Prevention and reconditioning of injuries in Football Association

Coordinators

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CONTENTS

1. Physical fitness performance and motor-control functional characteristics of professional women footballers: a preliminary descriptive study
   MAITANE RUIZ-RIOS, IGOR SETUAIN, ASIER INTXAURBE, ASIER GONZALEZ-ARTETXE, AND IBAI GARCIA-TABAR

2. Within-player variability of wellness scores and muscle injury prediction in football players
   DIEGO MARQUÉS-JIMÉNEZ, PABLO QUÍLEZ-LARRAYAD, AND KRISTIAN ÁLVAREZ-GARCÍA

3. Incorporation of objective and subjective autoregulation strategies in anterior cruciate ligament injury prevention resistance training protocols: a comprehensive and innovative approach for increased effectiveness
   LOUDOVIKOS-DIMITRIOS LIOSIS

4. Distancia de carrera a alta velocidad (HSR) acumulada en sesiones centrales del microciclo competitivo en el fútbol profesional en función de la demarcación: ¿cuándo y cuánto?
   KÉVIN MARÍN, AND JULEN CASTELLANO

5. Efectos del entrenamiento de fuerza hasta el fallo muscular vs. sin fallo sobre la arquitectura muscular del cuádriceps en jugadores de deportes de equipo: metaanálisis
   JAVIER PECCI, GONZALO REVERTE-PAGOLA, ANGEL CARNERO-DIAZ, AND HELIOS PAREJA-GALEANO

6. Analysis of multicomponent screening and physical performance tests during four preseasons in a semi-professional female football team. "The Basque Female Football Cohort (BFFC) study"
   ASIER INTXAURBE, IBAI GARCIA-TABAR, MAITANE RUIZ-RIOS, ASIER GONZALEZ-ARTETXE, AND IGOR SETUAIN

PREFACE

On July 14th, 2024, in the Olympiastadion of Berlin, Spain conquered the UEFA EURO2024, beating England by two goals to one. Against all odds, the Spanish team prevailed in all seven games, the first squad to do so in the 17 editions of the tournament. It became the most successful country, with four cups in total. Amongst a team of outstanding players, Rodri Hernández, the midfielder born in Madrid who plays for Manchester City, was nominated as the best player in the championship.

Two months later, in the 16th minute of the first half of the game against Arsenal, Rodri sustained an anterior cruciate ligament injury that ruled him out for the rest of the season. ACL injuries are the most frequent severe injuries any footballer can suffer. Still, Rodri's case has gained extra attention due to his previous complaints and warnings about the dangerous increasing number of games in men's professional football. Unfortunately, his fears became a reality in the 5th fixture of the 2024/25 Premier League season.

Injury prevention, recovery, and reconditioning are essential to the practice of any sport. Still, they are of paramount importance when it comes to preserving the tricky balance between the interests of the industry and the interests of the professionals themselves. For this reason, training and conditioning specialists play a significant role in those staff teams that help players make their dreams come true, and this book is devoted to them.

This volume contains the best contributions made by football researchers and practitioners to the two editions of the ***International Congress on Reconditioning and Prevention of Football Injuries*** organised by the University of the Basque Country in 2022 and 2024 in Vitoria-Gasteiz. The scientific committees of both congresses have carefully selected the six works included that cover a range of exciting topics: motor control and anthropometric characteristics of female footballers; the predictive ability of perceived wellness on the occurrence of muscle injuries; the effects of resistance training on muscle architecture; the autoregulation strategies in the prevention of anterior cruciate ligament injuries.

This eBook on a relevant and topical subject as the prevention and reconditioning of football injuries has been made possible thanks to the selfless dedication of many people and the institutional support of the Department of Physical Education and Sport of the University of the Basque Country (UPV/EHU), the Basque School of Sport of the Basque Government and the Official Association of Physical Education and Physical Activity and Sport Sciences Graduates of the Basque Country. Thank you all very much.

The thrill of competition, the excitement in the stands, and the massive amount of cash running through the veins of the football industry impede us from expecting a change of direction in the situation Rodri was complaining about. If injuries are a painful sign of what football practice is, this little contribution wants to be our thankful sign of what science and research can put in play when success is not measured in goals but in longer, healthier careers and more efficient recovery periods.

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PHYSICAL FITNESS PERFORMANCE AND MOTOR-CONTROL FUNCTIONAL CHARACTERISTICS OF PROFESSIONAL WOMEN FOOTBALLERS: A PRELIMINARY DESCRIPTIVE STUDY

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1. INTRODUCTION

Professional women's football is experiencing a surge in popularity, competition demands and professionalism (Nassis et al., 2021; Okholm Kryger et al., 2022). In the last several competitive seasons, the injury type and severity of these players have changed (Horan et al., 2022). This outcome suggests a change in the usual pattern of female injuries, which were previously reported to be more likely to involve the quadriceps muscles and anterior cruciate ligament (ACL) ligaments, to a higher incidence of hamstring injuries (Larruskain et al., 2018). Parallel to this change in the injury profile, physical demands of women's football games increased, with players covering more distance at high speeds (Randell et al., 2021). A 30% increase in total distance covered at high speed between the 2015- and 2019-Women's World Cups suggests that the rising physical demands of the sport may contribute to changes in injury patterns (FIFA, 2019). While research on women's football is growing (Okholm Kryger et al., 2022), there is a lack of comprehensive normative data on their physical fitness and motor-control injury screening profile. Understanding these factors is crucial for developing effective individualized football specific and generic fitness and injury prevention training programs in this population.

2. OBJETIVE

Therefore, this study aimed to systematically outline the fitness and motor-control characteristics of professional women footballers. This information would help adapting football specific training to players' fitness and motor-control profiles and establish a basis for future research on the field. The findings could provide valuable data for clubs, medical and conditioning staff to interpret their own records.

3. METHODS

3.1. Information sources and search strategy

This systematic review strictly followed the Preferred Reporting Items for Systematic Review and Meta-analyses (PRISMA) statement (Page et al., 2021). A comprehensive search of electronic databases was conducted on February 20, 2023: PubMed/MEDLINE and Scopus. Table 1 describes the search strategy incorporated.

3.2. Eligibility criteria

Scientific articles published in English that investigated the fitness and motor-control characteristics of women footballers (aged 16-40 years) competing at a professional level (national/international, semi-professional, or professional). Studies using football or soccer training interventions were included regardless of whether they had a comparison group. The exclusion criteria were set as follows: veteran women footballers over 40 years old, pre-existing medical conditions; women with musculoskeletal limitations; men or studies with mixed sample; performance level; participants who played other sports; studies not assessing fitness and motor-control characteristics; and animals' studies.

3.3. Study selection process

Data extraction from included studies was collected according to title and abstracts. Same researchers screened the full-text versions of the selected studies based on the eligibility criteria, and resolved inconsistencies, if any. The following characteristics were extracted: bibliographic details (i.e., author and year of publication), study design (O'Donoghue, 2009), participants' characteristics (i.e., sample size, age, body mass and height) and performance level (McKay et al., 2022), and assessed measurements with their respective descriptive results.

3.4. Study risk-of-bias and certainty assessments

The methodological quality of the included studies was assessed by the QAT scale for Quantitative Studies (Thomas et al., 2004). The QAT dictionary (Thomas et al., 2004) guided the rating of each study component for each of the six areas on a 1-3 scale using specific criteria. The methodology of the studies was classified as *strong*, *moderate,* or *weak* based on a global rating using the QAT dictionary (Thomas et al., 2004).

4. RESULTS

4.1. Study selection

Initial database search yielded 1144 publications. After removing duplicates, 1130 remained. Full-text assessment of 98 articles was carried out. However, only eight met all the inclusion criteria (Figure 1).

4.2. Risk of bias in studies and certainty of evidence

Table 1 shows that all studies had a *strong* global quality.

4.3. Results and synthesis of individual studies

Table 2 provides numerical descriptions of fitness performance and motor-control injury screening measures.

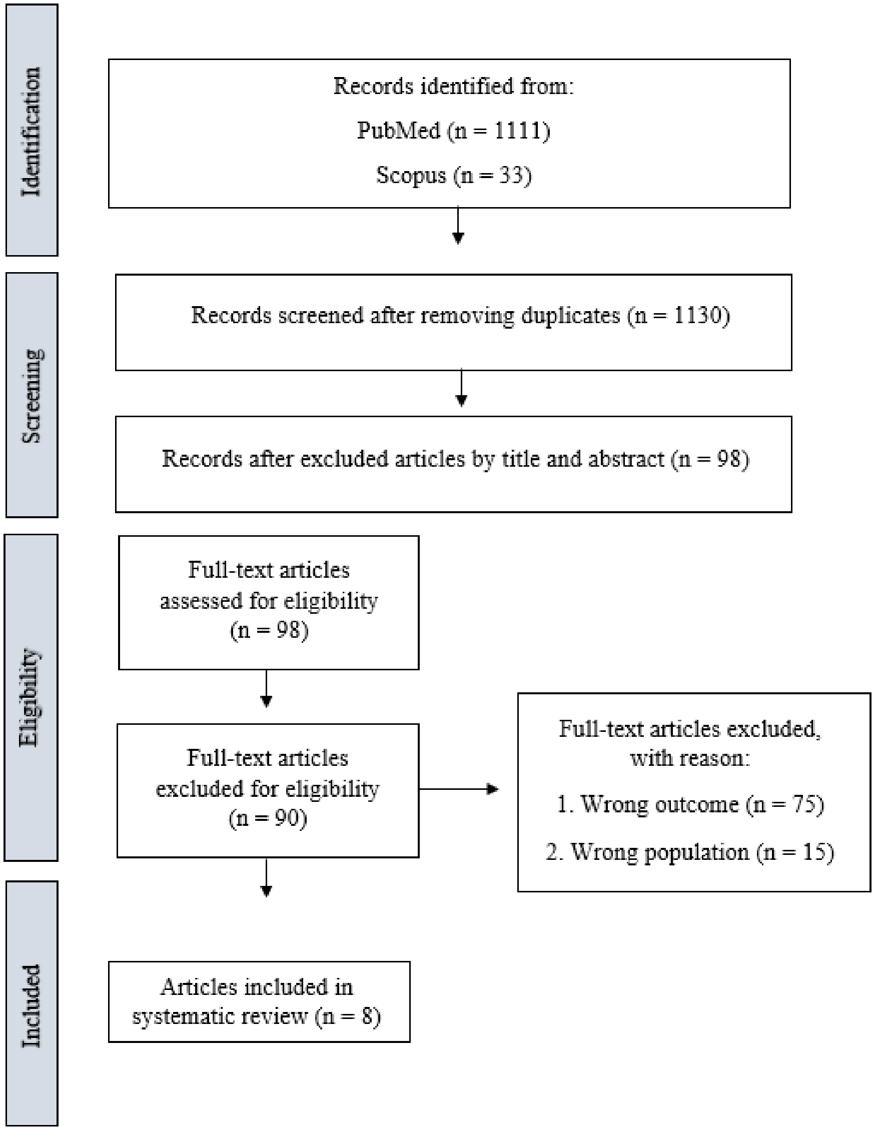

FIGURE 1. *Flowchart diagram.*

TABLE 1. *Search strategy and results of the quality assessment scores (global rating) from the included studies.*

<table>
<tr><td>Search strategy</td><td colspan="7">(Female* OR Wom*) AND (Football* OR Soccer) NOT Animal NOT "American football" AND (Perform* OR Injur*) AND (Anthropometr* OR Function* OR Physical*) AND (Endurance OR Aerobic OR Strength OR Resistance OR "Range of motion" OR ROM)</td></tr>
<tr><td>Study</td><td>Selection bias</td><td>Study design</td><td>Cofounders</td><td>Blinding</td><td>Data</td><td>Withdrawal</td><td>Global rating</td></tr>
<tr><td>Roso-Moliner et al. (2023)</td><td>1</td><td>2</td><td>1</td><td>—</td><td>1</td><td>2</td><td><i>Strong</i></td></tr>
<tr><td>González-Fernández et al. (2022)</td><td>1</td><td>2</td><td>1</td><td>—</td><td>2</td><td>2</td><td><i>Strong</i></td></tr>
<tr><td>Zhang et al. (2021)</td><td>1</td><td>2</td><td>1</td><td>—</td><td>2</td><td>2</td><td><i>Strong</i></td></tr>
<tr><td>Güler et al. (2020)</td><td>1</td><td>2</td><td>1</td><td>—</td><td>2</td><td>2</td><td><i>Strong</i></td></tr>
<tr><td>Parpa & Michaelides (2020)</td><td>1</td><td>2</td><td>1</td><td>—</td><td>2</td><td>2</td><td><i>Strong</i></td></tr>
<tr><td>Bishop et al. (2019)</td><td>1</td><td>2</td><td>1</td><td>—</td><td>1</td><td>2</td><td><i>Strong</i></td></tr>
<tr><td>Ozbar et al. (2014)</td><td>1</td><td>1</td><td>1</td><td>—</td><td>1</td><td>2</td><td><i>Strong</i></td></tr>
<tr><td>Andersson et al. (2008)</td><td>1</td><td>1</td><td>1</td><td>—</td><td>2</td><td>2</td><td><i>Strong</i></td></tr>
</table>

Note: "Data" is data-collecting methods. The quality assessment scores criteria were 1, strong*; 2,* moderate*; 3,* weak*; and - , not applicable. Please see the "Methods" section for more details about the applied criteria and the assessment of global rating.*

4.4. Fitness performance characteristics

Only three studies (38%) provided direct VO$_{2max}$ measurements (Andersson et al., 2008; Güler et al., 2020; Parpa & Michaelides, 2020) indicating 52.6 ± 4.4 mL·min^{-1}·kg^{-1}. Five studies (63%) (Andersson et al., 2008; Bishop et al., 2019; González-Fernández et al., 2022; Roso-Moliner et al., 2023; Zhang et al., 2021) performed linear 5-40 m sprints, with ≈3.6 ± 0.2 s for 20 m. Four studies (50%) (Andersson et al., 2008; Bishop et al., 2019; González-Fernández et al., 2022; Ozbar et al., 2014) provided different jump measures. Three studies (38%) (Andersson et al., 2008; González-Fernández et al., 2022; Ozbar et al., 2014) recorded the bilateral countermovement jump (CMJ) of ≈30.5 ± 2.7 cm, while two studies (25%) (Ozbar et al., 2014; Roso-Moliner et al., 2023) reported horizontal jump (HJ) of ≈157.2 ± 11.0 cm.

