeno je u početnom dijelu pripremnog perioda, dok je oporavak bio najslabiji u drugom tjednu, kada je istodobno zabilježen i pad CMJ izvedbe. Nadalje, utvrđene su značajne povezanosti između većeg unutarnjeg trenažnog opterećenja i slabijeg oporavka, veće percipirane mišićne boli te slabije neuromišićne izvedbe. Vrijednosti indeksa TS- Δ bile su povezane s naknadnim oporavkom, što upućuje na njegovu potencijalnu korisnost u svakodnevnom praćenju ravnoteže između zahtjeva treninga i stanja oporavka sportaša. Ipak, taj nalaz valja tumačiti s određenim oprezom, budući da rezultati podupiru njegovu praktičnu primjenjivost u konkretnom kontekstu istraživanja, ali ne predstavljaju konačnu potvrdu njegove šire valjanosti. Stoga se može zaključiti da je i treći parcijalni cilj ostvaren, dok je treća hipoteza u najvećoj mjeri potvrđena.

Na temelju sva tri istraživanja može se zaključiti da su postavljeni parcijalni ciljevi doktorskog rada ostvareni te da su hipoteze uglavnom potvrđene. Prva i druga hipoteza potvrđene su jasnije i izravnije, budući da su dobiveni rezultati pokazali značajne promjene i očekivane povezanosti između unutarnjeg trenažnog opterećenja, dobrobiti, sna, varijabilnosti srčanog ritma i neuromišićne izvedbe. Treća hipoteza također je potvrđena u dijelu koji se odnosi na tjedne varijacije i povezanosti između opterećenja, oporavka, mišićne boli i neuromišićne izvedbe, dok dio vezan uz TS- Δ treba promatrati kao potporu njegovoj potencijalnoj praktičnoj korisnosti, a ne kao konačnu validaciju pokazatelja.

5.1. Praktična primjena

Analizom rezultata sva tri istraživanja ovog doktorskog rada mogu se izdvojiti sljedeće praktične smjernice za monitoring nogometaša i trenažnog procesa te upravljanje opterećenjem nogometne ekipe tijekom pripremnog perioda: 1) subjektivne mjere unutarnjeg trenažnog opterećenja pokazale su se osjetljivima na promjene u trenažnim procesima, a istovremeno vrlo

praktičnima za svakodnevnu primjenu u praksi, zbog čega se preporučuje njihovo redovito korištenje kao osnove za kvantifikaciju trenažnog opterećenja; 2) praćenje statusa dobrobiti nogometaša (razine umora, kvalitete sna, razine stresa, raspoloženja i mišićne boli) omogućuje trenerskom osoblju rano prepoznavanje negativnih odgovora na povećani intenzitet trenažnog opterećenja, pri čemu redovita primjena validiranih WBI upitnika može pomoći u individualizaciji opterećenja prema individualnim potrebama i zahtjevima nogometaša; 3) rezultati istraživanja pokazali su da promjene u unutarnjem trenažnom opterećenju imaju izravnu povezanost s promjenama u neuromišićnoj izvedbi procijenjenoj CMJ testom, pa se preporučuje korištenje CMJ testa kao jednostavnog i brzog alata za procjenu akutnog neuromišićnog umora; 4) utvrđena povezanost unutarnjeg trenažnog opterećenja, WBI statusa i CMJ izvedbe omogućuje praktičnu primjenu koncepta „doza–odgovor“, pri čemu treneri mogu koristiti dobivene informacije za optimizaciju opterećenja s ciljem postizanja željene razine adaptacije i smanjenja rizika od ozljede; 5) varijabilnost srčanog ritma (lnRMSSD i lnRMSSDCV) pokazao se kao osjetljiva mjera na promjene u trenažnom opterećenju i oporavku nogometaša, te njegova primjena kao dijela monitoringa može pružiti dodatne informacije o adaptaciji i pomoći u donošenju odluka o dnevnom doziranju opterećenja; 6) rezultati istraživanja upućuju i na jasnu povezanost unutarnjeg trenažnog opterećenja i trajanja sna te varijabli za detekciju umora, zbog čega korištenje objektivnih i subjektivnih mjera za praćenje sna može doprinijeti boljem uvidu u stanje i oporavak nogometaša tijekom intenzivnih perioda; indeks TS– Δ pokazao se kao koristan alat za procjenu ravnoteže trenažnog opterećenja i oporavka, čija jednostavna i brza implementacija omogućuje trenerima brz uvid u akumulirani stres i trenutne razine oporavka te olakšava donošenje odluka o prilagodbi opterećenja.

5.2. Ograničenja i smjernice za buduća istraživanja

Unatoč relevantnim i praktičnim zaključcima i spoznajama, rezultate ovog doktorskog rada potrebno je interpretirati uzimajući u obzir sljedeća ograničenja i prijedloge za buduća istraživanja: 1) iako karakteristično za primijenjena mjerenja u profesionalnom sportu, sva istraživanja provedena su na relativno malom uzorku (10 do 25 ispitanika), stoga bi buduća istraživanja trebala pokušati uključiti veći broj ekipa istovremeno, kroz suradnju većeg broja klubova ili praćenje većeg broja natjecateljskih sezona; 2) zbog provedbe istraživanja u realnim uvjetima na profesionalnoj razini nije bilo lako uključiti kontrolnu skupinu niti primijeniti takvu vrstu eksperimenta, pa bi buduća istraživanja trebala razmotriti paralelno uspoređivanje

više ekipa ili različitih trenažnih protokola kroz iste metode praćenja. Nadalje iako su mjerenja provedena u standardiziranim i stručnim uvjetima, nije bilo moguće u potpunosti kontrolirati svakodnevne aktivnosti ispitanika prije i nakon treninga, uključujući prehranu i životni stres, zbog čega bi buduća istraživanja mogla uključiti detaljniju kontrolu kontekstualnih, socijalnih i psiholoških čimbenika kao zasebnih faktora; 3) nogomet je karakteriziran visokom varijabilnošću u trenažnim i natjecateljskim zahtjevima koja može utjecati na odgovore igrača na trenažni proces, pa bi buduća istraživanja mogla koristiti sofisticiranije statističke modele za evidentiranje individualnih razlika unutar ekipa; 4) istraživanja ovog doktorskog rada provedena su na dvije ekipe koje se natječu u istoj ligi i istom natjecateljskom rangu, stoga bi buduća istraživanja trebala uključiti veći broj ekipa iz različitih liga i natjecateljskih rangova; 5) neuromišićna izvedba procijenjena je uz pomoć optičkog sustava (OptoJump) koji predstavlja pouzdanu metodu mjerenja, no u budućim istraživanjima bilo bi korisno primijeniti i silomjerne platforme kako bi se omogućila detaljnija analiza neuromišićnih varijabli; 6) naposljetku, sva provedena istraživanja bila su u okviru opservacijskog dizajna, što nije omogućilo donošenje uzročno-posljedičnih zaključaka, pa bi buduća istraživanja trebala uključiti intervencijske studije usmjerene na učinkovitost različitih monitoring alata i upravljanja trenažnim procesima.

6. LITERATURA

- Abarghoueinejad, M., Baxter-Jones, A., Gomes, T., Barreira, D., & Maia, J. (2021). Motor Performance in Male Youth Soccer Players: A Systematic Review of Longitudinal Studies. *Sports*, 9(4), 53. <https://doi.org/10.3390/sports9040053>
- Afonso, J., Nakamura, F. Y., Canário-Lemos, R., Peixoto, R., Fernandes, C., Mota, T., Ferreira, M., Silva, R., Teixeira, A., & Clemente, F. M. (2021). A Novel Approach to Training Monotony and Acute-Chronic Workload Index: A Comparative Study in Soccer. *Frontiers in Sports and Active Living*, 3, 661200. <https://doi.org/10.3389/FSPOR.2021.661200/FULL>
- Afonso, P., Forte, P., Branquinho, L., Ferraz, R., Garrido, N. D., & Teixeira, J. E. (2025). Shaping Training Load, Technical–Tactical Behaviour, and Well-Being in Football: A Systematic Review. *Sports*, 13(8), 244. <https://doi.org/10.3390/sports13080244>
- Akenhead, R., & Nassis, G. P. (2016). Training Load and Player Monitoring in High-Level Football: Current Practice and Perceptions. *International Journal of Sports Physiology and Performance*, 11(5), 587–593. <https://doi.org/10.1123/ijsp.2015-0331>
- Alba-Jiménez, C., Moreno-Doutres, D., & Peña, J. (2022). Trends Assessing Neuromuscular Fatigue in Team Sports: A Narrative Review. *Sports*, 10(3), 33. <https://doi.org/10.3390/sports10030033>
- Algrøy, E. A., Hetlelid, K. J., Seiler, S., & Pedersen, J. I. S. (2011). Quantifying training intensity distribution in a group of Norwegian professional soccer players. *International Journal of Sports Physiology and Performance*, 6(1), 70–81. <https://doi.org/10.1123/IJSP.6.1.70>
- Anderegg, J., Brefin, S. L., Nigg, C. R., Koschnick, D., Paul, C., & Ketelhut, S. (2025). Load and Recovery Monitoring in Top-Level Youth Soccer Players: Exploring the Associations of a Web Application-Based Score With Recognized Load Measures. *European Journal of Sport Science*, 25(9). <https://doi.org/10.1002/ejsc.70031>
- Aoki, M. S., Arruda, A. F. S., Freitas, C. G., Miloski, B., Marcelino, P. R., Drago, G., Drago, M., & Moreira, A. (2016). Monitoring training loads, mood states, and jump performance over two periodized training mesocycles in elite young volleyball players. [Http://Dx.Doi.Org/10.1177/1747954116684394](http://Dx.Doi.Org/10.1177/1747954116684394), 12(1), 130–137. <https://doi.org/10.1177/1747954116684394>
- Arcos, A. L., Martínez-Santos, R., Yanci, J., Mendiguchia, J., & Méndez-Villanueva, A. (2015). Negative Associations between Perceived Training Load, Volume and Changes in Physical Fitness in Professional Soccer Players. *Journal of Sports Science & Medicine*, 14(2), 394. [/pmc/articles/PMC4424470/](https://pubmed.ncbi.nlm.nih.gov/24424470/)
- Armstrong, L. E., & VanHeest, J. L. (2002). The unknown mechanism of the overtraining syndrome: clues from depression and psychoneuroimmunology. *Sports Medicine (Auckland, N.Z.)*, 32(3), 185–209. <https://doi.org/10.2165/00007256-200232030-00003>

- Atkins, R., Lam, W.-K., Scanlan, A. T., Beaven, C. M., & Driller, M. (2020). Lower-body compression garments worn following exercise improves perceived recovery but not subsequent performance in basketball athletes. *Journal of Sports Sciences*, *38*(9), 961–969. <https://doi.org/10.1080/02640414.2020.1737387>
- Azmi, K., & Kusnanik, N. W. (2018). Effect of Exercise Program Speed, Agility, and Quickness (SAQ) in Improving Speed, Agility, and Acceleration. *Journal of Physics: Conference Series*, *947*, 012043. <https://doi.org/10.1088/1742-6596/947/1/012043>
- Bakdash, J. Z., & Marusich, L. R. (2017). Repeated Measures Correlation. *Frontiers in Psychology*, *8*. <https://doi.org/10.3389/fpsyg.2017.00456>
- Barrero, A., Schnell, F., Carrault, G., Kervio, G., Matelot, D., Carré, F., & Le Douairon Lahaye, S. (2019). Daily fatigue-recovery balance monitoring with heart rate variability in well-trained female cyclists on the Tour de France circuit. *PLOS ONE*, *14*(3), e0213472. <https://doi.org/10.1371/journal.pone.0213472>
- Batterham, A. M., & Hopkins, W. G. (2006). Making meaningful inferences about magnitudes. *International Journal of Sports Physiology and Performance*, *1*(1), 50–57. <http://www.ncbi.nlm.nih.gov/pubmed/19114737>
- Bauer, J., Muehlbauer, T., Geiger, S., & Gruber, M. (2024). Interaction between the leg recovery test and subjective measures of fatigue in handball players: short-, mid-, and long-term assessment. *Frontiers in Sports and Active Living*, *6*. <https://doi.org/10.3389/fspor.2024.1474385>
- Beato, M., Madsen, E. E., Clubb, J., Emmonds, S., & Krstrup, P. (2024). Monitoring Readiness to Train and Perform in Female Football: Current Evidence and Recommendations for Practitioners. *International Journal of Sports Physiology and Performance*, *19*(3), 223–231. <https://doi.org/10.1123/ijsp.2023-0405>
- Bender, A. M., Lawson, D., Werthner, P., & Samuels, C. H. (2018). The Clinical Validation of the Athlete Sleep Screening Questionnaire: an Instrument to Identify Athletes that Need Further Sleep Assessment. *Sports Medicine - Open*, *4*(1), 23. <https://doi.org/10.1186/s40798-018-0140-5>
- Bishop, C., Jordan, M., Torres-Ronda, L., Loturco, I., Harry, J., Virgile, A., Mundy, P., Turner, A., & Comfort, P. (2023). Selecting Metrics That Matter: Comparing the Use of the Countermovement Jump for Performance Profiling, Neuromuscular Fatigue Monitoring, and Injury Rehabilitation Testing. *Strength & Conditioning Journal*, *45*(5), 545–553. <https://doi.org/10.1519/SSC.0000000000000772>
- Bloomfield, D. M., Magnano, A., Bigger, J. T., Rivadeneira, H., Parides, M., & Steinman, R. C. (2001). Comparison of spontaneous vs. metronome-guided breathing on assessment of vagal modulation using RR variability. *American Journal of Physiology-Heart and Circulatory Physiology*, *280*(3), H1145–H1150. <https://doi.org/10.1152/ajpheart.2001.280.3.H1145>
- Borg, G. (1970). Perceived exertion as an indicator of somatic stress. - PscNET. *Scandinavian Journal of Rehabilitation Medicine*, *2*(2), 92–98. <https://psycnet.apa.org/record/2018-29834-001>

- Borg, G. (1998). *Borg's Perceived Exertion and Pain Scales*. Human Kinetics.
- Borges, T. O., Moreira, A., Thiengo, C. R., Medrado, R. G. S. D., Titton, A., Lima, M. R., Marins, A. N., & Aoki, M. S. (2019). Training intensity distribution of young elite soccer players. *Revista Brasileira de Cineantropometria & Desempenho Humano*, 21. <https://doi.org/10.5007/1980-0037.2019V21E56955>
- Botonis, P. G., Smilios, I., & Toubekis, A. G. (2021). Supercompensation in Elite Water Polo: Heart Rate Variability and Perceived Recovery. *Sports Medicine International Open*, 5(02), E53–E58. <https://doi.org/10.1055/a-1494-9254>
- Boullosa, D. A., Abreu, L., Nakamura, F. Y., Muñoz, V. E., Domínguez, E., & Leicht, A. S. (2013). Cardiac Autonomic Adaptations in Elite Spanish Soccer Players During Preseason. *International Journal of Sports Physiology and Performance*, 8(4), 400–409. <https://doi.org/10.1123/ijsp.8.4.400>
- Bourdon, P. C., Cardinale, M., Murray, A., Gatin, P., Kellmann, M., Varley, M. C., Gabbett, T. J., Coutts, A. J., Burgess, D. J., Gregson, W., & Cable, N. T. (2017). Monitoring Athlete Training Loads: Consensus Statement. *International Journal of Sports Physiology and Performance*, 12(Suppl 2), 161–170. <https://doi.org/10.1123/IJSPP.2017-0208>
- Brasch, M. T., Neeld, K. L., Konkol, K., & Pettitt, R. (2019). Value of Wellness Ratings and Countermovement Jumping Velocity to Monitor Performance. *International Journal of Exercise Science*, 12(4), 88–99.
- Bucher Sandbakk, S., Walther, J., Solli, G. S., Tønnessen, E., & Haugen, T. (2023). Training Quality—What Is It and How Can We Improve It? *International Journal of Sports Physiology and Performance*, 18(5), 557–560. <https://doi.org/10.1123/ijsp.2022-0484>
- Buchheit, M. (2008). The 30-15 intermittent fitness test: accuracy for individualizing interval training of young intermittent sport players. *Journal of Strength and Conditioning Research*, 22(2), 365–374. <https://doi.org/10.1519/JSC.0B013E3181635B2E>
- Buchheit, M. (2014). Sensitivity of Monthly Heart Rate and Psychometric Measures for Monitoring Physical Performance in Highly Trained Young Handball Players. *International Journal of Sports Medicine*, 36(05), 351–356. <https://doi.org/10.1055/s-0034-1385882>
- Buchheit, M., Racinais, S., Bilsborough, J. C., Bourdon, P. C., Voss, S. C., Hocking, J., Cordy, J., Mendez-Villanueva, A., & Coutts, A. J. (2013). Monitoring fitness, fatigue and running performance during a pre-season training camp in elite football players. *Journal of Science and Medicine in Sport*, 16(6), 550–555. <https://doi.org/10.1016/J.JSAMS.2012.12.003>
- Carrasco-Poyatos, M., González-Quílez, A., Martínez-González-Moro, I., & Granero-Gallegos, A. (2020). HRV-Guided Training for Professional Endurance Athletes: A Protocol for a Cluster-Randomized Controlled Trial. *International Journal of Environmental Research and Public Health*, 17(15), 5465. <https://doi.org/10.3390/ijerph17155465>

- Casamichana, D., Castellano, J., Calleja-Gonzalez, J., San Román, J., & Castagna, C. (2013). Relationship Between Indicators of Training Load in Soccer Players. *Journal of Strength and Conditioning Research*, 27(2), 369–374. <https://doi.org/10.1519/JSC.0b013e3182548af1>
- Chen, Y., Buggy, C., & Kelly, S. (2019). Winning at all costs: a review of risk-taking behaviour and sporting injury from an occupational safety and health perspective. *Sports Medicine - Open* 2019 5:1, 5(1), 1–21. <https://doi.org/10.1186/S40798-019-0189-9>
- Claudino, J. G., Cronin, J., Mezêncio, B., McMaster, D. T., McGuigan, M., Tricoli, V., Amadio, A. C., & Serrão, J. C. (2017). The countermovement jump to monitor neuromuscular status: A meta-analysis. *Journal of Science and Medicine in Sport*, 20(4), 397–402. <https://doi.org/10.1016/j.jsams.2016.08.011>
- Clemente, F. M., Bredt, S. da G. T., Praça, G. M., Duarte, E., & Mendes, B. (2020). Relationships between wellness status and perceived training load on daily and weekly bases over a basketball season. *Kinesiology*, 52(1.), 151–156. <https://doi.org/10.26582/K.52.1.18>
- Clemente, F. M., Clark, C., Castillo, D., Sarmiento, H., Nikolaidis, P. T., Rosemann, T., & Knechtle, B. (2019). Variations of training load, monotony, and strain and dose-response relationships with maximal aerobic speed, maximal oxygen uptake, and isokinetic strength in professional soccer players. *PloS One*, 14(12). <https://doi.org/10.1371/JOURNAL.PONE.0225522>
- Clemente, F. M., Mendes, B., Nikolaidis, P. T., Calvete, F., Carriço, S., & Owen, A. L. (2017). Internal training load and its longitudinal relationship with seasonal player wellness in elite professional soccer. *Physiology & Behavior*, 179, 262–267. <https://doi.org/10.1016/J.PHYSBEH.2017.06.021>
- Clemente, F. M., Silva, A. F., Clark, C. C. T., Conte, D., Ribeiro, J., Mendes, B., & Lima, R. (2020). Analyzing the Seasonal Changes and Relationships in Training Load and Wellness in Elite Volleyball Players. *International Journal of Sports Physiology and Performance*, 15(5), 731–740. <https://doi.org/10.1123/IJSP.2019-0251>
- Clemente, F. M., Silva, R., Castillo, D., Los Arcos, A., Mendes, B., & Afonso, J. (2020). Weekly Load Variations of Distance-Based Variables in Professional Soccer Players: A Full-Season Study. *International Journal of Environmental Research and Public Health*, 17(9), 3300. <https://doi.org/10.3390/ijerph17093300>
- Cohen, J. (1992). Statistical Power Analysis. *Current Directions in Psychological Science*, 1(3), 98–101. <https://doi.org/10.1111/1467-8721.ep10768783>
- Concheiro-Moscoso, P., Groba, B., Alvarez-Estevéz, D., Miranda-Duro, M. del C., Pousada, T., Nieto-Riveiro, L., Mejuto-Muiño, F. J., & Pereira, J. (2023). Quality of Sleep Data Validation From the Xiaomi Mi Band 5 Against Polysomnography: Comparison Study. *Journal of Medical Internet Research*, 25, e42073. <https://doi.org/10.2196/42073>
- Concheiro-Moscoso, P., Groba, B., Martínez-Martínez, F. J., Miranda-Duro, M. del C., Nieto-Riveiro, L., Pousada, T., & Pereira, J. (2022). Use of the Xiaomi Mi Band for sleep