TABLE 2. *Descriptive outcomes of fitness and motor-control characteristics of professional women footballers.*

Reference	Descriptive results				
	Principal characteristics	Study type	Study period	Physical fitness	Motor-control
Roso-Moliner et al. (2023)	Professional women footballers (*n* = 38) From Second Division, Spain Calibre: Highly Trained/National Level	Observational, cohort	Not specified	10 m sprint 1.93 ± 0.19 s 20 m sprint 3.36 ± 0.21 s 30 m sprint 4.72 ± 0.29 s 40 m sprint 6.13 ± 0.37 s	WB-DF-L 42.0 ± 5.1 cm WB-DF-R 42.8 ± 4.7 cm CMJ-L 13.6 ± 1.4 cm CMJ-R 13.6 ± 1.7 cm HJ-L 147.2 ± 11.3 cm HJ-R 146.4 ± 12.1 cm CODS-L 2.62 ± 0.18 s CODS-R 2.62 ± 0.16 s
González-Fernández et al. (2022)	Professional women footballers (*n* = 16) From Second Division, Spain Calibre: Highly Trained/National Level	Observational, cohort	Pre-season	CMJ 23.8 ± 2.3 cm 30 m sprint 5.20 ± 0.18 s RSA (minimum/maximum): 138.16 ± 22.06 s /165.72 ± 22.16 s	Hop test DL 121.9 ± 7.6 cm Hop test NDL 123.9 ± 9.3 cm R-hip angle 92.19 ± 6.29 L-hip angle 102.13 ± 7.71 Internal rotation: R-hip extension 28.22 ± 6.74 °; L-hip extension 32.97 ± 8.19 ° External rotation: R-hip extension 36.13 ± 6.02 °; L-hip extension 38.00 ± 9.66 ° R-internal rotation 38.09 ± 7.00 °; L-internal rotation 36.19 ± 9.89 ° R-external rotation 42.75 ± 7.02 °; L-external rotation 43.28 ± 8.29 °
Zhang et al. (2021)	Professional women footballers (*n* = 14) From the National Team, France Calibre: Highly Trained/National Level	Experimental, cohort	Not specified	20 m sprint 3.87 ± 0.12 s	Quadriceps-DL PT at 240°·s^{-1} 89.89 ± 20.23 N·m Quadriceps-NDL PT at 240°·s^{-1} 91.46 ± 21.48 N·m Hamstring-DL PT at 240°·s^{-1} 55.23 ± 16.08 N·m Hamstring-NDL PT at 240°·s^{-1}

					54.92 ± 15.79 N·m Quadriceps-DL PT at 60°·s^{-1} 129.56 ± 21.08 N·m Quadriceps-NDL PT at 60°·s^{-1} 130.02 ± 19.49 N·m Hamstring-DL PT at 60°·s^{-1} 72.04 ± 14.00 N·m Hamstring-NDL PT at 60°·s^{-1} 73.59 ± 17.09 N·m Quadriceps-DL PT at 30°·s^{-1} 160.65 ± 34.61 N·m Quadriceps-NDL PT at 30°·s^{-1} 163.49 ± 32.55 N·m Hamstring-DL PT at 30°·s^{-1} 97.81 ± 11.42 N·m Hamstring-NDL PT at 30°·s^{-1} 101.19 ± 14.19 N·m
Güler et al. (2020)	Professional women footballers (*n* = 16) Calibre: Highly Trained/National Level	Observational	Not specified	VO$_{2max}$ 52.3 ± 5.7 mL·min^{-1}·kg^{-1}	Balance test 0.90 ± 1.40 °
Parpa & Michaelides (2020)	Professional women footballers (*n* = 18) From the highest Cyprus football league (UEFA Women's Champions League) Calibre: World Class Goalkeepers were excluded	Observational, cohort	Transition period	VO$_{2max}$ 50.8 ± 4.6 mL·min^{-1}·kg^{-1}	Quadriceps-R PT at 60°·s^{-1} 133.98 ± 22.72 N·m Quadriceps-L at PT 60°·s^{-1} 137.34 ± 27.92 N·m Hamstring-R at PT 60°·s^{-1} 100.39 ± 15.50 N·m Hamstring-L at PT 60°·s^{-1} 100.56 ± 19.86 N·m
Bishop et al. (2019)	Professional women footballers (*n* = 16) From the Category 3 Regional Talent Centre at a professional club, United Kingdom Calibre: Highly Trained/National Level	Observational, cohort	Pre-season	10 m sprint 2.00 ± 0.10 s 30 m sprint 4.89 ± 0.17 s	CMJ-L 14.1 ± 2.5 cm CMJ-R 13.5 ± 2.1 cm DJ-L 13.4 ± 2.2 cm DJ-R 12.7 ± 2.2 cm CODS-L 2.55 ± 0.09 s CODS-R 2.52 ± 0.10 s

Ozbar et al. (2014)	Professional women footballers (*n* = 18) From the Second League, Turkey Calibre: Highly Trained/National Level Goalkeepers were excluded	Experimental, experiment	Not specified	HJ 178.0 ± 9.6 cm CMJ 37.6 ± 4.6 cm 20 m sprint 3.80 ± 0.35 s	Triple hop DL 475.0 ± 40.0 cm Triple hop NDL 475.0 ± 50.0 cm
Andersson et al. (2008)	Professional women footballers (*n* = 17) Highest division in Sweden and Norway Calibre: Highly Trained/International Level Goalkeepers were excluded	Experimental, experiment	In-season	VO_{2max} 54.6 ± 3.0 $mL·min^{-1}·kg^{-1}$ 20 m sprint 3.18 ± 0.03 s CMJ 30.2 ± 1.2 cm	Quadriceps PT at $60°·s^{-1}$ 171.0 ± 4.5 N·m Hamstring PT at $60°·s^{-1}$ 103.0 ± 50.0 N·m

Note: CMJ, countermovement jump; CMJA, countermovement jump with arm-swing; CODS, change of direction speed; DJ, drop jump; DL, dominant leg; FMS, functional movement screen; F, functional; HJ, horizontal jump; L, left; n, sample size; NDL, non-dominant leg; PT, peak torque; R, right; RSA, repeated sprint ability; SJ, squat jump; VO_{2max}*, maximal oxygen consumption (*$mL·min^{-1}·kg^{-1}$*); WB-DF, weight bearing dorsiflexion; y, years.*

4.5. Motor-control injury screening characteristics

Two studies (25%) (Bishop et al., 2019; Roso-Moliner et al., 2023) measured the unilateral CMJ (UCMJ), being height similar for both legs, with an average jump height of around 14.1 cm (≈ 14.1 ± 2.2 cm) on the dominant leg and 14.6 cm (≈ 14.6 ± 2.1 cm) on the non-dominant leg. Three studies (38%) (Andersson et al., 2008; Parpa & Michaelides, 2020; Zhang et al., 2021) reported quadriceps and hamstring peak torque (PT) at $60°·s^{-1}$ of ≈140.4 ± 19.1 and ≈89.9 ± 23.3 N·m, respectively (Andersson et al., 2008; Parpa & Michaelides, 2020; Zhang et al., 2021). Minimal differences in the change of direction speed (Bishop et al., 2019; Roso-Moliner et al., 2023) were found between dominant and non-dominant leg (≈2.57 ± 0.13 s and ≈2.59 ± 0.14 s, respectively).

5. DISCUSSION

This is the first descriptive study summarizing the fitness and motor-control characteristics of professional women footballers. The fitness and motor-control profile could be better defined by including force-velocity assessments, field tests of aerobic capacity and aerobic power, lower limb range of motion (ROM) and abdominal-lumbo-pelvic complex (CORE) isometric strength. Understanding these variables is crucial for designing training programs that optimize football performance and prevent injuries. This review offers normative data on professional women footballers, aiding medical and conditioning staff in interpreting players' data and enhancing training.

The studies (75% published in the last 5 years, Table 1) reflect the growing investment in women's football (Nassis et al., 2021). This professionalization likely contributes to evolving fitness demands and injury risks faced by these players (Garcia-Tabar et al., 2022). This issue makes this descriptive study timely. Considerable variety exists in fitness and motor-control measurements.

Risk of bias analysis of the included studies showed higher methodological quality (100% *strong*) (Table 2). The QAT for Quantitative Studies likely inflated overall ratings, as "blinding" was not applicable and "selection bias" is usually *strong* within studies focused on practical outcomes. These factors may have resulted in higher overall quality scores and a greater number of studies categorized as *strong*. To advance future research on professional women footballers, it is essential to acknowledge the limitations in the use of the QAT scale.

When considering force-velocity indicators, linear sprint (75% of studies) (Andersson et al., 2008; Bishop et al., 2019; González-Fernández et al., 2022; Güler et al., 2020; Ozbar et al., 2014; Parpa & Michaelides, 2020; Roso-Moliner et al., 2023; Zhang et al., 2021) and bilateral CMJ (38%) (Andersson et al., 2008; Bishop et al., 2019; González-Fernández et al., 2022; Güler et al., 2020; Ozbar et al., 2014; Parpa & Michaelides, 2020; Roso-Moliner et al., 2023; Zhang et al., 2021) are the most common utilized variables. These variables reflect lower limb explosive power, also known as force-velocity capabilities. Some velocity-based variables measured with linear encoders are essential for tailoring effective football strength training programs (González-Badillo et al., 2015; Gorostiaga et al., 2004). Nevertheless, they were not utilized in the included studies. For endurance performance, only three studies

(38%) measured VO_{2max} (Andersson et al., 2008; Güler et al., 2020; Parpa & Michaelides, 2020). VO_{2max} assessment requires sophisticated and expensive equipment and is time consuming (Ward, 2018). Other field tests to determine aerobic capacity (Garcia-Tabar et al., 2022) or aerobic power (Garcia-Tabar et al., 2024) are time efficient, affordable, and commonly used in football (Asimakidis et al., 2024). Incorporating linear encoders for explosive force assessment and practical field tests for aerobic capacity and power could provide a more comprehensive understanding of professional women footballers' fitness performance and establish valuable normative data.

Regarding motor-control variables for injury risk assessment, the UCMJ was the most common, although it was only reported three times. This is a strong indicator of heterogeneity in the use of motor-control tests for professional women footballers. Only one study (13%) reported hip ROM (González-Fernández et al., 2022) and another (13%) reported ankle ROM (Roso-Moliner et al., 2023). Isometric CORE strength values were not provided, although are considered relevant for injury prevention training programs in women's football (Álvarez-Zafra et al., 2021; Lewis, 2000). Incorporating assessments of ROM and isometric CORE strength would provide a better definition of their motor-control functionality.