- monitoring and its influence on the daily life of older people living in a nursing home. *DIGITAL HEALTH*, 8, 205520762211211. <https://doi.org/10.1177/20552076221121162>
- Coutts, J. A., Crowcroft, S., & Kempton, T. (2017). Developing athlete monitoring systems: Theoretical basis and practical applications. In M. Kellman & J. Beckmann (Eds.), *Sport, Recovery, and Performance*. Routledge.
- Coyne, J., Coutts, A., Newton, R., & Haff, G. G. (2021). Training Load, Heart Rate Variability, Direct Current Potential and Elite Long Jump Performance Prior and during the 2016 Olympic Games. *Journal of Sports Science and Medicine*, 482–491. <https://doi.org/10.52082/jssm.2021.482>
- Coyne, J. O. C., Coutts, A. J., Newton, R. U., & Haff, G. G. (2022). The Current State of Subjective Training Load Monitoring: Follow-Up and Future Directions. *Sports Medicine - Open*, 8(1), 53. <https://doi.org/10.1186/s40798-022-00433-y>
- Cruz, I. de F., Pereira, L. A., Kobal, R., Kitamura, K., Cedra, C., Loturco, I., & Abad, C. C. C. (2018). Perceived training load and jumping responses following nine weeks of a competitive period in young female basketball players. *PeerJ*, 6(7). <https://doi.org/10.7717/PEERJ.5225>
- Cunha, L. A., Costa, J. A., Marques, E. A., Brito, J., Lastella, M., & Figueiredo, P. (2023). The Impact of Sleep Interventions on Athletic Performance: A Systematic Review. *Sports Medicine - Open*, 9(1), 58. <https://doi.org/10.1186/s40798-023-00599-z>
- Curtis, R. M., Huggins, R. A., Benjamin, C. L., Sekiguchi, Y., Adams, W. M., Arent, S. M., Jain, R., Miller, S. J., Walker, A. J., & Casa, D. J. (2020). Contextual Factors Influencing External and Internal Training Loads in Collegiate Men's Soccer. *Journal of Strength and Conditioning Research*, 34(2), 374–381. <https://doi.org/10.1519/JSC.0000000000003361>
- Dalen, T., Jørgen, I., Gertjan, E., Geir Havard, H., & Ulrik, W. (2016). Player Load, Acceleration, and Deceleration During Forty-Five Competitive Matches of Elite Soccer. *Journal of Strength and Conditioning Research*, 30(2), 351–359. <https://doi.org/10.1519/JSC.0000000000001063>
- de Araujo, G. H. O., Figueiredo, D. H., Figueiredo, D. H., Kauffman, A. P., Peserico, C. S., & Machado, F. A. (2022). Effect of 3-week progressive overloading and 1-week tapering on performance, internal training load, stress tolerance and heart rate variability in under-19 Brazilian badminton players. *Archivos de Medicina Del Deporte*, 39(4), 190–197. <https://doi.org/10.18176/archmeddeporte.00090>
- Djaoui, L., Haddad, M., Chamari, K., & Dellal, A. (2017). Monitoring training load and fatigue in soccer players with physiological markers. *Physiology and Behavior*, 181, 86–94. <https://doi.org/10.1016/j.physbeh.2017.09.004>
- Drew, M. K., Raysmith, B. P., & Charlton, P. C. (2017). Injuries impair the chance of successful performance by sportspeople: a systematic review. *British Journal of Sports Medicine*, 51(16), 1209–1214. <https://doi.org/10.1136/bjsports-2016-096731>

- Driller, M. W., Mah, C. D., & Halson, S. L. (2018). Development of the athlete sleep behavior questionnaire: A tool for identifying maladaptive sleep practices in elite athletes. *Sleep Science, 11*(01), 37–44. <https://doi.org/10.5935/1984-0063.20180009>
- Eggenberger, P., Buffat, N., Weber, T., Gubler, R., & Brunner, E. (2024). Recovery and stress monitoring in elite ice hockey: A longitudinal pilot-study. *Current Issues in Sport Science (CISS), 9*(2), 038. <https://doi.org/10.36950/2024.2ciss038>
- Ekstrand, J., Spreco, A., Windt, J., & Khan, K. M. (2020). Are Elite Soccer Teams' Preseason Training Sessions Associated With Fewer In-Season Injuries? A 15-Year Analysis From the Union of European Football Associations (UEFA) Elite Club Injury Study. *The American Journal of Sports Medicine, 48*(3), 723–729. <https://doi.org/10.1177/0363546519899359>
- Eliakim, E., Doron, O., Meckel, Y., Nemet, D., & Eliakim, A. (2018). Pre-season Fitness Level and Injury Rate in Professional Soccer – A Prospective Study. *Sports Medicine International Open, 02*(03), E84–E90. <https://doi.org/10.1055/a-0631-9346>
- Enoka, R. M., & Duchateau, J. (2016). Translating Fatigue to Human Performance. *Medicine & Science in Sports & Exercise, 48*(11), 2228–2238. <https://doi.org/10.1249/MSS.0000000000000929>
- Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*(2), 175–191. <http://www.ncbi.nlm.nih.gov/pubmed/17695343>
- Ferreira, A. B. de M., Ribeiro, B. L. L., Batista, E. dos S., Dantas, M. P., & Mortatti, A. L. (2023). The Influence of Different Training Load Magnitudes on Sleep Pattern, Perceived Recovery, and Stress Tolerance in Young Soccer Players. *Journal of Strength & Conditioning Research, 37*(2), 351–357. <https://doi.org/10.1519/JSC.0000000000004235>
- Fessi, M. S., Nouira, S., Dellal, A., Owen, A., Elloumi, M., & Moalla, W. (2016). Changes of the psychophysical state and feeling of wellness of professional soccer players during pre-season and in-season periods. *Research in Sports Medicine (Print), 24*(4), 375–386. <https://doi.org/10.1080/15438627.2016.1222278>
- Fessi, M. S., Zarrouk, N., Di Salvo, V., Filetti, C., Barker, A. R., & Moalla, W. (2016). Effects of tapering on physical match activities in professional soccer players. *Journal of Sports Sciences, 34*(24), 2189–2194. <https://doi.org/10.1080/02640414.2016.1171891>
- Fessi, M. S., Zarrouk, N., Filetti, C., Rebai, H., Elloumi, M., & Moalla, W. (2016). Physical and anthropometric changes during pre- and in-season in professional soccer players. *The Journal of Sports Medicine and Physical Fitness, 56*(10), 1163–1170.
- Figueiredo, D. H., Figueiredo, D. H., Moreira, A., Gonçalves, H. R., & Stanganelli, L. C. R. (2019). Effect of Overload and Tapering on Individual Heart Rate Variability, Stress Tolerance, and Intermittent Running Performance in Soccer Players During a Preseason. *Journal of Strength and Conditioning Research, 33*(5), 1222–1231. <https://doi.org/10.1519/JSC.0000000000003127>

- Flatt, A. A., & Esco, M. R. (2016). Evaluating Individual Training Adaptation With Smartphone-Derived Heart Rate Variability in a Collegiate Female Soccer Team. *Journal of Strength and Conditioning Research*, *30*(2), 378–385. <https://doi.org/10.1519/JSC.0000000000001095>
- Flatt, A. A., Esco, M. R., & Nakamura, F. Y. (2017). Individual Heart Rate Variability Responses to Preseason Training in High Level Female Soccer Players. *Journal of Strength and Conditioning Research*, *31*(2), 531–538. <https://doi.org/10.1519/JSC.0000000000001482>
- Flatt, A. A., & Howells, D. (2019). Effects of varying training load on heart rate variability and running performance among an Olympic rugby sevens team. *Journal of Science and Medicine in Sport*, *22*(2), 222–226. <https://doi.org/10.1016/j.jsams.2018.07.014>
- Foster, C. (1998). Monitoring training in athletes with reference to overtraining syndrome. *Medicine and Science in Sports and Exercise*, *30*(7), 1164–1168. <https://doi.org/10.1097/00005768-199807000-00023>
- Foster, C., Florhaug, J. A., Franklin, J., Gottschall, L., Hrovatin, L. A., Parker, S., Doleshal, P., & Dodge, C. (2001). A New Approach to Monitoring Exercise Training. *Journal of Strength and Conditioning Research*, *15*(1), 109–115. [https://doi.org/10.1519/1533-4287\(2001\)015<0109:ANATME>2.0.CO;2](https://doi.org/10.1519/1533-4287(2001)015<0109:ANATME>2.0.CO;2)
- Foster, C., Rodriguez-Marroyo, J. A., & De Koning, J. J. (2017). Monitoring Training Loads: The Past, the Present, and the Future. *International Journal of Sports Physiology and Performance*, *12*(Suppl 2), 2–8. <https://doi.org/10.1123/IJSP.2016-0388>
- Freitas, V. H., Nakamura, F. Y., Miloski, B., Samulski, D., & Bara-Filho, M. G. (2014). Sensitivity of Physiological and Psychological Markers to Training Load Intensification in Volleyball Players. *Journal of Sports Science & Medicine*, *13*(3), 571. [/pmc/articles/PMC4126294/](https://pubmed.ncbi.nlm.nih.gov/24126294/)
- Fullagar, H. H. K., Duffield, R., Skorski, S., Coutts, A. J., Julian, R., & Meyer, T. (2015). Sleep and Recovery in Team Sport: Current Sleep-Related Issues Facing Professional Team-Sport Athletes. *International Journal of Sports Physiology and Performance*, *10*(8), 950–957. <https://doi.org/10.1123/IJSP.2014-0565>
- Gabbett, T. J. (2016). The training-injury prevention paradox: should athletes be training smarter and harder? *British Journal of Sports Medicine*, *50*(5), 273–280. <https://doi.org/10.1136/BJSPORTS-2015-095788>
- Garrett, J., Graham, S. R., Eston, R. G., Burgess, D. J., Garrett, L. J., Jakeman, J., & Norton, K. (2019). A Novel Method of Assessment for Monitoring Neuromuscular Fatigue in Australian Rules Football Players. *International Journal of Sports Physiology and Performance*, *14*(5), 598–605. <https://doi.org/10.1123/ijsp.2018-0253>
- Gathercole, R., Sporer, B., & Stellingwerff, T. (2015). Countermovement Jump Performance with Increased Training Loads in Elite Female Rugby Athletes. *International Journal of Sports Medicine*, *36*(09), 722–728. <https://doi.org/10.1055/s-0035-1547262>
- Gdovin, J. R., Galloway, R., Tomasiello, L. S., Seabolt, M., & Booker, R. (2023). External Training Load Monitoring and the Impact on Training Load Management in Collegiate

- Male Soccer Players. *Journal of Strength & Conditioning Research*, 37(7), 1434–1439.
<https://doi.org/10.1519/JSC.0000000000004080>
- Gisselman, A. S., Baxter, G. D., Wright, A., Hegedus, E., & Tumilty, S. (2016). Musculoskeletal overuse injuries and heart rate variability: Is there a link? *Medical Hypotheses*, 87, 1–7. <https://doi.org/10.1016/j.mehy.2015.12.003>
- Gualtieri, A., Rampinini, E., Dello Iacono, A., & Beato, M. (2023). High-speed running and sprinting in professional adult soccer: Current thresholds definition, match demands and training strategies. A systematic review. *Frontiers in Sports and Active Living*, 5. <https://doi.org/10.3389/fspor.2023.1116293>
- Guridi Lopategui, I., Castellano Paulis, J., & Echeazarra Escudero, I. (2021). Physical Demands and Internal Response in Football Sessions According to Tactical Periodization. *International Journal of Sports Physiology and Performance*, 16(6), 858–864. <https://doi.org/10.1123/ijsp.2019-0829>
- Halson, S. L. (2014). Monitoring Training Load to Understand Fatigue in Athletes. *Sports Medicine*, 44(S2), 139–147. <https://doi.org/10.1007/s40279-014-0253-z>
- Halson, S. L. (2019). Sleep Monitoring in Athletes: Motivation, Methods, Miscalculations and Why it Matters. *Sports Medicine (Auckland, N.Z.)*, 49(10), 1487–1497. <https://doi.org/10.1007/s40279-019-01119-4>
- Halson, S. L., Johnston, R. D., Piromalli, L., Lalor, B. J., Cormack, S., Roach, G. D., & Sargent, C. (2022). Sleep Regularity and Predictors of Sleep Efficiency and Sleep Duration in Elite Team Sport Athletes. *Sports Medicine - Open*, 8(1), 79. <https://doi.org/10.1186/s40798-022-00470-7>
- Hamlin, M. J., Deuchrass, R. W., Olsen, P. D., Choukri, M. A., Marshall, H. C., Lizamore, C. A., Leong, C., & Elliot, C. A. (2021). The Effect of Sleep Quality and Quantity on Athlete's Health and Perceived Training Quality. *Frontiers in Sports and Active Living*, 3. <https://doi.org/10.3389/fspor.2021.705650>
- Hattersley, C., Wells, C., Blagrove, R., Trangmar, S., & Patterson, S. (2018). Impact of Fixture Congestion on Indices of Performance & Recovery in Youth Soccer Players. *Sport Performance & Science Reports*.
- Hautala, A. J., Kiviniemi, A. M., & Tulppo, M. P. (2009). Individual responses to aerobic exercise: The role of the autonomic nervous system. *Neuroscience & Biobehavioral Reviews*, 33(2), 107–115. <https://doi.org/10.1016/j.neubiorev.2008.04.009>
- Hecksteden, A., Kellner, R., & Donath, L. (2022). Dealing with small samples in football research. *Science and Medicine in Football*, 6(3), 389–397. <https://doi.org/10.1080/24733938.2021.1978106>
- Hills, S. P., & Rogerson, D. J. (2018). Associations Between Self-Reported Well-being and Neuromuscular Performance During a Professional Rugby Union Season. *Journal of Strength and Conditioning Research*, 32(9), 2498–2509. <https://doi.org/10.1519/JSC.0000000000002531>

- Hody, S., Croisier, J.-L., Bury, T., Rogister, B., & Leprince, P. (2019). Eccentric Muscle Contractions: Risks and Benefits. *Frontiers in Physiology, 10*. <https://doi.org/10.3389/fphys.2019.00536>
- Holmes, C. J., Wind, S. A., & Esco, M. R. (2018). Heart Rate Variability Responses to an Undulating Resistance Training Program in Free-Living Conditions: A Case Study in a Collegiate Athlete. *Sports, 6*(4), 121. <https://doi.org/10.3390/sports6040121>
- Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive Statistics for Studies in Sports Medicine and Exercise Science. *Medicine & Science in Sports & Exercise, 41*(1), 3–12. <https://doi.org/10.1249/MSS.0b013e31818cb278>
- Hu, Y., Visser, M., & Kaiser, S. (2020). Perceived Stress and Sleep Quality in Midlife and Later: Controlling for Genetic and Environmental Influences. *Behavioral Sleep Medicine, 18*(4), 537–549. <https://doi.org/10.1080/15402002.2019.1629443>
- Impellizzeri, F. M., Marcora, S. M., & Coutts, A. J. (2019). Internal and External Training Load: 15 Years On. *International Journal of Sports Physiology and Performance, 14*(2), 270–273. <https://doi.org/10.1123/ijsp.2018-0935>
- Impellizzeri, F. M., Menaspà, P., Coutts, A. J., Kalkhoven, J., & Menaspà, M. J. (2020). Training Load and Its Role in Injury Prevention, Part I: Back to the Future. *Journal of Athletic Training, 55*(9), 885–892. <https://doi.org/10.4085/1062-6050-500-19>
- Jaspers, A., Brink, M. S., Probst, S. G. M., Frencken, W. G. P., & Helsen, W. F. (2017). Relationships Between Training Load Indicators and Training Outcomes in Professional Soccer. *Sports Medicine, 47*(3), 533–544. <https://doi.org/10.1007/s40279-016-0591-0>
- Jeong, T.-S., Reilly, T., Morton, J., Bae, S.-W., & Drust, B. (2011). Quantification of the physiological loading of one week of “pre-season” and one week of “in-season” training in professional soccer players. *Journal of Sports Sciences, 29*(11), 1161–1166. <https://doi.org/10.1080/02640414.2011.583671>
- Johnston, R. D., Gibson, N. V., Twist, C., Gabbett, T. J., MacNay, S. A., & MacFarlane, N. G. (2013). Physiological responses to an intensified period of rugby league competition. *Journal of Strength and Conditioning Research, 27*(3), 643–654. <https://doi.org/10.1519/JSC.0B013E31825BB469>
- Kamandulis, S., Juodsnukis, A., Stanislovaitiene, J., Zuoziene, I. J., Bogdelis, A., Mickevicius, M., Eimantas, N., Snieckus, A., Olstad, B. H., & Venckunas, T. (2020). Daily Resting Heart Rate Variability in Adolescent Swimmers during 11 Weeks of Training. *International Journal of Environmental Research and Public Health, 17*(6), 2097. <https://doi.org/10.3390/ijerph17062097>
- Kasper, K. (2019). Sports Training Principles. *Current Sports Medicine Reports, 18*(4), 95–96. <https://doi.org/10.1249/JSR.0000000000000576>
- Kellmann, M., Bertollo, M., Bosquet, L., Brink, M., Coutts, A. J., Duffield, R., Erlacher, D., Halson, S. L., Hecksteden, A., Heidari, J., Kallus, K. W., Meeusen, R., Mujika, I., Robazza, C., Skorski, S., Venter, R., & Beckmann, J. (2018). Recovery and Performance in Sport: Consensus Statement. *International Journal of Sports Physiology and Performance, 13*(2), 240–245. <https://doi.org/10.1123/ijsp.2017-0759>

- Kenttä, G., & Hassmén, P. (1998). Overtraining and recovery. A conceptual model. *Sports Medicine (Auckland, N.Z.)*, 26(1), 1–16. <https://doi.org/10.2165/00007256-199826010-00001>
- Kirkman, B. L., & Chen, G. (2011). Maximizing Your Data or Data Slicing? Recommendations for Managing Multiple Submissions from the Same Dataset. *Management and Organization Review*, 7(3), 433–446. <https://doi.org/10.1111/j.1740-8784.2011.00228.x>
- Knihs, D. A., Detanico, D., Silva, D. R. da, & Dal Pupo, J. (2021). Reliability and sensitivity of countermovement jump-derived variables in detecting different fatigue levels. *Journal of Physical Education*. <https://doi.org/10.4025/jphyseduc.v32i1.3232>
- Kobal, R., Carvalho, L., Abad, C. C., Faust, B., Rossetti, M., Saito, T., Klosterhoff, R. R., De Souza, E. O., & Barroso Renato. (2022). Preseason in soccer: a paradox between a high volume of technical/tactical training and improvement in the neuromuscular performance of elite women soccer players. *The Journal of Sports Medicine and Physical Fitness*, 62(6). <https://doi.org/10.23736/S0022-4707.21.12427-2>
- Kovacevic, Z., Zuvela, F., & Kuvacic, G. (2018). Metric Characteristics of Tests Assessing Speed and Agility in Youth Soccer Players. *Sport Mont*, 16(3), 9–14. <https://doi.org/10.26773/smj.181002>
- Kyle, U. G., Bosaeus, I., De Lorenzo, A. D., Deurenberg, P., Elia, M., Manuel Gómez, J., Lilienthal Heitmann, B., Kent-Smith, L., Melchior, J.-C., Pirlich, M., Scharfetter, H., M.W.J Schols, A., Pichard, C., & ESPEN. (2004). Bioelectrical impedance analysis—part II: utilization in clinical practice. *Clinical Nutrition*, 23(6), 1430–1453. <https://doi.org/10.1016/j.clnu.2004.09.012>
- Lambert, E. V, St Clair Gibson, A., & Noakes, T. D. (2005). Complex systems model of fatigue: integrative homeostatic control of peripheral physiological systems during exercise in humans. *British Journal of Sports Medicine*, 39(1), 52–62. <https://doi.org/10.1136/bjism.2003.011247>
- Lechner, S., Ammar, A., Boukhris, O., Trabelsi, K., M Glenn, J., Schwarz, J., Hammouda, O., Zmijewski, P., Chtourou, H., Driss, T., & Hoekelmann, A. (2023). Monitoring training load in youth soccer players: effects of a six-week preparatory training program and the associations between external and internal loads. *Biology of Sport*, 40(1), 63–75. <https://doi.org/10.5114/biol sport.2023.112094>
- Los Arcos, A., Martínez-Santos, R., Clemente, F. M., & Castillo, D. (2020). Changes in jump and sprint performances during 14 preseasons in a Spanish reserve elite soccer team. *Kinesiology*, 52(2), 224–231. <https://doi.org/10.26582/k.52.2.10>
- Lovell, T. W. J., Sirotic, A. C., Impellizzeri, F. M., & Coutts, A. J. (2013). Factors affecting perception of effort (session rating of perceived exertion) during rugby league training. *International Journal of Sports Physiology and Performance*, 8(1), 62–69. <https://doi.org/10.1123/IJSP.8.1.62>