6. CONCLUSIONS

This is the first study describing the physical fitness and motor-control injury screening profile of professional women footballers. The generation of normative data provides valuable information for staff of women's football teams. However, there are still some practical concerns to be addressed in future investigations. There is a quite sparse heterogeneity on the evaluation models employed and analysed variables among others that makes data standardization challenging. Additionally, this study identifies methodological limitations that should be addressed in future research on women's football to produce higher quality scientific evidence.

It seems indispensable that research be aware of the evolving nature of the physical conditioning and motor control level profiles among women football players. This could help to understand the injury incidence pattern that seems also evolving among this population.

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WITHIN-PLAYER VARIABILITY OF WELLNESS SCORES AND MUSCLE INJURY PREDICTION IN FOOTBALL PLAYERS

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1. INTRODUCTION

Association football, a physically demanding sport, presents significant challenges for player health and team performance. Given the contemporary challenges of congested match scheduling (Julian et al., 2021), the incidence of injury in professional men's football may increase (Page et al., 2023). Muscle injuries represent a considerable problem for players and their clubs as constituted 31% of all injuries and caused 27% of the total injury absence (Ekstrand et al., 2011). The financial implications of injuries for professional clubs are substantial (Ekstrand, 2013; Eliakim et al., 2020) and player availability can also influence team performance, success, and future career prospects (Calleja-González et al., 2023; Hägglund, Waldén, Magnusson et al., 2013; Windt et al., 2018). Given these consequences, professional football clubs have a strong imperative to implement comprehensive muscle injury prevention strategies.

Wellness questionnaires are considered one of the most important monitoring tools for injury prevention among football practitioners (McCall et al., 2016). These questionnaires may help to obtain information related to a player's health, wellness status and overall readiness to train or compete (Saw et al., 2015). Additionally, these tools are non-invasive, inexpensive, time-efficient, and relatively simple to administer (Saw et al., 2015). In relation to injuries, recent systematic reviews have reported relationships between perceived wellness and injury occurrence (Jiang et al., 2022; Pillitteri et al., 2024). However, limitations remain present, and inconclusive findings emerged due to the inclusion of populations with heterogeneous characteristics, the analysis of injury risk factors grouping all types of injuries together, and disparities in statistical methods and approaches.

A potential confounding factor in identifying athletes at high risk of injury may lie in the utilization of statistical methods not optimized for handling class imbalance issues (e.g., muscle injuries), where the number of prospectively reported injured players (i.e., minority class) is consistently lower than the number of non-injured players (i.e., majority class) (Galar et al., 2012). Thus, it seems more appropriate to compare injured players to themselves (Lolli et al., 2020), because estimating how the players themselves evolve would provide a simpler and more valid approach to determine the reference ranges used to guide interpretations (Bland & Altman, 1996; Carroll, 2003). In this regard, within-player variability might represent a valuable alternative to facilitate the longitudinal tracking of perceptual responses over time both for research and applied purposes.

2. OBJETIVE

The aim of this study was to examine the predictive ability of perceived wellness on muscle injury occurrence by adopting the within-player variability of injured players as their control comparison. This exploratory study may provide insights into whether within-player variability of wellness scores may be useful for predicting muscle injury in association football players.

3. METHODS

3.1. Participants

Eighteen outfield male professional footballers (age: 26.2 ± 4.72 years, height: 1.78 ± 0.06 m, body mass: 73.1 ± 9.36 kg) of the same team were initially recruited to participate in the study. The team competed in the fourth tier of the Spanish football league system.

This study was conducted in accordance with the Declaration of Helsinki (2013). All participants volunteered to participate in the study and were informed of the objectives, procedures, benefits, and risks involved with participation in the study before providing written informed consent.

3.2. Design

This longitudinal study was conducted under nonexperimental conditions. Data were collected over nine months (from the beginning of pre-season to April). During pre-season, the team trained six times a week (97.3 ± 8.33 minutes per training session) and played six friendly matches. During the in-season period, the team trained five times a week (84.3 ± 9.02 minutes per training session) and was involved in an official match every weekend. Thus, this study included 133 training sessions and 32 matches (friendly: 6; official: 26). Wellness scores of each participant were retrospectively included in the statistical analysis only if the participant suffered a muscle injury during the data collection period ($n = 7$).

3.3. Wellness monitoring

A five-point Likert questionnaire (scores 1–5) was administered to assess a player's perceived fatigue, sleep quality, delayed onset muscle soreness (DOMS), and stress. Similarly, a five-point Likert scale has been previously used to examine self-reported wellness in football players (Abbott et al., 2018). In the current study, 1 indicated "very, very high" (fatigue, DOMS, and stress) or "very, very bad" (sleep quality) and 5 indicated "very, very low" (fatigue, DOMS, and stress) or "very, very good" (sleep quality). The questionnaire was administered individually 2 hours before each training session and match using cloud-based software (Google Docs). The use of technology has been suggested as beneficial in the implementation of self-reported questionnaires (Saw et al., 2015). Thus, this method helped to minimize factors that might influence player's wellness rating, such as peer pressure and replicating other player's scores. Participants were familiar with the psychometric tool as it was completed daily as part of their normal team monitoring routine.

3.4. Injury surveillance

Injury data were gathered prospectively through an internal platform employed by the team's medical staff for injury record management. These data were collected monthly, maintaining regular communication with the team physician/physiotherapist to ensure prompt and accurate reporting. An injury was defined as acute pain that occurred during training or a match play and resulted in immediate termination of all activity and a subsequent inability to participate in the next training session or match (van Dyk et al., 2018). Injuries were confirmed through a clinical examination by the team physician/physiotherapist and, when deemed necessary, magnetic resonance imaging was employed to support the diagnosis. Only muscle injuries that resulted in more than three days of absence were included in this study, calculated from the date of injury to the date of the player's return to full unrestricted participation in a training session or match (Lolli et al., 2020).

3.2. Statistical analysis

Descriptive results are presented as mean (M) and standard deviations (SD). For each injured player, mean scores of fatigue, sleep quality, DOMS, and stress were calculated into 7-day periods of data and expressed as percentage change from their previous 7-day periods. A logistic regression with the forced entry method was applied to determine the probability of muscle injury occurrence based on the within-player variability of wellness scores. The Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC) were used to evaluate how well the model fit the data. The percentage of the variance in the dependent variable (i.e., muscle injury occurrence) that was determined collectively by the independent variables (i.e., within-player variability of wellness scores) was calculated based on the coefficient of determination (R-Squared, R^2). R^2 was interpreted according to the following thresholds (Moore et al., 2013): very weak (<0.3), weak or low (0.3–0.5), moderate (0.5–0.7), and strong (>0.7). Afterwards, the odds ratio (OR) was calculated to measure the probability that the event of interest (i.e., muscle injury) occurs compared to the probability that it does not (Bland & Altman, 2000). The OR was estimated by the ratio of the number of times the event of interest (i.e., muscle injury) occurs to the number of times it does not (Bland & Altman, 2000). The range of OR is from zero to infinity, and a value of 1 implies no association with the specified risk, but as the value of OR increases or decreases away from 1, the association grows increasingly stronger (Chen et al., 2010). The OR was interpreted according to the following thresholds (Chen et al., 2010): very small (<1.68), small (1.68-3.47), medium (3.47–6.71) and large (>6.71). Statistical significance was inferred at $p < 0.05$. Statistical analyses were carried out using the JASP 0.16.3.0 software (University of Amsterdam, Amsterdam, Netherlands).

4. RESULTS

The average time-loss days for muscle injury were 23.9 ± 14.6 days. Each injured player missed 17 ± 10.7 training sessions (12.8 ± 8.03% of the total training sessions) and 2.80 ± 2.35 matches (8.75 ± 7.34% of the total matches).

Coefficients of logistic regression and model summary are reported in Table 1. The percentage of the variance in muscle injury occurrence that was determined collectively by the within-player variability of wellness scores was very weak ($R^2 = 0.169$; $p = 0.043$), but the model yielded significant effects for sleep quality and stress ($p < 0.05$). Notwithstanding, the probability of muscle injury occurrence depending on the variability of sleep quality and stress was very small (OR: 1.12, $p = 0.026$; OR: 0.86, $p = 0.017$; respectively).

TABLE 1. *Coefficients of logistic regression and model summary.*

	Estimate	Standard error	Odds ratio	z	Wald test	
					Wald statistic	*p*
Fatigue	-0.027	0.034	0.973	-0.798	0.637	0.425
Sleep	0.111	0.050	1.117	2.220	4.930	0.026*
DOMS	0.027	0.030	1.028	0.901	0.812	0.367
Stress	-0.149	0.062	0.861	-2.394	5.733	0.017*

*Note: *, statistically significant ($p < 0.05$)*
Model summary
Deviance: 59.774; AIC: 69.774; BIC: 85.242; p: *0.043;* R^2: *0.169.*

Figure 1 represents the s-shaped probability curve for being injured based on the within-player variability of sleep quality and stress.

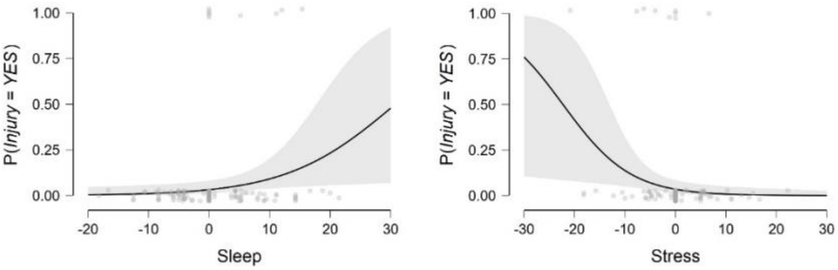

FIGURE 1. *Inferential plot with s-shaped probability curve for being injured. X-axes represent the percentage change from the previous 7-day periods.*

5. DISCUSSION

The aim of this study was to examine the predictive ability of perceived wellness on muscle injury occurrence by adopting the within-player variability of injured players as their control comparison. The main finding indicates that individual variations in sleep quality and stress may be linked to the risk of muscle injuries, though this relationship was very small.

An injury is a complex multifactorial phenomenon determined by the interaction of modifiable and non-modifiable factors (Bahr & Holme, 2003; Hägglund, Waldén, & Ekstrand, 2013), so predicting muscle injuries with high accuracy represents a complex task due to their multifactorial nature (Mandorino et al., 2021). In this regard, the current results indicate that the individual ability of some potential risk factors (i.e., within-player variability of sleep quality and stress) to impact on the likelihood of suffering a muscle injury was very small while others (i.e., within-player variability of fatigue and DOMS) were not statistically significant. Perhaps one of the main reasons behind the model's limited ability to explain muscle injury occurrence could be the sample size. It has been suggested that prospective studies investigating potential risk factors for sports injuries require a minimum of 20–50 injury cases to detect moderate to strong associations (Bahr & Holme, 2003). Another reason for this finding might be that the predictive ability of each potential risk factor could be very small unless analysed in conjunction with other known factors simultaneously, as a complex component or factor (Mandorino et al., 2021; Mendiguchia et al., 2012; López-Valenciano et al., 2018).

Although evidence is not conclusive, previous studies have also reported that sleep and stress might be associated with the risk of injury occurrence in professional footballers (Ayala et al., 2019; Laux et al., 2015; Silva et al., 2020; Vallance et al., 2020), for one-week (Vallance et al., 2020) and one- (Laux et al., 2015; Vallance et al., 2020) and nine-month time horizon (Ayala et al., 2019). However, these findings were not consistent, as no clear relationship was found between the occurrence of injuries and other daily, weekly, and monthly measures of perceived wellness in youth football players (Brink et al., 2010; Watson et al., 2017).

Several factors may be responsible for the observed discrepancies between previous studies and the current one, including individual interpretations of the wellness scale and scoring (Saw et al., 2015), the current lack of a comprehensive theoretical framework underpinning wellness as a construct (Jeffries et al., 2020), and the absence of established validation procedures (e.g., clinimetrics) for individual wellness items (Jeffries et al., 2020; Saw, et al., 2017). On one hand, it is important to acknowledge the inherent lack of standardization in individual scoring (Saw et al., 2015). Some players may exhibit consistent scores within a narrow range, while others may demonstrate significant variability. Additionally, the value a player considers as their normal may be the midpoint on the scale or at the lower or upper end of the scale, so equivalent scores may not indicate equivalent levels of fatigue, sleep quality, DOMS, and stress. This observation highlights the necessity of interpreting wellness data within the context of each player's scoring habits (Saw et al., 2017). Thus, as previously suggested (Saw et al., 2017), the use of within-player variability of wellness scores is strongly recommended to analyse the potential influence of perceived wellness on muscle injury occurrence. On the other hand, the potential individual interpretation and scoring is also related to the issues with the scales themselves as it is yet to be precisely determined whether the single items can accurately reflect complex and multifactorial constructs (Jeffries et al., 2020; Saw, et al., 2017). Finally, discrepancies may also arise from methodological variations across studies, including statistical analysis methods, types of injuries, data manipulation and data collection periods.