- Lundstrom, C. J., Foreman, N. A., & Biltz, G. (2023). Practices and Applications of Heart Rate Variability Monitoring in Endurance Athletes. *International Journal of Sports Medicine*, 44(01), 9–19. <https://doi.org/10.1055/a-1864-9726>
- M. Oliva-Lozano, J., Riboli, A., Fortes, V., & M. Muyor, J. (2023). Monitoring physical match performance relative to peak locomotor demands: implications for training professional soccer players. *Biology of Sport*, 40(2), 253–260. <https://doi.org/10.5114/biol sport.2023.116450>
- Macedo, A. G., Almeida, T. A. F., Massini, D. A., de Oliveira, D. M., Espada, M. C., Robalo, R. A. M., Hernández-Beltrán, V., Gamonales, J. M., Vilela Terra, A. M. S., & Pessôa Filho, D. M. (2024). Load Monitoring Methods for Controlling Training Effectiveness on Physical Conditioning and Planning Involvement: A Narrative Review. *Applied Sciences*, 14(22), 10465. <https://doi.org/10.3390/app142210465>
- Maleš, J., Ouergui, I., Kuna, D., Žuvela, F., De Giorgio, A., & Kuvačić, G. (2022). Monitoring Internal Training Intensity Correlated with Neuromuscular and Well-Being Status in Croatian Professional Soccer Players during Five Weeks of the Pre-Season Training Phase. *Sports (Basel, Switzerland)*, 10(11). <https://doi.org/10.3390/SPORTS10110172>
- Malone, J. J., Murtagh, C. F., Morgans, R., Burgess, D. J., Morton, J. P., & Drust, B. (2015). Countermovement Jump Performance Is Not Affected During an In-Season Training Microcycle in Elite Youth Soccer Players. *Journal of Strength and Conditioning Research*, 29(3), 752–757. <https://doi.org/10.1519/JSC.0000000000000701>
- Malone, S., Owen, A., Newton, M., Mendes, B., Collins, K. D., & Gabbett, T. J. (2017). The acute:chronic workload ratio in relation to injury risk in professional soccer. *Journal of Science and Medicine in Sport*, 20(6), 561–565. <https://doi.org/10.1016/J.JSAMS.2016.10.014>
- Malone, S., Owen, A., Newton, M., Mendes, B., Tiernan, L., Hughes, B., & Collins, K. (2018). Wellbeing perception and the impact on external training output among elite soccer players. *Journal of Science and Medicine in Sport*, 21(1), 29–34. <https://doi.org/10.1016/J.JSAMS.2017.03.019>
- Mandorino, M., Figueiredo, A. J., Cima, G., & Tessitore, A. (2022). Analysis of Relationship between Training Load and Recovery Status in Adult Soccer Players: a Machine Learning Approach. *International Journal of Computer Science in Sport*, 21(2), 1–16. <https://doi.org/10.2478/ijcss-2022-0007>
- Manuel Clemente, F., Ramirez-Campillo, R., Nakamura, F. Y., & Sarmiento, H. (2021). Effects of high-intensity interval training in men soccer player's physical fitness: A systematic review with meta-analysis of randomized-controlled and non-controlled trials. *Journal of Sports Sciences*, 39(11), 1202–1222. <https://doi.org/10.1080/02640414.2020.1863644>
- Manzi, V., Bovenzi, A., Impellizzeri, M. F., Carminati, I., & Castagna, C. (2013). Individual training-load and aerobic-fitness variables in premiership soccer players during the precompetitive season. *Journal of Strength and Conditioning Research*, 27(3), 631–636. <https://doi.org/10.1519/JSC.0B013E31825DBD81>

- Marco-Contreras, L. A., Bachero-Mena, B., Rodríguez-Rosell, D., & González-Badillo, J. J. (2021). Load Index and Vertical Jump to Monitor Neuromuscular Fatigue in an Elite 800-m Athlete. *International Journal of Sports Physiology and Performance*, *16*(9), 1354–1358. <https://doi.org/10.1123/ijsp.2020-0474>
- Marrier, B., Meur, Y. Le, Robineau, J., Lacombe, M., Couderc, A., Hausswirth, C., Piscione, J., & Morin, J. B. (2017). Quantifying Neuromuscular Fatigue Induced by an Intense Training Session in Rugby Sevens. *International Journal of Sports Physiology and Performance*, *12*(2), 218–223. <https://doi.org/10.1123/IJSPP.2016-0030>
- Martin, M., Rampinini, E., Bosio, A., Azzalin, A., McCall, A., & Ward, P. (2023). Relationships Between Internal and External Load Measures and Fitness Level Changes in Professional Soccer Players. *Research Quarterly for Exercise and Sport*, *94*(3), 760–772. <https://doi.org/10.1080/02701367.2022.2053646>
- Martinho, D. V., Rebelo, A., Field, A., Ribeiro, A. S., Pereira, F., Bizarro, B., Ribeiro, J., Len, S. M., Gouveia, É. R., & Sarmiento, H. (2024). The Quantification of Physical Performance and Internal Training Load in Youth Male Soccer Players During Preseason. *International Journal of Sports Physiology and Performance*, *19*(5), 480–486. <https://doi.org/10.1123/ijsp.2023-0312>
- Marusich, L. R., & Bakdash, J. Z. (2021). rmcrrShiny: A web and standalone application for repeated measures correlation. *F1000Research*, *10*, 697. <https://doi.org/10.12688/f1000research.55027.1>
- Matos, S., Clemente, F. M., Brandão, A., Pereira, J., Rosemann, T., Nikolaidis, P. T., & Knechtle, B. (2019). Training Load, Aerobic Capacity and Their Relationship With Wellness Status in Recreational Trail Runners. *Frontiers in Physiology*, *10*. <https://doi.org/10.3389/FPHYS.2019.01189>
- McGuigan, H., Hassmén, P., Rosic, N., & Stevens, C. J. (2020). Training monitoring methods used in the field by coaches and practitioners: A systematic review. *International Journal of Sports Science & Coaching*, *15*(3), 439–451. <https://doi.org/10.1177/1747954120913172>
- McKay, A. K. A., Stellingwerff, T., Smith, E. S., Martin, D. T., Mujika, I., Goosey-Tolfrey, V. L., Sheppard, J., & Burke, L. M. (2022). Defining Training and Performance Caliber: A Participant Classification Framework. *International Journal of Sports Physiology and Performance*, *17*(2), 317–331. <https://doi.org/10.1123/ijsp.2021-0451>
- McLean, B. D., Coutts, A. J., Kelly, V., McGuigan, M. R., & Cormack, S. J. (2010). Neuromuscular, endocrine, and perceptual fatigue responses during different length between-match microcycles in professional rugby league players. *International Journal of Sports Physiology and Performance*, *5*(3), 367–383. <https://doi.org/10.1123/IJSPP.5.3.367>
- Medeiros, A. R., Leicht, A. S., Michael, S., & Boulosa, D. (2021). Weekly vagal modulations and their associations with physical fitness and physical activity. *European Journal of Sport Science*, *21*(9), 1326–1336. <https://doi.org/10.1080/17461391.2020.1838619>

- Milanović, Z., Sporiš, G., James, N., Trajković, N., Ignjatović, A., Sarmiento, H., Trecroci, A., & Mendes, B. M. B. (2017). Physiological Demands, Morphological Characteristics, Physical Abilities and Injuries of Female Soccer Players. *Journal of Human Kinetics*, *60*(1), 77–83. <https://doi.org/10.1515/hukin-2017-0091>
- Miloski, B., De Freitas, V. H., Nakamura, F. Y., De A Nogueira, F. C., & Bara-Filho, M. G. (2016). Seasonal Training Load Distribution of Professional Futsal Players: Effects on Physical Fitness, Muscle Damage and Hormonal Status. *Journal of Strength and Conditioning Research*, *30*(6), 1525–1533. <https://doi.org/10.1519/JSC.0000000000001270>
- Miranda-Mendoza, J., Hernández-Cruz, G., Reynoso-Sánchez, L. F., González-Fimbres, R. A., & Cejas-Hernández, B. A. (2023). Control of recovery using the Total Quality Recovery (TQR) scale during four accumulation microcycles and its relationship to physiological factors. *Retos*, *50*, 1155–1162. <https://doi.org/10.47197/retos.v50.100290>
- Mishica, C., Kyröläinen, H., Hynynen, E., Nummela, A., Holmberg, H.-C., & Linnamo, V. (2022). Evaluation of nocturnal vs. morning measures of heart rate indices in young athletes. *PLOS ONE*, *17*(1), e0262333. <https://doi.org/10.1371/journal.pone.0262333>
- Moalla, W., Fessi, M. S., Farhat, F., Nour, S., Wong, D. P., & Dupont, G. (2016). Relationship between daily training load and psychometric status of professional soccer players. *Research in Sports Medicine (Print)*, *24*(4), 387–394. <https://doi.org/10.1080/15438627.2016.1239579>
- Mujika, I. (2017). Quantification of Training and Competition Loads in Endurance Sports: Methods and Applications. *International Journal of Sports Physiology and Performance*, *12*(Suppl 2), 9–17. <https://doi.org/10.1123/IJSP.2016-0403>
- Muñoz-López, A., Nakamura, F., & Naranjo Orellana, J. (2021). Soccer Matches but Not Training Sessions Disturb Cardiac-Autonomic Regulation During National Soccer Team Training Camps. *Research Quarterly for Exercise and Sport*, *92*(1), 43–51. <https://doi.org/10.1080/02701367.2019.1708843>
- Nakamura, F. Y., Costa, J. A., Travassos, B., Ortuño, D., & Pino-Ortega, J. (2023). Intraindividual Relationships Between Training Loads and Heart-Rate Variability in High-Level Female Futsal Players: A Longitudinal Study. *International Journal of Sports Physiology and Performance*, *18*(3), 306–312. <https://doi.org/10.1123/ijsp.2021-0500>
- Nakamura, F. Y., & Flatt, A. A. (2020). To vary or not to vary? Interpreting HRV in soccer players. *European Journal of Human Movement*, *45*, 1–3. <https://doi.org/10.21134/eurjhm.2020.45.0>
- Nakamura, F. Y., Pereira, L. A., Rabelo, F. N., Flatt, A. A., Esco, M. R., Bertollo, M., & Loturco, I. (2016). Monitoring weekly heart rate variability in futsal players during the preseason: the importance of maintaining high vagal activity. *Journal of Sports Sciences*, *34*(24), 2262–2268. <https://doi.org/10.1080/02640414.2016.1186282>
- Naughton, M., McLean, S., Scott, T. J., Weaving, D., & Solomon, C. (2021). Quantifying Fatigue in the Rugby Codes: The Interplay Between Collision Characteristics and

- Neuromuscular Performance, Biochemical Measures, and Self-Reported Assessments of Fatigue. *Frontiers in Physiology*, 12. <https://doi.org/10.3389/fphys.2021.711634>
- Navalta, J. W., & Stone, W. J. (2019). Ethical Issues Relating to Scientific Discovery in Exercise Science. *International Journal of Exercise Science*, 12(1), 1–8. <https://doi.org/10.70252/EYCD6235>
- Nobari, H., Alves, A. R., Haghghi, H., Clemente, F. M., Carlos-Vivas, J., Pérez-Gómez, J., & Ardigò, L. P. (2021). Association between Training Load and Well-Being Measures in Young Soccer Players during a Season. *International Journal of Environmental Research and Public Health*, 18(9). <https://doi.org/10.3390/IJERPH18094451>
- Nobari, H., Aquino, R., Clemente, F. M., Khalafi, M., Adsuar, J. C., & Pérez-Gómez, J. (2020). Description of acute and chronic load, training monotony and strain over a season and its relationships with well-being status: A study in elite under-16 soccer players. *Physiology & Behavior*, 225, 113117. <https://doi.org/10.1016/j.physbeh.2020.113117>
- Nobari, H., Banihashemi, M., Saedmocheshi, S., Prieto-González, P., & Oliveira, R. (2023). Overview of the impact of sleep monitoring on optimal performance, immune system function and injury risk reduction in athletes: A narrative review. *Science Progress*, 106(4). <https://doi.org/10.1177/00368504231206265>
- Nobari, H., Ceylan, H. İ., Khani, S., Öztürk, M. E., & Mainer-Pardos, E. (2022). Relationship Between Variations Accumulated Workload and Sprint Performance in Elite Adolescent Soccer Players. *Journal of Men's Health*, 18(7), 157. <https://doi.org/10.31083/J.JOMH1807157/1875-6859-18-7-157/FIG1.JPG>
- Nobari, H., Ramachandran, A. K., Brito, J. P., & Oliveira, R. (2022). Quantification of Pre-Season and In-Season Training Intensity across an Entire Competitive Season of Asian Professional Soccer Players. *Healthcare (Basel, Switzerland)*, 10(8). <https://doi.org/10.3390/HEALTHCARE10081367>
- Nobari, H., Silva, R., Akyildiz, Z., Günay, M., Clemente, F., Formenti, D., & Ardigò, L. (2022). Season jump performance and wellness variables in Turkish national youth wrestlers. *Human Movement*, 24(3). <https://doi.org/10.5114/HM.2023.116411>
- Noblet, A. J., & Gifford, S. M. (2002). The sources of stress experienced by professional Australian footballers. *Journal of Applied Sport Psychology*, 14(1), 1–13. <https://psycnet.apa.org/record/2002-12605-001>
- Nuetzel, B. (2025). Stress and its impact on elite athletes' wellbeing and mental health—a mini narrative review. *Frontiers in Sports and Active Living*, 7. <https://doi.org/10.3389/fspor.2025.1630784>
- Oliveira, R., Brito, J. P., Martins, A., Mendes, B., Marinho, D. A., Ferraz, R., & Marques, M. C. (2019). In-season internal and external training load quantification of an elite European soccer team. *PloS One*, 14(4). <https://doi.org/10.1371/JOURNAL.PONE.0209393>
- Op De Beéck, T., Jaspers, A., Brink, M. S., Frencken, W. G. P., Staes, F., Davis, J. J., & Helsen, W. F. (2019). Predicting Future Perceived Wellness in Professional Soccer: The

- Role of Preceding Load and Wellness. *International Journal of Sports Physiology and Performance*, 14(8), 1074–1080. <https://doi.org/10.1123/ijsp.2017-0864>
- Ouergui, I., Franchini, E., Selmi, O., Levitt, D. E., Chtourou, H., Bouhlel, E., & Ardigò, L. P. (2020). Relationship between Perceived Training Load, Well-Being Indices, Recovery State and Physical Enjoyment during Judo-Specific Training. *International Journal of Environmental Research and Public Health*, 17(20), 7400. <https://doi.org/10.3390/ijerph17207400>
- Owen, A. L., Djaoui, L., Newton, M., Malone, S., & Mendes, B. (2017). A contemporary multi-modal mechanical approach to training monitoring in elite professional soccer. *Science and Medicine in Football*, 1(3), 216–221. <https://doi.org/10.1080/24733938.2017.1334958>
- Owen, A. L., Forsyth, J. J., Wong, D. P., Dellal, A., Connelly, S. P., & Chamari, K. (2015). Heart Rate–Based Training Intensity and Its Impact on Injury Incidence Among Elite-Level Professional Soccer Players. *Journal of Strength and Conditioning Research*, 29(6), 1705–1712. <https://doi.org/10.1519/JSC.0000000000000810>
- Pereira, L. A., Freitas, T. T., Zanetti, V., & Loturco, I. (2022). Variations in Internal and External Training Load Measures and Neuromuscular Performance of Professional Soccer Players During a Preseason Training Period. *Journal of Human Kinetics*, 81(1), 149–162. <https://doi.org/10.2478/HUKIN-2022-0012>
- Prudholme, D. C., Coburn, J. W., Lynn, S. K., & Lockie, R. G. (2023). Relationships between Sprint, Acceleration, and Deceleration Metrics with Training Load in Division I Collegiate Women’s Soccer Players. *Journal of Human Kinetics*, 85(1), 53–62. <https://doi.org/10.2478/hukin-2022-0109>
- Rabbani, A., Baseri, M. K., Reisi, J., Clemente, F. M., & Kargarfard, M. (2018). Monitoring collegiate soccer players during a congested match schedule: Heart rate variability versus subjective wellness measures. *Physiology & Behavior*, 194, 527–531. <https://doi.org/10.1016/j.physbeh.2018.07.001>
- Rađa, A., Kuvacić, G., De Giorgio, A., Sellami, M., Ardigò, L. P., Bragazzi, N. L., & Padulo, J. (2019). The ball kicking speed: A new, efficient performance indicator in youth soccer. *PloS One*, 14(5), e0217101. <https://doi.org/10.1371/journal.pone.0217101>
- Rago, V., Brito, J., Figueiredo, P., Costa, J., Krstrup, P., & Rebelo, A. (2020). Internal training load monitoring in professional football: a systematic review of methods using rating of perceived exertion. *The Journal of Sports Medicine and Physical Fitness*, 60(1). <https://doi.org/10.23736/S0022-4707.19.10000-X>
- Rhini, M., Hickner, R. C., Naidoo, R., & Sookan-Kassie, T. (2025). Seasonal Variations in the Physical Fitness of South African Premier Soccer League Players over an Annual Training Macrocycle (Nine Months). *Journal of Functional Morphology and Kinesiology*, 10(1), 38. <https://doi.org/10.3390/jfmk10010038>
- Rico-González, M., Oliveira, R., González Fernández, F. T., & Clemente, F. M. (2022). Acute:chronic workload ratio and training monotony variations over the season in youth

soccer players: A systematic review. <https://doi.org/10.1177/17479541221104589>.
<https://doi.org/10.1177/17479541221104589>

- Ruf, L., Altmann, S., Müller, K., Rehborn, A., Schindler, F., Woll, A., & Härtel, S. (2024). Concurrent validity of countermovement and squat jump height assessed with a contact mat and force platform in professional soccer players. *Frontiers in Sports and Active Living*, 6. <https://doi.org/10.3389/fspor.2024.1437230>
- Sansone, P., Tschan, H., Foster, C., & Tessitore, A. (2018). Monitoring Training Load and Perceived Recovery in Female Basketball: Implications for Training Design. *Journal of Strength and Conditioning Research*, 34(10), 2929–2936. <https://doi.org/10.1519/JSC.0000000000002971>
- Sargent, C., Lastella, M., Halson, S. L., & Roach, G. D. (2021). How Much Sleep Does an Elite Athlete Need? *International Journal of Sports Physiology and Performance*, 16(12), 1746–1757. <https://doi.org/10.1123/ijsp.2020-0896>
- Saw, A. E., Main, L. C., & Gastin, P. B. (2015a). Impact of Sport Context and Support on the Use of a Self-Report Measure for Athlete Monitoring. *Journal of Sports Science & Medicine*, 14(4), 732–739.
- Saw, A. E., Main, L. C., & Gastin, P. B. (2015b). Monitoring athletes through self-report: factors influencing implementation. *Journal of Sports Science & Medicine*, 14(1), 137–146.
- Saw, A. E., Main, L. C., & Gastin, P. B. (2016). Monitoring the athlete training response: subjective self-reported measures trump commonly used objective measures: a systematic review. *British Journal of Sports Medicine*, 50(5), 281–291. <https://doi.org/10.1136/BJSPORTS-2015-094758>
- Schneider, C., Hanakam, F., Wiewelhove, T., Döweling, A., Kellmann, M., Meyer, T., Pfeiffer, M., & Ferrauti, A. (2018). Heart Rate Monitoring in Team Sports—A Conceptual Framework for Contextualizing Heart Rate Measures for Training and Recovery Prescription. *Frontiers in Physiology*, 9. <https://doi.org/10.3389/fphys.2018.00639>
- Schweltnus, M., Soligard, T., Alonso, J.-M., Bahr, R., Clarsen, B., Dijkstra, H. P., Gabbett, T. J., Gleeson, M., Häggglund, M., Hutchinson, M. R., Janse Van Rensburg, C., Meeusen, R., Orchard, J. W., Pluim, B. M., Raftery, M., Budgett, R., & Engebretsen, L. (2016). How much is too much? (Part 2) International Olympic Committee consensus statement on load in sport and risk of illness. *British Journal of Sports Medicine*, 50(17), 1043–1052. <https://doi.org/10.1136/bjsports-2016-096572>
- Seiler, K. S., & Kjerland, G. Ø. (2006). Quantifying training intensity distribution in elite endurance athletes: is there evidence for an “optimal” distribution? *Scandinavian Journal of Medicine & Science in Sports*, 16(1), 49–56. <https://doi.org/10.1111/J.1600-0838.2004.00418.X>
- Selmi, O., Gonçalves, B., Ouergui, I., Levitt, D. E., Sampaio, J., & Bouassida, A. (2021). Influence of Well-Being Indices and Recovery State on the Technical and Physiological

Aspects of Play During Small-Sided Games. *Journal of Strength and Conditioning Research*, 35(10), 2802–2809. <https://doi.org/10.1519/JSC.0000000000003228>

Selmi, O., Marzouki, H., Ouergui, I., BenKhalifa, W., & Bouassida, A. (2018). Influence of intense training cycle and psychometric status on technical and physiological aspects performed during the small-sided games in soccer players. *Research in Sports Medicine (Print)*, 26(4), 401–412. <https://doi.org/10.1080/15438627.2018.1492398>

Selmi, O., Ouergui, I., Levitt, D. E., Marzouki, H., Knechtle, B., Nikolaidis, P. T., & Bouassida, A. (2022). Training, psychometric status, biological markers and neuromuscular fatigue in soccer. *Biology of Sport*, 39(2), 319–327. <https://doi.org/10.5114/BIOLSPORT.2022.104065>

Selmi, O., Ouergui, I., Muscella, A., My, G., Marsigliante, S., Nobari, H., Suzuki, K., & Bouassida, A. (2022). Monitoring Psychometric States of Recovery to Improve Performance in Soccer Players: A Brief Review. *International Journal of Environmental Research and Public Health*, 19(15), 9385. <https://doi.org/10.3390/ijerph19159385>

Shankland, R., Kotsou, I., Cuny, C., Strub, L., & Brown, J. L. N. (2017). Reducing Current Limitations in Order to Enhance the Quality of Subjective Well-Being Research: The Example of Mindfulness. In G. Brulé & F. Maggino (Eds.), *Metrics of Subjective Well-Being: Limits and Improvements*. Springer International Publishing AG 2017.