Apart from the small sample size and the specific characteristics of the participants, which may influence the study findings, other limitations require careful consideration. On one hand, the study employed a five-point Likert questionnaire with custom measures widely used in research and practice (Duignan et al., 2020), but its validity was not rigorously evaluated as recommended by previous studies (Jeffries et al., 2020; Saw et al., 2017). Consequently, the psychometric properties of self-reported wellness questionnaires used in future research should be evaluated, as the findings may not be interpretable without a robust framework for understanding what these measures truly represent. On the other hand, this study used technology-based solutions to mitigate potential peer pressure influencing player responses. However, it was not able to confirm whether participants completed the questionnaire independently before joining their teammates (i.e., in their own time) or upon arrival at the venue, potentially within a group setting.

From a practical perspective, the findings of the current research advocate for the incorporation of a perceived wellness questionnaire into the monitoring practices of professional football teams. By analysing changes in players' daily perceived wellness, practitioners may obtain valuable information about player health and overall readiness to train or compete (Saw et al., 2015). In this regard, the use of a self-reported wellness questionnaires may offer valuable insights into explaining some potential risk factors that could be related to muscle injury occurrence. However, it is crucial to consider this data alongside other potential intrinsic and extrinsic risk factors known to influence injury occurrence (Bahr & Holme, 2003; Hägglund, Waldén & Ekstrand, 2013; Mandorino et al., 2021). Moreover, such data can support objective decision-making, as daily monitoring of players' perceived wellness may be important to promptly identifying warning signals and to taking timely preventive measures, such as training load reduction, recovery strategies, or individualized training sessions.

6. CONCLUSIONS

Results of this prospective study indicate that the proportion of the variance in muscle injury occurrence that may be explained by the within-player variability of wellness scores was very weak. Interestingly, individual variations in sleep quality and stress may be linked to the risk of muscle injuries, though this relationship was very small. Thus, the practical significance of this finding warrants cautious interpretation due to the model's limited ability to explain muscle injury occurrence.

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INCORPORATION OF OBJECTIVE AND SUBJECTIVE AUTOREGULATION STRATEGIES IN ANTERIOR CRUCIATE LIGAMENT INJURY PREVENTION RESISTANCE TRAINING PROTOCOLS: A COMPREHENSIVE AND INNOVATIVE APPROACH FOR INCREASED EFFECTIVENESS

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1. INTRODUCTION

The anterior cruciate ligament (ACL) is one of the main stabilizers in the knee joint preventing anterior tibial translation on the femur, as well as medial and lateral rotation of the tibia (Dewig et al, 2024). Although extensive research has been conducted on ACL injuries, the rate of such injuries in professional contact and non-contact sports has not decreased over the years (Mazza et al, 2022). The overall incidence of ACL injuries in association football athletes has been reported to range from 0.06 to 10 injuries per 1000 game hours, with the highest rates observed in professional players (Brophy et al, 2015); interestingly, the mean annual ACL injury occurrence rate in European professional players competing in the top 8 European Leagues has been reported to be around 1.42% (Mazza et al, 2022). It should also be noted that 27% of females and 10% of males that have underwent ACL surgical reconstruction have suffered a secondary ACL injury (Hong et al, 2023).

This chapter will give an overview of preventable ACL injury types, main mechanisms of ACL injury, and associated risk factors before discussing the basic elements of ACL reconditioning and ACL injury prevention protocols as presented in literature. Subsequently, the suggested use of training load as a marker of strength/power training progression/regression as well as a fatigue monitoring tool will lead to the analysis of the predominant load monitoring training strategies along with the corresponding guidelines for their implementation in the practical setting. The main proximity to failure strategies used by researchers and practitioners will be illustrated both in isolation and in tandem, using sample protocols applicable to ACL injury prevention for footballers. The chapter will then proceed in recommending a comprehensive, flexible, and innovative load monitoring training strategy for ACL injury prevention in association football, by viewing proximity to failure methods as complementary and not mutually exclusive. Practical implementation of the proposed framework will be enabled by different training scenarios and circumstances, whereby the utility of this model will be demonstrated.

2. ACL IN ITSELF

ACL injuries that emerge under contact circumstances cannot be easily prevented; however, exercise-based risk prevention interventions have demonstrated stronger effects on non-contact ACL injuries (Chia et al, 2022). Non-contact ACL injuries account for up to 70-84% of all ACL injuries in athletes and mainly occur because of cutting/stopping drills coupled with deceleration/change of direction and landing from a jump (Kaneko et al, 2017). It must also be noted that indirect contact ACL injuries in football have been reported to be as frequent as non-contact injuries and mainly result from mechanical perturbation experienced under pressing circumstances or during tackling and kicking conditions (Della Villa et al, 2020). The most frequent mechanism of ACL injury incorporates an abducted and flexed hip with the knee at the first degrees of flexion and under valgus external rotation (Grassi et al, 2017); knee and hip flexion angles of around 0-30 degrees have been correlated with ACL injury occurrences (Schick et al, 2023).

Several anatomic, neuromuscular, intrinsic, and extrinsic factors have been correlated with increased risks of experiencing an ACL injury.

- Anatomic factors incorporate decreased femoral intercondylar notch width, altered geometry of the tibial plateau (including decreased depth of concavity of the medial tibial plateau), increased posterior-inferior-directed slope of the medial/lateral tibial plateau, and increased anterior-posterior knee laxity; however, the proposed neuromuscular factors, such as increased hip abduction and valgus intersegmental moment have not been fully validated (Smith et al, 2012a).

- One of the main intrinsic factors in the manifestation of ACL injuries is gender, with female footballers being 2.67 times more likely to experience an ACL injury compared to their male counterparts (Prodromos et al, 2007). Research has also demonstrated that ACL injuries are more likely to occur during the preovulatory phase of the menstrual cycle (Shultz et al, 2010), although such allegations have not been fully validated (Smith et al, 2012b). Another intrinsic factor that has been associated with increased ACL injury risk is genetic predisposition, with injured athletes being more likely to have a relative that has suffered an ACL injury in the past (Flynn et al, 2005), while gene codes that have been associated with ACL injury risk have been shown to be overrepresented in athletes that have suffered ACL tears (Posthumus et al, 2009). Additionally, a proposed intrinsic risk factor that needs to be further explored is neurocognitive function, with ACL injured patients demonstrating slower reaction time and processing speed compared to uninjured individuals (Swanik et al, 2007). Past injuries, including ACL reconstruction surgery and ankle sprain can also predispose athletes to ACL tear in the contralateral and ipsilateral leg respectively (Walden et al, 2006; Kramer et al, 2007).
- Extrinsic risk factors are comprised of weather, type and condition of playing surface, and footwear, which eventually affect shoe-surface interaction (Orchard et al, 2001). Although further research is warranted to determine if friction coefficients and mechanical interlock between shoe and playing surface are correlated with ACL

injury risk (Smith et al, 2012b), it is suggested that a high level of friction and mechanical interlock may be generated among others, by the shoe type and number of cleats, the design of the shoe, type of grass, floor surface, and weather conditions (Orchard et al, 2003). It is important to note that ACL risk factors of any type may act in combination to affect the severity of injury risk (Smith et al,2012a).

2.1. Basic elements of ACL reconditioning

I have devised and implemented an extensive range of ACL injury prevention/reconditioning protocols following medical and physiotherapeutic clearance. All protocols have demonstrated high levels of efficacy as assessed by orthopedic doctors and physiotherapists at regular time intervals during the reconditioning/prevention macrocycle. I have specifically worked with athletes of multiple sporting backgrounds, including association football, basketball, tennis, boxing, mixed martial arts, and skateboard. When constructing the reconditioning/prevention regimen, a strength and conditioning coach-applied sports scientist needs to take into consideration the intricacies of each respective sport and adopt a highly personalized approach to address inter-individual variability. Regardless of the initial periodized planning procedure, the reconditioning/prevention protocol may also require additional adjustments on a frequent basis to make up for the potentially distinct responses of each respective athlete to the training stimuli.

Reconditioning protocols following ACL reconstruction should emphasize on several key areas including neuromuscular performance (e.g., strength and power), optimization of landing mechanics, movement quality, restoration of knee extensor strength/rate of force development, and lower limb closed-chain strength/power (Buckthorpe & Della Villa, 2021).

- Neuromuscular performance training focuses on eliminating lower-limb neuromuscular control, strength, ground reaction force production/absorption deficits and functional limitations so that re-injury risk is minimized and optimal performance is realized (Myer et al, 2008). Neuromuscular control deficits have been also associated with lateral trunk deviation and subsequent suboptimal landing mechanics, which may augment ACL re-injury risk (Bell et al, 2014). It has also been reported that movement quality has been compromised in both the injured and non-injured limb following ACL reconstruction in a multitude of functional tasks and its restoration should be emphasized accordingly (Buckthorpe et al, 2020).

- Strength training wise, it is essential to utilize both closed and open kinetic chain exercises of both limbs and gradually progress to functional movements, as part of a periodized ACL reconditioning protocol; strength training should not be limited to the muscles of the affected joint but also address dysfunctions at the hip and core musculature in order to ensure a comprehensive approach to knee extension strength restoration (Buckthorpe et al, 2019). Additionally, deficits in rate of force development should be addressed as part of reestablishing lower limb strength and power (Angelozzi et al, 2012).

Despite the effectiveness of various strength, proprioceptive, and neuromuscular control drills/exercises on facilitating a fast and safe return to sport (Wilk & Arigo, 2016), explicit guidelines for implementation of such protocols cannot be determined from current research.

2.2. Basic elements of ACL injury prevention

Literature has focused on three tenets of exercise modalities in ACL injury prevention:

- Plyometrics; plyometric exercises are employed with a direct focus on body mechanics and landing strategies to optimize technique, which can safeguard athletes against ACL injuries.

- Neuromuscular training; balance and proprioceptive activities with an emphasis on the optimization of muscle firing rate, dynamic joint stability, and postural control, which can collectively enhance bilateral deficits in key lower limb measures.
- Strength training; resistance training exercises can boost the overall effectiveness of ACL injury prevention programs when combined with the previously mentioned components (Nessler et al, 2017).

A position statement composed by the National Athletic Trainer's Association provided similar recommendations with multi-component training programs consisting of feedback on exercise form and at least three exercise categories out of strength, plyometrics, agility, flexibility, balance, and proprioception; the principal goal of such programs is to enhance lower limb biomechanics (e.g., increase sagittal- and decrease frontal/transverse-plane movement), balance, lower-limb strength/power, muscle activation (e.g., hamstrings/glutes) , as well as functional performance (vertical displacement, sprint speed), and decrease impact force upon landing (Padua et al, 2018).

Another ACL injury prevention strategy is the FIFA 11+ warm-up protocol, which is comprised of activities targeting core stabilization, dynamic stabilization, hamstring eccentric strength, proprioception, plyometric ability, and postural control (Sadigurski et al, 2017). The FIFA 11+ warm-up program has been demonstrated as an efficacious ACL injury prevention strategy, purported to decrease injury risk by 30% (Olivares-Jabalera et al, 2017). Despite the suggested effectiveness of evidence-based ACL injury prevention protocols, the optimal composition of such protocols remains unclear; on top of this, intensity and volume considerations have not been delineated (Taylor et al, 2015), posing a challenge to the development of explicit ACL injury prevention protocols.

3. ACL INJURY PREVENTION/RECONDITIONING AND TRAINING LOAD

A proposed methodology of preventing the injury or re-injury risk following rehabilitation as well as enabling a safe return to sport following ACL reconstruction is the quantification of external and internal loads experienced during training (Taylor et al, 2021). Training load can be either measured as the mechanical work performed by an athlete (external load) or the physiological/psychological stress imposed upon the athlete following a training session (internal load) and has been correlated with the incidence rates of injury (Soligard et al, 2016). Methods of external load measurement incorporate total distance covered, number of accelerations, decelerations, or changes of direction (COD) executed, as well as number of jumps performed in a training session/actual competitive setting and total volume load during resistance training, while internal load measurement is facilitated by ratings of perceived exertion scales (RPE), repetitions in reserve-based (RIR) RPE scales, and physiological responses like resting heart rate variability (HRV) (Helms et al, 2016; Taylor et al, 2021). Training load measures can be calculated using wearable technology or wearable devices including global positioning system (GPS) instruments, velocity-based training devices (VBT)/accelerometers, force measuring insoles, and heart rate monitors or just simple mathematical calculations; these devices have demonstrated adequate validity and reliability (Scott et al, 2016; O'Driscoll et al, 2020). Nevertheless, workload monitoring has not been applied during ACL rehabilitation-reconditioning-prevention protocols to either facilitate a safe return to sport following ACL reconstruction (Taylor et al, 2021) or prevent the occurrence of ACL-related injuries in the first place.

Longitudinal workload monitoring is suggested to be a useful tool in exploring the relationship between changes in training load/fatigue and the occurrence of injury in the long-term (Jones et al, 2017). Such monitoring could potentially unveil injury trends and establish the requisite guidelines for individualized training prescription throughout the macrocycle, with the aim of performance optimization, overtraining prevention, and injury rate reduction (Halson, 2014). There is moderate evidence that demonstrates the link between the applied training load and the incidence of injury, rendering the establishment of load monitoring strategies as an essential injury/re-injury prevention tool (Drew & Finch, 2016). Nevertheless, there is no strong evidence that advocates the use of training load data to inform the manipulation of training variables in periodized injury prevention/reconditioning plans (Impellizeri et al, 2020a). It should be noted that training load should not be used as an independent measure of injury risk assessments but as a complementary tool to professional experience, evidence-based practice, and scientific knowledge of physiological mechanisms/adaptations pertaining to training stimuli (Impellizeri et al, 2020b).

4. CURRENT GUIDELINES OF PROXIMITY TO FAILURE TRAINING STRATEGIES IN ACL INJURY PREVENTION/RECONDITIONING

4.1. Percentage-based training

From my experience, percentage-based (PBT)/multiple RM (MRM) training has been predominantly used for load monitoring and prescription during ACL reconditioning/prevention protocols. Since its inception by Thomas Delorne in the 1940s, PBT has been widely used by practitioners and explored by the research community (Liao et al, 2021).

- Bieler et al (2014) investigated the effects of high and low intensity resistance training on knee extensor power and knee function restoration following ACL reconstruction; they prescribed a progressive weight training protocol with either a high load intensity ranging from 20RM to 8RM or a low load intensity from 30RM to 20RM to volitional failure (Bieler et al, 2014).
- It has also been recommended that muscular strength maximization requires 2-6 sets of 1-12 reps of moderate to heavy loads at an intensity of at least 60-67% 1RM during the third phase of ACL rehabilitation, while power is suggested to peak at 30% 1RM, and speed and rate of force development is best targeted when 1-5 reps at 75-

90% 1RM are being performed during the fourth phase of ACL rehabilitation (Bousquet et al, 2018).

- Welling et al (2019) employed two maximal sets of 15-25 repetitions at <50% 1RM to elicit muscle endurance adaptations during the third and fourth phase of ACL rehabilitation, while maximum strength development was targeted using 2-4 sets of 8-10 reps at 60-80% 1RM during the third phase, and 5 sets of 3 reps at an intensity greater than 80% 1RM during the fourth ACL rehabilitation phase.
- Fort-Vanmeerhaeghe et al (2021) recommended traditional guidelines of 3-5 sets of 6-12 reps at 65-85% 1RM as most appropriate during the ACL injury return to activity phase, and supported that individuals should gradually progress from lower to higher intensities and volumes and finally build the capacity to perform 6-8 maximal repetitions at 80-85% 1RM for the fundamental lower-limb strength exercises (e.g., barbell back squat) by the end of this phase.
- On the other hand, Larson et al (2021) supported the use of a programming progression compatible with the principles of Vermeil's hierarchy; 2-4 sets of 12-20 reps at <70% 1RM for muscular endurance maximization, 6-10 sets of 8-12 reps at 70-80% 1RM to target muscle hypertrophy, 3-5 sets of 5-8 reps at an intensity greater than 80% if the goal is maximum strength, 3-6 sets of 3-6 reps at 30-45% 1RM to elicit peak power/rate of force development adaptations, and 3-6 sets of 3-6 reps at<30% 1RM for reactive strength maximization.

It is evident that research lacks consistent guidelines about the prescription of resistance training following ACL reconstruction; in fact, existing literature may not be fully compatible with evidence-based resistance training principles (Nichols et al, 2021).

Despite its widespread use and popularity, PBT is not likely to cause momentary or volitional failure for every individual, as well as the same inter-individual repetitions in reserve for submaximal efforts (Pelland et al, 2022). Daily fluctuations in the expression of acute strength resulting from normal biological variability and fatigue prevent the accurate determination of the relative load intensity from the absolute load intensity, even more so in novice athletes who experience large strength increases following a few training sessions (Zhang et al, 2023). It is important to note that regardless of the training protocol used, evidence suggests that training to failure is not deemed necessary for muscle strength and size gains to be realized (Grgic et al, 2022), while safety in the early stages of rehabilitation may be compromised (Larson et al, 2021); in fact, it has been suggested that one of the main limitations of PBT corresponds with the reduction of type II muscle fiber adaptation resulting from consistently training to failure (Liao et al, 2021). Such considerations necessitate the exploration of complementary/alternative proximity to failure training strategies to address the limitations of PBT.

4.2. Autoregulation training as an alternative/complement to percentage-based training

Autoregulation was originally introduced in physiotherapeutic research and subsequently its use was extended to the sports performance arena, although additional research is warranted to evaluate its effectiveness (Burton, 2021).

- Autoregulation training was initially applied using progressive resistance training (PRE), whereby progressively heavier sets of 10 repetitions were executed: one set at 50% 10RM, one set at 75% 10RM, and one set at 100% 10RM (Delorme et al, 1950).
- Subsequently, DAPRE (daily adjustable progressive resistance exercise) was introduced as an extension of the PRE-method and incorporated an autoregulated training set, which was purported to account for the variation in the daily readiness of an individual during the rehabilitation procedure and allowed for an objective determination of the ideal timing to increase the applied

  resistance as well as the ideal amount of weight to be increased (Greig et al, 2020; Burton, 2021).

- DAPRE was further revised to address inter-individual variability and distinct training goals with the introduction of APRE (autoregulatory progressive resistance exercise), which enables systematic neuromuscular adaptations and prevents tissue/joint overload and subsequent injury/re-injury (Brummit & Cuddeford, 2015). The implementation of APRE as an autoregulated training strategy has been demonstrated to be safe and effective for strength enhancement in both healthy individuals and populations rehabilitating from injury, at least in the short-term (Horschig et al, 2014). APRE protocols require the establishment of 1RM or MRM; however, as expected during certain periods of the rehabilitation process, training sets to failure may be contraindicated (Lorenz & Morsison, 2015).

Subjective autoregulation using RPE scales allows the determination of exercise intensity without the need for maximal training sets and represents a viable alternative option (Helms et al, 2020). The development of a resistance-training specific scale, the RIR-based RPE scale can also prevent training to failure and counteract the intra-individual fluctuations in daily exercise readiness (Lovegrove et al, 2021), while it has been suggested to be an effective proximity to failure/load prescription-monitoring training strategy (Zourdos et al, 2016), especially during sets with a relatively low repetition volume (Orsmbee et al, 2019; Larsen et al, 2021). Furthermore, it may also be applicable to clinical populations recovering from injury (Fairman et al, 2018). Despite the substantial benefits of subjective autoregulation, objective autoregulation training strategies seem to be more effective (Shattock & Tee, 2020).

Objective autoregulation manifested using velocity-based linear transducers or inertial measurement units that measure barbell velocity during a resistance training set, are purported to be more sensitive to daily fluctuations in fatigue as well as better estimate the desired proximity to failure compared to PBT (Shattock & Tee, 2020). For instance, changes in 1 repetition maximum (1RM), as assessed by PBT may not correlate with changes in the entire force-velocity spectrum, missing essential information about the athlete's high- and low speed strength capacity (Jovanovic & Flanagan, 2014). Force velocity profiling is a physiological monitoring tool, whereby athletes execute maximal efforts against various load intensities, while the generated force and velocity are being measured (Lindberg et al, 2021). Force-velocity profiling is very useful in load monitoring and prescription especially when practitioners measure the force velocity imbalance, which corresponds with the difference between the actual and desired force velocity profile of a respective athlete (Jimenes-Reyes et al, 2017); it seems that individualized force-velocity profiles need to be assessed in conjunction with 1RM/MRM changes.

Velocity-based training (VBT) devices have been employed in monitoring fatigue/exertion or quantifying training load during resistance training and have demonstrated high validity and reliability (Thompson et al, 2020; Włodarczyk et al, 2021; Achermann et al, 2023). VBT may induce strength, countermovement jump, sprint, and change of direction performance improvements with lower total training load and reduced accumulation of fatigue (Pareja-Blanco et al, 2017). The application of VBT is facilitated using two variables:

- The initial fastest repetition velocity, which is used to prescribe load intensity instead of the relative 1RM percentage.
- The velocity loss threshold, which is used to determine set completion instead of a fixed number of repetitions (Liao et al, 2021).

The fastest repetition velocity has been demonstrated to quite accurately predict the maximum number of repetitions that can be performed during VBT training protocols and represents a useful load intensity prescription tool (Jukic et al, 2023). Research has also demonstrated that velocity loss thresholds have the capacity to maintain velocity and power output during resistance training providing the practitioner with an additional prescription strategy. The overall predictive ability of velocity-based training (VBT) strategies may be further enhanced by the incorporation of subjective autoregulation (Balsalobre-Fernandez et al, 2021), while recent evidence has demonstrated that both subjective and objective autoregulation are likewise effective with PBT proximity to failure strategies in improving strength/power qualities (Hickmott et al, 2022). It is proposed that practitioners should take advantage of all available proximity to failure training strategies by acknowledging the limitations pertaining to each one of them.

4.3. Application of subjective/objective autoregulation in ACL injury prevention/reconditioning

There is paucity of research in the application of both objective and subjective autoregulation proximity to failure training strategies on load prescription/monitoring following ACL reconstruction.

- Germano-Maciel et al (2022) recently explored the use of RPE autoregulation training as a load monitoring strategy in individuals that had undergone ACL reconstruction and concluded that RPE could affect the progress of rehabilitation process by either over- or under-prescribing total volume load.
- Forelli et al (2024) recently presented a clinical commentary on the implementation of VBT as a means of optimizing return to sprint after ACL reconstruction in football players, stressing the importance of maximum voluntary velocity as an insightful measurement variable during both non-sprint and sprint specific strength training (Forelli et al, 2024; Balsalobre-Fernandez et al, 2021); determination of the maximal velocity during strength training exercises can better inform specific strength development in relation to the speed of movement (Forelli et al, 2024).

- Samozino & Picot (2023) supported that most ACL rehabilitation strength training protocols have targeted the force segment of the force velocity curve and have failed to address the high velocity component even though athletes may be more likely to demonstrate force deficits at higher velocities (Samozino & Picot, 2023). VBT may develop strength qualities at low, intermediate, and high movement velocities and address the distinct neuromuscular and structural requirements associated with each respective velocity zone (Samozino & Picot, 2023).

Despite the lack of VBT research in the field of physiotherapy, it is suggested that it may serve as a helpful tool in musculoskeletal rehabilitation even more so in athletes taking part in strength and conditioning activities or transitioning from rehabilitation to strength and conditioning (Lorenz & Morrison, 2015; Forelli et al, 2024). Given the substantial strength-power requirements of the ACL reconditioning process, the effects of different proximity to failure training strategies need to be further investigated. Proximity to failure strategies are not only warranted during ACL reconditioning training but also during ACL injury prevention protocols. However, to my knowledge there is no current evidence on the application of proximity to failure strategies on ACL injury prevention protocols. Research has neither adequately addressed nor developed explicit guidelines regarding the volume load component of ACL injury prevention protocols (Taylor et al, 2015).

5. OBJETIVE

This chapter focuses on how strength-power training, an essential component of neuromuscular performance training during ACL injury prevention training protocols, can benefit from the combined application of PBT, subjective and objective proximity to failure training strategies. The optimization and standardization of basic guidelines in resistance exercise prescription and associated variables during ACL prevention training strategies is warranted. You may access three injury prevention protocol samples using

PBT, VBT, and VBT+RIR/RPE respectively below (Tables 1-3). It can be further speculated that VBT combined with the RIR/RPE scale and PBT may provide practitioners with a harmonized, possibly safer, highly flexible, and more efficacious strategy of resistance training load monitoring/prescription during year-round ACL injury prevention mesocycles. It is expected that strength-power improvements via the application of PBT, VBT, and RIR/RPE can serve the basis for subsequent improvements in the abovementioned parameters of jump, sprint, and change of direction performance (Suchomel et al, 2016). It can be theoretically proposed that improvements in physical performance parameters as a result of the combined implementation of PBT, VBT and RIR/RPE may further optimize landing mechanics, limit the occurrence of dynamic knee valgus (Schweizer et al, 2022), optimize acceleration and maximal velocity mechanics, gradually restore knee flexion range of motion and internal knee extension moment reductions (Pairot-De-Fontenay et al, 2019; Schweizer et al, 2022), as well as limit external knee valgus moment, internal tibial rotation moment, and knee flexion angle asymmetry (Marques et al, 2020).