Shushan, T., McLaren, S. J., Buchheit, M., Scott, T. J., Barrett, S., & Lovell, R. (2022). Submaximal Fitness Tests in Team Sports: A Theoretical Framework for Evaluating Physiological State. *Sports Medicine*, 52(11), 2605–2626. <https://doi.org/10.1007/s40279-022-01712-0>

Silva, H., Nakamura, F. Y., Beato, M., & Marcelino, R. (2023). Acceleration and deceleration demands during training sessions in football: a systematic review. *Science and Medicine in Football*, 7(3), 198–213. <https://doi.org/10.1080/24733938.2022.2090600>

Silva, J. R., Magalhães, J. F., Ascensão, A. A., Oliveira, E. M., Seabra, A. F., & Rebelo, A. N. (2011). Individual match playing time during the season affects fitness-related parameters of male professional soccer players. *Journal of Strength and Conditioning Research*, 25(10), 2729–2739. <https://doi.org/10.1519/JSC.0B013E31820DA078>

Silva, R. M., Clemente, F. M., González-Fernández, F. T., Nobari, H., Oliveira, R., Silva, A. F., & Cancela-Carral, J. M. (2022). Relationships between Internal Training Intensity and Well-Being Changes in Youth Football Players. *Healthcare 2022, Vol. 10, Page 1814*, 10(10), 1814. <https://doi.org/10.3390/HEALTHCARE10101814>

Sim, J., & Wright, C. C. (2005). The Kappa Statistic in Reliability Studies: Use, Interpretation, and Sample Size Requirements. *Physical Therapy*, 85(3), 257–268. <https://doi.org/10.1093/PTJ/85.3.257>

Soligard, T., Schweltnus, M., Alonso, J.-M., Bahr, R., Clarsen, B., Dijkstra, H. P., Gabbett, T., Gleeson, M., Häggglund, M., Hutchinson, M. R., Janse van Rensburg, C., Khan, K. M., Meeusen, R., Orchard, J. W., Pluim, B. M., Raftery, M., Budgett, R., & Engebretsen, L. (2016). How much is too much? (Part 1) International Olympic Committee consensus

- statement on load in sport and risk of injury. *British Journal of Sports Medicine*, 50(17), 1030–1041. <https://doi.org/10.1136/bjsports-2016-096581>
- Tarvainen, M. P., Niskanen, J.-P., Lipponen, J. A., Ranta-aho, P. O., & Karjalainen, P. A. (2014). Kubios HRV – Heart rate variability analysis software. *Computer Methods and Programs in Biomedicine*, 113(1), 210–220. <https://doi.org/10.1016/j.cmpb.2013.07.024>
- Tavares, F., Healey, P., Smith, T. B., & Driller, M. (2018). The effect of training load on neuromuscular performance, muscle soreness and wellness during an in-season non-competitive week in elite rugby athletes. *The Journal of Sports Medicine and Physical Fitness*, 58(11), 1565–1571. <https://doi.org/10.23736/S0022-4707.17.07618-6>
- Taylor, J. B., Wright, A. A., Dischiavi, S. L., Townsend, M. A., & Marmon, A. R. (2017). Activity Demands During Multi-Directional Team Sports: A Systematic Review. *Sports Medicine*, 47(12), 2533–2551. <https://doi.org/10.1007/s40279-017-0772-5>
- Temm, D. A., Standing, R. J., & Best, R. (2022). Training, Wellbeing and Recovery Load Monitoring in Female Youth Athletes. *International Journal of Environmental Research and Public Health*, 19(18), 11463. <https://doi.org/10.3390/ijerph191811463>
- Thorpe, R. T., Strudwick, A. J., Buchheit, M., Atkinson, G., Drust, B., & Gregson, W. (2015). Monitoring Fatigue During the In-Season Competitive Phase in Elite Soccer Players. *International Journal of Sports Physiology and Performance*, 10(8), 958–964. <https://doi.org/10.1123/IJSPP.2015-0004>
- Thorpe, R. T., Strudwick, A. J., Buchheit, M., Atkinson, G., Drust, B., & Gregson, W. (2017). The Influence of Changes in Acute Training Load on Daily Sensitivity of Morning-Measured Fatigue Variables in Elite Soccer Players. *International Journal of Sports Physiology and Performance*, 12(s2), S2-107-S2-113. <https://doi.org/10.1123/ijsp.2016-0433>
- Twist, C., & Highton, J. (2013). Monitoring Fatigue and Recovery in Rugby League Players. *International Journal of Sports Physiology and Performance*, 8(5), 467–474. <https://doi.org/10.1123/ijsp.8.5.467>
- Vachon, A., Sauvet, F., Pasquier, F., Paquet, J.-B., & Bosquet, L. (2023). Effects of a Sleep Hygiene Strategy on Parameters of Sleep Quality and Quantity in Youth Elite Rugby Union Players. *International Journal of Sports Physiology and Performance*, 18(10), 1101–1108. <https://doi.org/10.1123/ijsp.2023-0069>
- Vanrenterghem, J., Nedergaard, N. J., Robinson, M. A., & Drust, B. (2017). Training Load Monitoring in Team Sports: A Novel Framework Separating Physiological and Biomechanical Load-Adaptation Pathways. *Sports Medicine*, 47(11), 2135–2142. <https://doi.org/10.1007/s40279-017-0714-2>
- Vázquez-Espino, K., Fernández-Tena, C., Lizarraga-Dallo, M. A., & Farran-Codina, A. (2020). Development and Validation of a Short Sport Nutrition Knowledge Questionnaire for Athletes. *Nutrients*, 12(11), 1–14. <https://doi.org/10.3390/NU12113561>

- Versic, S., Modric, T., Katanic, B., Jelcic, M., & Sekulic, D. (2022). Analysis of the Association between Internal and External Training Load Indicators in Elite Soccer; Multiple Regression Study. *Sports, 10*(9), 135. <https://doi.org/10.3390/sports10090135>
- Walsh, N. P., Halson, S. L., Sargent, C., Roach, G. D., Nédélec, M., Gupta, L., Leeder, J., Fullagar, H. H., Coutts, A. J., Edwards, B. J., Pullinger, S. A., Robertson, C. M., Burniston, J. G., Lastella, M., Le Meur, Y., Hausswirth, C., Bender, A. M., Grandner, M. A., & Samuels, C. H. (2021). Sleep and the athlete: narrative review and 2021 expert consensus recommendations. *British Journal of Sports Medicine, 55*(7), 356–368. <https://doi.org/10.1136/bjsports-2020-102025>
- Wang, A., Healy, J., Hyett, N., Berthelot, G., & Okholm Kryger, K. (2021). A systematic review on methodological variation in acute:chronic workload research in elite male football players. *Science and Medicine in Football, 5*(1), 18–34. <https://doi.org/10.1080/24733938.2020.1765007>
- West, S. W., Clubb, J., Torres-Ronda, L., Howells, D., Leng, E., Vescovi, J. D., Carmody, S., Posthumus, M., Dalen-Lorentsen, T., & Windt, J. (2021). More than a Metric: How Training Load is Used in Elite Sport for Athlete Management. *International Journal of Sports Medicine, 42*(04), 300–306. <https://doi.org/10.1055/a-1268-8791>
- West, S. W., Williams, S., Kemp, S. P. T., Cross, M. J., & Stokes, K. A. (2019). Athlete Monitoring in Rugby Union: Is Heterogeneity in Data Capture Holding Us Back? *Sports, 7*(5), 98. <https://doi.org/10.3390/sports7050098>
- Weston, M. (2018). Training load monitoring in elite English soccer: a comparison of practices and perceptions between coaches and practitioners. *Science and Medicine in Football, 2*(3), 216–224. <https://doi.org/10.1080/24733938.2018.1427883>
- XDA developers. (2015). *Xiaomi Mi Band data extraction, analytics and Google Fit sync tools*. URL: <https://xdaforums.com/t/Xiaomi-Mi-Band-Data-Extraction-Analytics-and-Google-Fit-Sync-Tools.3019156/>.
- Xie, J., Wen, D., Liang, L., Jia, Y., Gao, L., & Lei, J. (2018). Evaluating the Validity of Current Mainstream Wearable Devices in Fitness Tracking Under Various Physical Activities: Comparative Study. *JMIR MHealth and UHealth, 6*(4), e94. <https://doi.org/10.2196/mhealth.9754>
- Yang, S., Yin, Y., Qiu, Z., & Meng, Q. (2024). Research application of session-RPE in monitoring the training load of elite endurance athletes. *Frontiers in Neuroscience, 18*. <https://doi.org/10.3389/fnins.2024.1341972>
- Yu, L., Altieri, C., BIRD, S. P., Corcoran, G., & Jiuxiang, G. (2021). The Importance of In-Season Strength and Power Training in Football Athletes: A Brief Review and Recommendations. *International Journal of Strength and Conditioning, 1*(1). <https://doi.org/10.47206/ijsc.vi0.23>

Popis slika

- **Slika 1.** *Percentage of the number of training sessions and matches carried out in the three intensity zones. Z1—low intensity zone; Z2—moderate intensity zone; Z3—high intensity zone; ¥—significantly lower than Z1 and Z2 at $p < 0.001$; #—significantly lower than Z1 at $p < 0.001$; §—significantly lower than Z3 at $p < 0.001$*
- **Slika 2.** *Daily internal training intensity (ITI) observed over the 35 days of the pre-season phase (5 weeks). The grey area represents the smallest worthwhile change (SWC = coefficient of variation $\times 0.3$), and the error bars show 90% confidence limits (CL). If the CL crossed one or both SWC boundaries, the terms “possibly” and “unclear” were used, respectively. The red line represents within-days intensity variations (CV%). MD—match day.*
- **Slika 3.** *Daily well-being status index (WBI) observed over the 35 days of the pre-season (5 weeks). The grey area represents the smallest worthwhile change (SWC = coefficient of variation $\times 0.3$), and the error bars show 90% confidence limits (CL). If the CL crossed one or both SWC boundaries, the terms “possibly” and “unclear” were used, respectively. The red line represents within-days well-being status variations (CV%).*
- **Slika 4.** *Countermovement jump (CMJ) height observed over the 5 weeks of the pre-season phase. The grey area represents the smallest worthwhile change (SWC = coefficient of variation $\times 0.3$), and the error bars show 90% confidence limits (CL). If the CL crossed one or both SWC boundaries, the terms “possibly” and “unclear” were used, respectively. The red line represents within-weeks CMJ variations (CV%); #—significantly higher than W1.*
- **Slika 5.** *Multiple comparisons between weeks in internal training intensity and well-being status measures expressed as the magnitude of effect size; meanITI—average weekly internal intensity; sumITI—accumulated weekly internal intensity; TM—training monotony; TS—training strain; DOMS—delayed onset of muscle soreness; WBI—well-being status index; W—week.*
- **Slika 6.** *Coefficients of correlation (r) determined between internal intensity and well-being status measures; meanITI—average weekly internal intensity; sumITI—*

accumulated weekly internal intensity; *TM*—training monotony, *TS*—training strain; *DOMS*—delayed onset of muscle soreness; *WBI*—well-being status index. Error bars represent 90% confidence limits (CL); *—significance at $p < 0.05$; **—significance at $p < 0.01$.