TABLE 1. *Percentage-based training (PBT) off-season strength training injury prevention protocol – 1st mesocycle.*

PBT lower body strength training protocol (focus on vastus medialis) 4-week mesocycle Frequency: 2 non-consecutive days per week		Sets	Reps	Rest interval
	Warm-up: dynamic stretching			
1	Barbell sumo squat (axial force vector)	3	6 @ 85% 5RM	2min
2	Barbell hip thrust (anteroposterior force vector)	3	6 @ 85% 5RM	2min
3	Physio ball single-leg squat (ball to the side of the uninvolved leg)-vastus medialis oblique activation	2	8 @ 75% 5RM	1min
4	Side lunge (sagittal + frontal plane)- (lateromedial force vectors)	2	8 @ 75% 5RM	1min
5	Single-leg knee extension (toes out)	2	10 @ 70% 8RM	1min
6	Single-leg contralateral landmine Romanian deadlift (torsional force vectors)	2	8 @ 75% 5RM	1min
7	Single-leg seated leg curl	2	10 @ 70% 8RM	1min
8	Transverse plane hip abduction	2	10 @ 70% 8RM	45sec
9	Transverse plane hip adduction	2	10 @ 70% 8RM	45sec
10	Heel to toe walking (weighted)	2	30sec	45sec
	Cool-down: static stretching			

TABLE 2. *Velocity-based training (VBT) pre-season strength training injury prevention protocol – 2nd mesocycle.*

VBT lower body strength training protocol (focus on vastus medialis) 4-week mesocycle Frequency: 2 non-consecutive days per week		Sets	Velocity	Velocity loss	Rest
	Warm-up: dynamic stretching				
1	Barbell deadlift (axial force vector)	3	0.30-0.40 m/s	≤25%	3min
2	Barbell front squat (axial force vector)	3	0.30-0.40 m/s	≤25%	3min
3	Barbell hip thrust (anteroposterior force vector)	3	0.30-0.40 m/s	≤25%	3min
4	Lateral step-up (lateromedial force vectors)	2	0.50-0.60 m/s	<25%	2min
5	Single-leg knee extension (toes out)	2	0.50-0.60 m/s	<25%	1min
6	Single-leg lying leg curl	2	0.50-0.60 m/s	<25%	1min
7	Smith-machine standing calf raise	3	0.50-0.60 m/s	<25%	1min
	Cool-down: static stretching				

TABLE 3. *Velocity-based training (VBT)-Repetitions in reserve-based (RIR) / Rating of perceived exertion scale (RPE) in-season strength training injury prevention protocol – 2nd mesocycle.*

VBT/RIR/RPE/PBT lower body strength training protocol (focus on vastus medialis) 2-week mesocycle Frequency: once per week		Sets	Velocity	Velocity loss/RIR	Rest
	Warm-up: dynamic stretching				
1	Power clean (axial force vector)	2-3	1.20-1.32 m/s	1-2 RIR	4min
2	Barbell front squat (axial force vector)	2-3	0.35-0.45 m/s	10-20% VL 1-3RIR	4min
3	Barbell hip thrust (anteroposterior force vectors)	2-3	0.35-0.45 m/s	10-20% VL 1-3RIR	4min
4	Single-leg contralateral landmine Romanian deadlift (torsional force vectors)	2	0.55-0.65 m/s	3RIR	2min
5	Lateral step-up (lateromedial force vector)	2	0.55-0.65 m/s	3RIR	2min
6	Nordic curls (anteroposterior force vectors)	2	-	3RIR	2min
	Cool-down: static stretching				

6. MY ACL INJURY PREVENTION PROPOSAL

Strength and conditioning coaches are the first line of defense against any kind of sports-related injury; they are in charge of developing, structuring and implementing the physical fitness periodization plan of athletes. Research advocates the implementation of strength and conditioning training protocols for injury prevention in football players (Tapley & Siesmaa, 2017;

Beato et al, 2021). However, strength and conditioning coaches need to acquire the requisite scientific knowledge to translate research into evidence-based practical applications. Targeted implementation of ACL injury prevention protocols for association football should incorporate the following: A) neuromuscular training programs to enhance lower-body strength-power and coordination (Steffen et al, 2013), B) the development and application of educational courses to upgrade the knowledge of coaches and athletes on ACL injury prevention principles (Myklebust et al, 2013), C) policies devised by sporting federations to facilitate the implementation of neuromuscular training programs (Bizzini et al, 2013). However, the strength and conditioning coach needs to be also aware of the intricacies of football as well as the individualized requirements of each athlete during each part of the season to ascertain the effectiveness and efficiency of the injury prevention protocols.

The combined use of PBT, VBT and RIR/RPE for resistance training load monitoring/prescription is suggested to provide practitioners with an individualized neuromuscular training strategy that can target improvements in strength, power, speed, and change of direction athletic capacities of footballers. However, it has not been applied in injury prevention in general, and ACL injury prevention strategies in particular. This commentary advocates the inclusion of a combined implementation of PBT, VBT and RIR/RPE in ACL injury prevention protocols and training interventions that can be implemented in real-life football training scenarios.

6.1. Recommendations for percentage-based training in ACL injury prevention for footballers

Practitioners should take into account the following recommendations when applying PBT as a load monitoring strategy in ACL injury prevention training protocols for football players:

- If strength optimization is the primary goal, then heavy loads for 1-5 repetitions per set at 80-100% 1RM should be applied.

- If hypertrophy is the main target, it is advisable to use moderate loads for 6-12 repetitions per set at 60-80% 1RM or train to volitional failure with a minimum threshold intensity of 30% 1RM.
- If muscular endurance is the primary aim, it is recommended to use light loads for 15 or more reps per set at less than 60% 1RM (Schoenfield et al, 2021).
- If lower-body muscle power is to be optimized, loads of more than 30% 1RM and less than 70% 1RM are required for the squat exercise, less than or equal to 30% 1RM for the squat jump exercise, and equal or greater than 70% 1RM for the hang power/power clean exercise.

Therefore, hypertrophic gains seem to be independent of the load intensity, strength gains seem to be more pronounced in high load intensity programs, and a wide range of load intensities ranging from low to moderately high, seem capable of maximizing power gains (Lopez et al, 2021).

6.2. Incorporation of subjective autoregulation in percentage-based injury prevention protocols for footballers

PBT training can be effectively complemented with subjective autoregulation training strategies in general and RIR-based RPE scales in particular, which are purported to better address daily fluctuations in exercise performance (Helms et al, 2016). Given the inherent variability in human performance due to genetic and psychological differences, as well as other factors, including sleep patterns, nutrition, recovery/adaptation capacity, hormonal/muscle damage biomarkers, training background, and everyday stressors, strength capacity may fluctuate on a daily basis (Helms et al, 2018; Larsen et al, 2021).

Helms et al (2016) created a chart whereby the corresponding percentages of 1RM were matched with repetitions, and RIR-based RPE values. The chart was developed according to the data provided by trained lifters taking part in a study put together by Zourdos et al (2016); given the variation in the number of repetitions that can be performed by different individuals for a given % 1RM, the daily fluctuations in repetitions performed at a given % 1RM for the same individual, and that the study was limited to the back-squat exercise and experienced lifters, this scale cannot be extrapolated to other populations and exercises (Helms et al, 2016). PBT can be combined with reference RIR values from the RIR-based RPE scale reaping the advantages of both proximity to failure training strategies. PBT has been demonstrated to be an effective strategy of load prescription and may allow practitioners to better handle the accumulation of residual fatigue and prevent the emergence of an unintended over-reaching state (Thompson et al, 2020). PBT load prescription has also exhibited similar maximal strength improvements with autoregulation resistance training strategies (Hickmott et al, 2022). On the other hand, RIR-based RPE has been shown to possess a small advantage over PBT in the back and front squat exercises for increasing 1RM (Larsen et al, 2021); RPE-based load prescription, which is a component of the RIR-based RPE scale has also exhibited small benefit over PBT in improving maximal strength during squats in the majority of tested individuals (Helms et al, 2018).

The validity of the RIR-based RPE scale for load intensity prescription depends on the extent that the final repetition velocity decreases as the score of the corresponding set increases, while such an inverse relationship is most prominent in experienced lifters and during sets that are executed close or a few repetitions short of volitional failure (Helms et al, 2016). A limitation associated with RIR-based RPE scales is that perceived effort may not be precisely estimated during a set because of inter-individual variability (Larsen et al, 2021).

Prescription of exercise intensity using the RIR-based RPE scale is not mutually exclusive with prescription of intensity with PBT proximity to failure strategy; the combined implementation of both strategies is characterized by a more objective approach to exercise prescription compared to the sole use of the highly subjective RIR-based RPE scale (Helms et al, 2016). The proposed exercise intensity prescription strategy for football players will initially be based on elements drawn from the research studies composed by Zourdos et al (2016), Helms et al (2016, 2018), and Burton (2021). Our initial suggestion will incorporate PBT, RIR, RPE, and associated load adjustments based on the combination of such proximity to failure strategies. For instance, if strength and conditioning coaches wish to prescribe 3 working sets of 5 repetitions @ 85% 1RM, they might also accompany the target volume load with the corresponding number of RIR; in this example the practitioners might seek for a range of 0-3 RIR, with the first two sets completed with 2-3 RIR, and the last set with 0-1 RIR. The RPE associated with 2-3 RIR would be 7-8, while 0-1 RIR correspond with 9-10 RPE; the lifter will adjust exercise intensity according to his daily performance state. Let us consider that our athlete completes the assigned 5 reps @ 85% 1RM during the first set with a 0-1 RIR instead of the targeted 2-3 RIR. The lifter will be instructed to lower the weight from around 4% to 8% to match the prescribed exercise intensity in the subsequent working set. Table 4 provides an illustration of how the corresponding variables could be incorporated and applied into a single model using various combinations of targeted reps at various percentages of repetition maximum.

It is important to note that the number of repetitions that can be executed during free weight exercises at variable percentages of 1RM is affected by the degree of muscle recruitment with higher recruitment (back squat versus bench press versus arm curl) enabling a higher number of completed repetitions at a given intensity regardless of the individual training status (Shimano et al, 2006). Although a generalized table that has recorded the relationship between repetitions and percentages of 1RM already exists, it possesses inherent limitations, failing to address variation between individuals; Nuzzo et al (2023) utilized meta-regression and analysed available evidence on failure training tests to generate a revised table applicable to most exercises and populations; it is warranted though that additional tables are developed to address muscle recruitment differences between exercise.

6.3. Incorporation of objective autoregulation (velocity-based training) in percentage-based training + subjective autoregulation in ACL injury prevention for footballers

Our model has been further extended to incorporate VBT, which is suggested to better inform practitioners and athletes if the calculated loads are compatible with the true maximum or not (Ramos, 2024). A minimum velocity threshold for a given exercise can offer valuable insights into whether the calculated 1RM/% 1RM is indeed valid; if the mean lifting velocity is higher than the minimum velocity threshold, it is indicated that the calculated 1RM/% 1RM is not a true representation of the actual 1RM/% 1RM (Weakly et al, 2020). One of the most fundamental exercises found in ACL injury prevention protocols is the barbell back squat, which has been used to exemplify the practical application of our suggested model. The back squat exercise has been shown to have a minimum velocity threshold of around 0.30 m/s (Romagnoli et al, 2022); values beyond 0.30 m/s do not represent a true 1RM. So, the minimal velocity threshold can further upgrade our suggested model and enhance its load prescription capacity for footballers. It must also be noted that VBT has elicited larger strength-power improvements compared to subjective autoregulation proximity to failure training strategies (Shattock & Tee, 2020) necessitating its inclusion in the recommended injury prevention strategy.

One of the VBT methods that can be used to prescribe absolute load intensity by matching relative load intensity (%1RM) with lifting velocity is velocity zone training; instead of prescribing loads that correspond to a specific % 1RM, practitioners prescribe loads according to the associated velocity range (Ramos, 2024). In our previous example, in addition to the prescribed intensity of 85% 1RM with 2-3 RIR during the first set of the barbell back squat exercise, a strength and conditioning coach may also prescribe a velocity zone range of 0.35-0.45 m/s. Given the fact that each exercise has a unique % 1RM-velocity profile, fixed velocity ranges would be compatible with distinct load intensity for each respective exercise and hence, different degrees of effort by an individual (Martinez Cava et al, 2019; Ramos, 2024).

Generalized load-velocity relationships have been introduced to address the inherent variation in the load-velocity profile of each distinct exercise and aim to determine the percentage of 1RM that is being applied as soon as the initial repetition is being executed with maximal intended velocity (Gonzalez-Badillo et al, 2017). For example, Sanchez-Medina et al (2017) tested 80 competitive athletes and reported mean 1RM barbell back squat velocity of around 0.30 ± 0.03 m/s; if our athlete performed 5 reps at 85% 1RM by reaching a velocity 0.30 m/s, it would mean that maximal exertion was used for that set instead of the targeted 2-3 RIR. However, the discrepancies that have been detected between studies investigating the same % 1RM velocity relationship along with several other limitations including, exercise modifications, gender, age, measurement device, testing equipment, individual differences, and training program configurations, demonstrate the limitations of adopting a generalized load-velocity profile approach to load intensity prescription (Ramos, 2024).

The abovementioned shortcomings led to the individualization of load-velocity profiles which has proven to be a reliable 1RM testing and load monitoring method for peak velocity (20-100% 1RM), mean propulsive velocity (20-90% 1RM), and mean velocity (20-90% 1RM) (Banyard et al, 2018; Thompson et al, 2020). For instance, an individualized load-velocity profile could have provided a velocity range of 0.35-0.45 m/s for 5 reps of barbell back squats at 85% 1RM for our athlete; individualized load-velocity profiles of different athletes could have differentiated the velocity range prescription.

6.3.1. Velocity loss thresholds

Another VBT method that has been utilized for load intensity monitoring and prescription incorporates the application of velocity loss thresholds, which are purported to address inter-individual variability and daily variation in exercise performance (Weakley et al, 2020). There is a strong correlation between the extent of velocity loss and the number of repetitions performed before reaching volitional/momentary muscle failure, while the number of repetitions short of failure at a given percentage of %1RM is suggested to be different in each respective individual (Richens & Cleather, 2014; Gonzallez-Badillo et al, 2017). Inter-individual, and inter-session variability has also been reported though during sets completed at different velocity loss thresholds of 10%, 20%, and 30% in the back squat exercise (Weakley et al, 2020). Exercise selection and load intensity used can further augment the corresponding variability in the completed repetitions, while it is also suggested that individuals completing different numbers of repetitions at the same velocity loss threshold are likely to demonstrate different magnitudes of neuromuscular, metabolic, and perceived fatigue-recovery, which will ultimately affect the ensuing training adaptations (Yukic et al, 2023).

Selection of low velocity loss thresholds allows for the completion of fewer repetitions and higher velocity/power output in comparison to a high velocity loss threshold because of lower fatigue accumulation and faster inter-set recovery (Weakley et al, 2020). Similar/higher explosive and maximal strength performances have been attributed to lower velocity loss thresholds, while higher hypertrophic gains have been linked to higher velocity loss thresholds (Andersen et al, 2024). Additionally, low to moderate velocity loss thresholds represent an efficient proximity to failure training strategy capable of optimizing muscle strength, endurance, jumping performance, sprinting capacity, and velocity at submaximal load intensities; on the other hand, high velocity loss thresholds can induce higher hypertrophic increments but at the expense of rate of force development, recovery, and expression rate of fast twitch muscle fibers (Jukic et al, 2023). So, a low velocity loss threshold of around 10% is purported to be more effective in improving countermovement jump and sprinting performance and should be the preferred option during the competitive phase of a periodized macrocycle, while a high velocity loss threshold of around 30% would be more suitable for the development of muscular hypertrophy and should not be used when peak sports performance is being sought (Weakley et al, 2024).

In summary, velocity loss thresholds of less than or equal to 25% have been suggested to be more effective in improving strength and sport-specific adaptations (Hernandez-Belmonte & Pallares, 2022), while velocity loss thresholds of more than 25% have been purported to be more conducive to hypertrophic gains (Hickmott et al, 2022); when volume was equated, velocity loss thresholds of both low and high magnitude have produced similar gains in strength and hypertrophy (Andersen et al, 2024). For example, our athlete could perform 5 barbell squat reps at 85% 1RM with 2-3 RIR by applying a velocity loss threshold of 20-25%, which would allow for approximately 50% of the maximum possible reps during squats at that corresponding load intensity (Rodriguez-Rosell et al, 2020); so if the maximum number of repetitions that could be performed at 85% 1RM was 6, then a velocity loss threshold of 20-25% would match with 3-4 completed reps, while simultaneously satisfying the prescribed RIR. Regardless of the applied velocity loss threshold, the training status of an individual, the exercise selected, and the load intensity of the corresponding exercise, are highly likely to impact upon the ensuing physiological response and training adaptations (Andersen et al, 2024; Jukic et al, 2023).

6.3.2. Average concentric velocity

Despite the fact that VBT is an objective proximity to failure training strategy, the relationship between velocity loss and RIR is not stable across different exercises, load intensities, and sets; it is suggested that individualized relationships between RIR and average concentric velocity can address this limitation by the application of absolute velocity stops (Pelland et al, 2022). Moran-Navarro et al (2019) demonstrated that no significant differences were noted in the average concentric velocity of a repetition at the same number of RIR in a variety of resistance training exercises including smith squat, bench press, prone bench pull, and shoulder press as long as the intensity was maintained at 65-85% 1RM. Hackett (2021) further reported similar average concentric velocity at 0 RIR after 5 sets of the bench press and squat exercises at 70%

1RM taken to failure. Exercise prescription for each individual would incorporate termination of each set at a pre-determined average concentric velocity at each corresponding RIR irrespective of volume as long as the intensity was kept at 65%-85% of 1RM (Moran-Navarro et al, 2019).

Individualized average concentric velocity/RIR relationships need to be established for each exercise that requires the determination of absolute velocity stops; this procedure is far more practical compared to velocity loss determination, since individuals just need to perform a single set at 65-85% 1RM to momentary failure and record average concentric velocity after the completion of each repetition (Pelland et al, 2022). Given the inter-session variability between average concentric velocity and RIR, it is recommended that velocity ranges for each respective RIR are being developed by incorporating all velocities that fall below the value corresponding with the previous RIR (Pelland et al, 2022). So, in our previous example, a strength and conditioning coach could prescribe a load intensity of 85% 1RM, with 2-3 RIR, and a RIR-matched average concentric velocity range of 0.37-0.40 m/s (Pelland et al, 2022). The robustness of load intensity prescription is expected to increase dramatically if such strategies are incorporated within the same model. Our theoretical proposal presented in Table 4 incorporates a hypothetical example of the average concentric velocity/RIR relationship applied in the back-squat exercise with 1RM velocity at 0.32 ± 0.03 m/s as recorded by Sanchez-Medina et al (2017).

7. PRACTICAL IMPLEMENTATION OF THE PROPOSED FRAMEWORK

The proposed framework provides the practitioner with an all-inclusive proximity to failure training strategy whereby elements may act in a synergistic manner as well as address potential limitations pertaining to each respective strategy. Practitioners targeting ACL injury prevention/ACL reconstruction/rehabilitation can create either more generalized or preferably individualized proximity to failure training guides as the one presented in this commentary to ascertain that football players use the appropriate intensity during fundamental exercises such as the barbell back squat and safely progress to more advanced stages of rehabilitation, prevent ACL injuries by assessing their fatigue-recovery state during periods of intense training schedules, and maximize training associated adaptations throughout a periodized macrocycle. It is recommended to utilize proximity to failure training strategies as complementary and not mutually exclusive, in order to increase the reliability of load intensity prescription and address individual variability/preferences as well as flexibly respond to different training circumstances.

Let us examine two training scenarios based on the theoretical framework presented in Table 4. In the first scenario, a strength and conditioning coach seeks to determine the requisite load intensity of the back squat exercise for a midfielder during the off-season injury prevention mesocycle. The main goal of the off-season for this athlete is to build muscle endurance before proceeding to the subsequent phases of a traditionally periodized macrocycle.

The PBT load intensity prescribed by the coach is 80% 6RM, which corresponds with around 66% 1RM and the expected/targeted repetition volume is between 12 and 14 repetitions. The athlete in this hypothetical scenario managed to complete 12 reps with the assigned load intensity and at first glance seems to have met the target. However, without incorporating additional proximity to failure training strategies we cannot ascertain the true intensity of that set for that particular athlete; 12 reps at 66% 1RM may yield volitional/momentary failure to some but not all athletes/training sets/training sessions. So, the coach takes advantage of the subjective RIR-based RPE scale to prescribe the required intensity with increased accuracy; in this example, the athlete is asked to complete 12-14 reps provided this repetitions range allows 1.5 repetitions in reserve, which equates with 1-2 repetitions short of failure. In this example, our athlete has satisfied the pre-determined RIR criterion, but it could be the case that the athlete had 0 RIR, which would necessitate load adjustment to satisfy our criteria. In our hypothetical example our athlete satisfied both criteria and that is why load adjustment was not deemed necessary. To further substantiate the validity of the prescribed intensity, velocity loss thresholds and RIR-matched average concentric velocity ranges are being applied to our scenario. When load intensities of around 70% 1RM are being applied, 2 RIR are associated with a velocity loss threshold 40% and an associated average concentric velocity of approximately 0.42-0.45 m/s. So, an athlete may have satisfied the subjective criteria at first glance but taking a closer look at the average concentric velocity, discrepancies may be detected. Given the consistent relationship between average concentric velocity and RIR for load intensities between 65-85% (Moran-Navarro et al, 2019), it can be inferred that what the athlete perceives as "true" load intensity may not be accurately reflected in the objectively measured repetition velocities; load adjustments will be required in such instances. In our example, our athlete has met average concentric velocity requirements and that is why load was maintained.

In the second scenario, a strength and conditioning coach wants to prescribe the corresponding load intensity of the back squat exercise for a left winger during the loading week of the in-season injury prevention mesocycle. The main goal of the in-season strength training is to maintain and even further enhance strength levels built in the pre-season, sustain high performance levels, and minimize the occurrence of injuries.

The PBT load intensity prescribed by the coach in this instance is 90% 1RM and the associated repetition volume is around 3. In this hypothetical scenario, our athlete completed 3 repetitions with the originally prescribed load intensity and seems to have satisfied the pre-determined criteria. Although fewer repetitions at higher exercise intensities are more likely to gauge the true load intensity of the prescribed training set, inter-individual variability and daily fluctuations in strength performance are still present. In this scenario, the prescribed exercise intensity corresponds with 0-1 RIR. Let us consider the case whereby our athlete completes the assigned reps but reports a leeway of two additional repetitions with prescribed load intensity. It seems that the load needs to be accordingly adjusted; objective autoregulation is also recruited to determine the required adjustments more precisely. A velocity loss of 35% matched with a velocity range of 0.35-0.37 m/s represents a challenging intensity that may prevent momentary/volitional failure and seems to match our requirements of 0-1 RIR. In our example, our athlete has reached higher exercise velocities than the ones required in the prescribed velocity range. Given the consistent relationship between average concentric velocity and RIR for load intensities between 65-85% (Pelland et al, 2022), it can be speculated that our athlete would need to attain a velocity range of 0.35-0.37 m/s to reach 0-1 RIR in the back squat exercise. It should be noted that higher velocity ranges of 0.55-0.70 m/s and lower velocity loss thresholds of 15%-25% will subsequently be applied to facilitate recovery and maximum performance.

It is evident from the above training scenarios how each proximity to failure strategy can complement each other and further enhance the validity of load intensity prescription in ACL injury prevention/reconditioning strength training protocols. It seems imperative to take advantage all tools available to determine the most appropriate intensity for footballers and ascertain that the necessary stimulus is applied at the right time. By doing so, chances are that the risks of non-functional overreaching and overtraining will be minimized, and the ACL structures will undergo the requisite adaptations that may safeguard their structural and functional integrity. Researchers are encouraged to apply such comprehensive proximity to failure training strategies to football players recovering from ACL reconstruction, recruit the proposed model as a solid ACL injury prevention strategy within various phases of a periodized macrocycle, and expand its use as a reconditioning/prevention tool for other common sports injuries.

To conclude, the main message of this chapter is to promote consistency in ACL injury prevention guidelines, while at the same time encourage flexibility in the application of proximity to failure strategies. By doing so, practitioners may realize the objectives of ACL injury prevention protocols for footballers of various levels and backgrounds. The key is to incorporate flexible tools within a solid and consistent framework based on evidence-based practice and scientific rigor.