- **Slika 7.** Internal training intensity values over the 5 weeks during the preseason in professional soccer players ($n = 10$). *ITI*_{mean} – weekly mean internal intensity, ↑ – positive direction of difference, ↓ – negative direction of difference, statistically different: 4 – from week 4, 5 – from week 5; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
- **Slika 8.** Individual and group heart rate variability values over the 5 weeks during the preseason in professional soccer players ($n = 10$). *lnRMSSD*_{mean} – weekly mean log-transformed root-mean-square difference of successive R-R intervals.
- **Slika 9.** Group heart rate variability values expressed as percentages over the 5 weeks during the preseason in professional soccer players ($n = 10$). *lnRMSSDCV* – coefficient of variation of weekly log-transformed root-mean-square difference of successive R-R intervals.
- **Slika 10.** Repeated-measures correlation plots between *lnRMSSD*_{mean} and *lnRMSSDCV*. Each shade of grey represents a unique participant, with points indicating their performance on both measures at specific time points, and the corresponding lines illustrate the rrm fit for each participant
- **Slika 11.** 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.
- **Slika 12.** 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. * $p < 0.05$, *** $p < 0.001$
- **Slika 13.** Weekly variations in neuromuscular performance (CMJ) and PMS over a 4-week period. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
- **Slika 14.** Daily variations in the *TS-Δ* index and *TQR*_{fw}.

Znanstvena aktivnost kandidata za vrijeme doktorskog studija

Znanstveni radovi objavljeni u publikacijama koje citiraju WoS i/ili Scopus baze:

- **Maleš, J.**, Ouergui, I., Kuna, D., Žuvela, F., De Giorgio, A., & Kuvačić, G. (2022). Monitoring Internal Training Intensity Correlated with Neuromuscular and Well-Being Status in Croatian Professional Soccer Players during Five Weeks of the Pre-Season Training Phase. *Sports*, 10(11), 172. <https://doi.org/10.3390/sports10110172>
- Žuvela, F., Mastelić, M., Jelaska, G., Matijašević, P., & **Maleš, J.** (2024). Predictors of Efficiency in Throwing Disciplines: Insights from 35 Elite Coaches. *Applied Sciences*, 14(24), 11837. <https://doi.org/10.3390/app142411837>
- Pezelj, L., Bourgois, J. G., Milić, M., **Maleš, J.**, & Caraballo, I. (2025). Anthropometric Profile, Body Composition and Somatotype of Elite ILCA 7 Class Sailors—Differences Across General Competitive Success Levels. *Applied Sciences*, 15(12), 6450. <https://doi.org/10.3390/app15126450>
- **Maleš, J.**, Ourgeui, I., Žuvela, F., Ceylan, I. H., Bragazzi, N. L., De Giorgio, A., & Kuvačić, G. (2025). Relationships between internal training intensity, heart rate variability, sleep duration, and neuromuscular performance in professional soccer players. *Human Movement*, 26(3): 101-114. <https://doi.org/10.5114/hm/205324>
- Matijašević, P., **Maleš, J.**, Cikojević, L., Žuvela, F., & Kuvačić, G. (2025). Development and Validation of a Running Drill Test Battery to Predict 5 m and 20 m Sprint Performance. *International Journal of Exercise Science*, 18(8):1269 - 1285. <https://doi.org/10.70252/LYKE8231>
- **Maleš, J.**, Žuvela, F., Bragazzi, N., De Giorgio, A., & Kuvačić, G. (2025). Perceived Recovery and Muscle Fatigue in Professional Soccer Players During Preseason, *International Journal of Exercise Science*, 18(8):1212 - 1227. <https://doi.org/10.70252/ERIN2946>

Znanstveni radovi u ostalim publikacijama:

- Čule, R., **Maleš, J.**, Krstulović, S., Žuvela, F., Rađa, A., Erceg, M., & Kuvačić, G. (2023). Heart Rate and Lactate Concentration During Amateur Boxing Matches A Brief Review. 2nd International conference on science and medicine in aquatic sports, Split, Croatia.
- Lasić, A., **Maleš, J.**, Žuvela, F., Erceg, M., Rađa, A., Krstulović, S., & Kuvačić, G. (2023). Monitoring Sleep, Wellness, and Training Load in Recreational Crossfit Athletes. 2nd International conference on science and medicine in aquatic sports, Split, Croatia.
- Cena, L., Krstulović, S., **Maleš, J.**, & Kuvačić, G. (2023). Long-term impact of rapid weight loss on the health status of former judo athletes. Applicable research in judo: 7th European Judo Research And Science Symposium 6th Scientific And Professional Conference On Judo.
- Rozga, I., Krstulović, S., **Maleš, J.**, & Kuvačić, G. (2024). Monitoring internal training load and wellness parameters in judo. In Proceedings of the 10th International Scientific Conference on Kinesiology: Current Trends and Innovations in Kinesiology Research (p. 208).
- **Maleš, J.**, Erceg, M., & Kuvačić, G. (2024). Dynamics of changes in individual physiological parameters during the performance of a specific test in soccer players. In Students' Congress of Science and Sport in Split (ST-CongreSS).
- **Maleš, J.**, Žuvela, F., & Kuvačić, G. (2024). Neuromuscular, cardiac, and sleep adaptations in soccer players during pre-season. In Proceedings of the 7th International Scientific Conference "Contemporary Kinesiology: Active Lifestyle".
- **Maleš, J.**, Žuvela, F., De Giorgio, A., & Kuvačić, G. (2024). Positional variations in internal training intensity and psychometric responses during soccer's pre-competitive phase. In Proceedings of the 21st Annual Scientific Conference of Montenegrin Sports Academy: Sport, Physical Activity and Health, Contemporary Perspectives. Montenegrin Sports Academy.
- **Maleš, J.**, Žuvela, F., Bragazzi, N., De Giorgio, A., & Kuvačić, G. (2025). Monitoring internal training load, recovery, neuromuscular performance, and muscle fatigue

during a 4-week football preseason. In Proceedings of the 19th FIEPS European Congress: Inspiring Excellence, Empowering the Future of Physical and Sport Education. FIEPS Europe.

Prisustvovanje (izlaganja) znanstvenim kongresima:

- 2nd International conference on science and medicine in aquatic sports (SMAS), Split, Croatia, 09.2023
- Students' Congress of Science and Sport in Split (ST-CongreSS), Split, 05.2024
- 7th International Scientific Conference "Contemporary Kinesiology: Active Lifestyle"., Split, 07.2024
- 21st Annual Scientific Conference of Montenegrin Sports Academy: Sport, Physical Activity and Health, Contemporary Perspectives. Montenegrin Sports Academy, Cavtat, 04.2024
- 19th FIEPS European Congress: Inspiring Excellence, Empowering the Future of Physical and Sport Education. FIEPS Europe, Antalya, Turkey, 04.2025

Životopis

Josip Maleš rođen je 23. ožujka 1994. godine u Splitu. Završio je srednjoškolsko obrazovanje u Školi za dizajn, grafiku i održivu gradnju, gdje je 2012. godine stekao zvanje medijski tehničar. Iste godine uspješno je položio državnu maturu i upisao je sveučilišni prijediplomski studij kineziologije na Kineziološkom fakultetu Sveučilišta u Splitu, koji je završio 2015. godine, s usmjerenjem kondicijska priprema sportaša. Na istom fakultetu 2017. godine završio je sveučilišni diplomski studij te stekao akademski naziv magistar kineziologije (mag. cin.). Doktorski studij Kineziologije na Kineziološkom fakultetu Sveučilišta u Splitu upisao je 2023. godine.

Tijekom studija nagrađivan je Rektorovom i Dekanovom nagradom za izvrsnost te nagradom za pet najboljih studenata generacije. Nakon završetka studija dodatno se stručno usavršavao kroz specijalizirane edukacije iz područja praćenja, kondicijske pripreme, dijagnostike i rehabilitacije sportaša, te posjeduje i CFSC (Certified Functional Strength Coach) lvl 1 licencu.

Od 2020. godine uključen je u nastavni i znanstveno-istraživački rad kao vanjski suradnik u zvanju asistenta na Kineziološkom fakultetu Sveučilišta u Splitu, a od 2022. godine zaposlen je u zvanju asistenta na Sveučilištu u Splitu, na studiju Hotelijerstva i gastronomije. U okviru nastavnog rada sudjeluje u izvođenju kolegija Tjelesna i zdravstvena kultura, Menadžment u zimskom turizmu, Menadžment wellnessa i animacije u hotelijerstvu te Menadžment u jahtingu, a uz nastavne i znanstveno-istraživačke obveze sudjeluje i u radu tijela, kao član Vijeća studija i Odbora za kvalitetu studija, te obnaša dužnost koordinatora za multimediju, koordinatora za e-učenje i odgovorne osobe za održavanje repozitorija Studija hotelijerstva i gastronomije.

Znanstvena i istraživačka aktivnost Josipa Maleša obuhvaća sudjelovanje u znanstvenim projektima, objavljivanje znanstvenih radova te aktivno sudjelovanje na domaćim i međunarodnim znanstvenim kongresima. U sklopu navedenih aktivnosti valja izdvojiti osvojenu nagradu: „Young resercher award (category Doctoral Students) 1. place“, u sklopu 7og međunarodnog znanstvenog kongresa „Contemporary Kinesiology“ u Splitu 2024 godine.

Profesionalno iskustvo u sportu stjecao je kao kondicijski trener u omladinskom i seniorskom uzrastu, ponajprije u odbojci i nogometu, te kao osobni kondicijski trener. Od 2017. godine do danas radio je kao kondicijski trener u klubovima NK Dugopolje, NK Omiš, NK Solin, OK Mladost Ribola Kaštela i NK Croatia Zmijavci. Također je, uz prof. dr. sc. Franu Žuvelu, radio kao pomoćni kondicijski trener muške Hrvatske odbojkaške reprezentacije

tijekom pripremnog perioda za Srebrnu europsku ligu 2018. godine, gdje je reprezentacija osvojila zlatnu medalju.

Uz stručni i znanstveni rad, Josip Maleš se aktivno bavio sportom. Tijekom natjecateljske karijere ostvario je rezultate na državnoj razini u sportovima; plivanje, boks, atletika i triatlon, a i danas je aktivno uključen u sport. Sudjelovao je i na Europskim zimskim sveučilišnim igrama u Val di Zoldu 2023. godine. Također radi kao učitelj skijanja od 2006. godine te posjeduje međunarodnu ISIA licencu učitelja skijanja, a od 2020. godine obnaša dužnost voditelja škole skijanja.