TABLE 4. *Theoretical proposal of the combined implementation of rating of perceived exertion (RPE), repetitions in reserve (RIR), percentage-based training (PBT), velocity-based training (VBT) and associated load adjustments for a lifter with a 1RM back-squat of 100 kg.*

RPE	RIR	VLT	ACV	Perceived effort	%RM	Targeted reps	Completed reps	Load adjustment
10	0	40%	0.32-0.34	Maximum effort, unable to increase load or reps	100% 5RM (87% 1RM)	5 @ 87kg	4 @ 87kg	decrease load by 6-8% (80-82kg)
9.5	0.5	35%	0.35-0.38	Unable to increase reps but may increase load	90% 1RM	3 @ 90kg	3 @ 90kg	maintain load (90kg)
9.0	1	32.5%	0.36-0.39	Able to complete one more rep	85% 3RM (77% 1RM)	8 @ 77kg	10 @ 77kg	increase load by 6-8% (82-83kg)
8.5	1.5	30%	0.38-0.41	Able to complete one-two more reps	80% 6RM (66% 1RM)	12-14 @ 66kg	12 @ 66kg	maintain load (66kg)
8	2	25%	0.39-0.42	Able to complete two more reps	87% 1RM	3 @ 87kg	1 @ 87kg	decrease load by 8-10% (78-80kg)
7.5	2.5	25%	0.43-0.46	Able to complete two-three more reps	100% 8RM (79% 1RM)	6 @ 79kg	5 @ 79kg	maintain load (79kg)
7	3	20%	0.44-0.47	Able to complete three more reps	90% 4RM (79% 1RM)	5 @ 79kg	7 @ 79kg	increase load by 6-8% (84-85kg)
5-6	4-6	15%	0.47-0.58	Able to complete four-six more reps	67% 1RM	7 @ 67kg	12 @ 67kg	increase load by 8-10% (72-74kg)
3-4	6-8	10%	0.58-0.69	Light effort Able to complete six-eight more reps	75% 2RM (69% 1RM)	5 @ 69kg	3 @ 69kg	decrease load by 8-10% (62-63kg)
1-2	8-10+	<10%	0.64-0.76	Little to no effort Able to complete eight-ten+ reps	82% 3RM (75% 1RM)	2 @ 75kg	2 @ 75kg	maintain load (75kg)

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DISTANCIA DE CARRERA A ALTA VELOCIDAD (HSR) ACUMULADA EN SESIONES CENTRALES DEL MICROCICLO COMPETITIVO EN EL FÚTBOL PROFESIONAL EN FUNCIÓN DE LA DEMARCACIÓN: ¿CUÁNDO Y CUÁNTO?

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1. INTRODUCCIÓN

1.1. Demanda condicional en la competición

El desempeño condicional de los jugadores en partidos de competición es intermitente, combinándose acciones de alta intensidad con periodos de baja actividad (Mohr, Krustrup & Bangsbo, 2003). Durante los partidos, los jugadores profesionales llevan a cabo más de medio centenar de acciones a alta velocidad, (HSR por las iniciales del término, *high speed running*, utilizado habitualmente en la literatura científica), con una distancia total recorrida de 0,7 a 3,9 km, lo que representa en torno al 10 % de la distancia total acumulada (Dolci et al., 2020; Modric, Versic, Morgans & Sekulic, 2023; Reinhardt, Schwesig, Lauenroth, Schulze, & Kurz, 2019). Dentro de esta distancia acumulada a alta velocidad, el jugador puede llegar a realizar entre 17 y 81 acciones de sprint (SPR), que constituyen aproximadamente el 3-5 % (entre 0,2 y 0,6 km) de la distancia total (Modric et al., 2023; Sarmento, Marcelino, Anguera, Campaniço, Matos & Leitão, 2014).

Durante los últimos 20 años, las demandas locomotoras en la competición han aumentado de manera significativa (Ponce-Borbón et al., 2024), no tanto en la distancia total acumulada (TD, *total distance*), pero, sobre todo, en las distancias acumuladas por los jugadores en rangos a alta velocidad. Estudios específicos sobre ligas domésticas como la *Premier League* (Allen et al., 2023), o La Liga española (Errekagorri, Castellano, Echeazarra, López-Del

Campo, & Resta 2022), reflejan este incremento en las demandas. Para hacer frente a esta demanda competitiva, una adecuada periodización (Iacono, Beato, Unnithan, & Shushan, 2023) del volumen, intensidad y distribución de la carga de entrenamiento es fundamental en el fútbol con la que preparar los jugadores para las exigencias de la competición y tratar de minimizar el riesgo de padecer lesiones (Beato et al., 2021; Buchheit, 2019).

No es novedad que el perfil de actividad física durante la competición es particular para cada demarcación. Son conocidas las grandes diferencias que existen entre demarcaciones (Modric, Versic, & Sekulic, 2021), siendo los centrocampistas los que cubren mayor distancia (~11,5 km) en comparación a los 10-10,5 km recorridos por los delanteros y defensas (Baptista, Johansen, Figueiredo, Rebelo, & Pettersen, 2019). Los defensas centrales (DC) y mediocentros (MC) recorren menos a HSR (~300-400 m) que los delanteros (DEL), mediocampistas laterales (ML) y defensas laterales (DL) (~600-800 m) (Casamichana et al., 2022; Rico-González, Oliveira, Vieira, Pino-Ortega, & Clemente, 2022). Además, los DL y MC muestran una mayor frecuencia de aceleración, mientras que los DC y MC tienden a desacelerar menos (Dalen, Jørgen, Gertjan, Havard, & Ulrik, 2016). Los centrocampistas también suelen acumular una mayor potencia metabólica (Rico-González et al., 2022). Este conocimiento en torno a la demanda condicional facilita la planificación del entrenamiento a diferentes escalas para maximizar el rendimiento individual y colectivo (Martín-García et al., 2018).

1.2. Periodización del microciclo competitivo

El cuerpo técnico es el responsable de proponer la estrategia de intervención semanal, planificando y diseñando sesiones de entrenamiento que se ajusten al calendario competitivo. A nivel macro, la planificación a largo plazo, considera ponderar y priorizar los objetivos físicos, psicológicos, técnicos y tácticos a lo largo de la temporada competitiva (Kinnerk et al., 2021; Casamichana, Castellano, Calleja-Gonzalez, San Román & Castagna 2013). A un nivel micro, la planificación está orientada en la organización de las diferentes sesiones de entrenamiento con diferente foco condicional, técnico-táctico y estratégico dentro de la semana competitiva (Buchheit, Lacome, Cholley, & Simpson, 2018; Marín & Castellano, 2023a).

En la última década, se han propuesto varios enfoques para la periodización en el fútbol, como la periodización táctica y el microciclo estructurado (Guridi, Castellano, & Etxeazarra, 2021; Delgado-Bordonau, & Mendez-Villanueva, 2014). Estas propuestas, distribuyen los contenidos del entrenamiento según el intervalo temporal entre partidos, generalmente utilizando el microciclo de siete días entre partidos como la unidad de planificación habitualmente referenciada (con seis días hábiles para planificar las sesiones de entrenamiento), aunque este periodo puede variar debido a los compromisos televisivos y la participación en varias competiciones nacionales e internacionales de los equipos.

Entre las alternativas a la longitud de los microciclos se han descrito patrones semanales de cuatro (Akenhead, Harley, & Tweddle, 2016; Jones, Greig, Mawéné, Barrow, & Page, 2019; Malone, Di Michele, Morgans, Burgess, Morton, & Drust, 2015; Owen, Djaoui, Newton, Malone, & Mendes, 2017a; Stevens, de Ruiter, Twisk, Savelsbergh, & Beek, 2017), cinco (Martín-García, Gómez Díaz, Bradley, Morera & Casamichana, 2018; Oliva-Lozano, Rojas-Valverde, Gómez-Carmona, Fortes, & Pino-Ortega, 2020) y seis sesiones de entrenamiento entre partidos (Clemente et al., 2019a; Los Arcos, Mendez-Villanueva, & Martínez-Santos, 2017), pero pudiendo ser más largos y, por tanto, con un aumento en la carga de entrenamiento demandada a los jugadores (Vardakis et al., 2023).

1.3. Distribución semanal de la demanda locomotora

Trabajos previos (Buchheit et al., 2018; Castillo, Raya-González, Weston & Yanci, 2021; Guridi, Castellano & Etxeazarra, 2021; Marín & Castellano, 2023b) coinciden en proponer una distribución de la carga de entrenamiento en el microciclo competitivo con un perfil en forma de U invertida. Esto implica una sucesión horizontal basada en tres fases: una fase inicial de recuperación inmediata después del partido o una sesión complementaria, seguida de una fase de desarrollo físico que incluye fuerza, resistencia y velocidad en los días intermedios de la semana, adaptada según la cantidad de días entre partidos, y finalmente, una fase de reducción en los dos días previos al siguiente partido (Guridi, Castellano & Etxeazarra, 2021).

En la primera fase de la periodización habitual del microciclo, la primera sesión se enfoca en la recuperación de los jugadores titulares y en una sesión complementaria para los jugadores con menos de 60 minutos en el partido previo. Sin embargo, en cuanto al día de descanso y la ubicación de la sesión postpartido la elección de la periodización influye en la programación de la sesión compensatoria para los jugadores con menos participación (Oliveira et al., 2022). La sesión compensatoria para los jugadores con menor participación puede programarse en el MD+1 (un día después del partido [*match-day*]), siguiendo un modelo estructurado (Casamichana, Martín-García, Díaz, Bradley, & Castellano, 2021; Martín-García et al., 2018), o en el MD+2, alineándose con la periodización táctica (Clemente et al., 2019a).

En la fase de adquisición, es común estimular las aceleraciones y desaceleraciones (ACC y DEC, respectivamente) en la sesión MD-4 (cuatro días antes del próximo partido) (Stevens et al., 2017), priorizar TD y HSR en MD-3 (Anderson et al., 2016), y enfocarse en SPR en MD-2 o el tercer día de adquisición (Buchheit et al., 2018). La periodización de alternancia horizontal trata de sobrecargar una capacidad física específica en un día sin afectar negativamente a otras cualidades, permitiendo la recuperación de estas últimas y trabajando todas las capacidades físicas a lo largo de la semana sin generar sobrecarga, fatiga excesiva o riesgo de lesiones. Los días centrales de la semana son óptimos para esta estimulación (Dolci et al., 2020; Mohr et al., 2003), separados de la competición tanto previa como posterior. La distribución del HSR en los días centrales varía según los microciclos en el fútbol profesional (Buchheit et al., 2021). La elección del tipo de trabajo a programar puede estar determinada por la duración específica del microciclo. Por ejemplo, Buchheit et al. (2021) sugieren entrenar fuerza en MD+3/MD-4, HSR en MD+4/MD-3 y velocidad y agilidad en MD+6/MD-1. Al pasar de un microciclo de siete días a uno de seis días, los profesionales de la preparación física deben redistribuir los contenidos habituales de dos o tres días, manteniendo el "día de agilidad/activación" en MD-2 y combinando "fuerza" y "resistencia" en MD+3/-3, reduciendo el volumen total de trabajo. Los contenidos que requieren alta demanda neuromuscular desaparecen consistentemente en microciclos de menos de cinco días (Buchheit et al., 2021).

Finalmente, en la tercera fase después de la alternancia horizontal de los componentes físicos en los días centrales de la semana, es esencial reducir la carga en los días previos a la competición (Lopategui et al., 2021). Estudios anteriores indican una disminución significativa de la carga, especialmente en MD-1, destacando la necesidad de una fase de *tapering* previo al próximo partido (Anderson et al., 2016; Malone et al., 2015; Akenhead et al., 2016). Durante MD-2, las metodologías varían entre priorizar la velocidad y la recuperación, mientras que en MD-1 se enfocan en trabajo ligero y táctico, evitando tareas físicas intensas, pero estimulando altas velocidades en situaciones de juego (Gómez-Piqueras et al., 2024).

1.4. Distribución semanal de la demanda locomotora en función de la demarcación

Como se mencionó anteriormente, las demandas físicas durante los partidos varían según la demarcación del jugador, particularmente en cuanto a HSR y SPR. Es crucial también analizar las sesiones de entrenamiento; por ejemplo, Clemente et al. (2020) observaron una mayor intensidad en los DL y los ML en HSR y número de SPR en comparación con otras demarcaciones. En varios mesociclos de temporada, los MC y los ML muestran una mayor intensidad de entrenamiento en TD y HSR que los DC (Oliveira et al., 2021). Por otro lado, los MC acumulan menos aceleraciones y desaceleraciones, mientras que los DEL muestran las mayores distancias recorridas en HSR y SPR (Guerrero-Calderón, Fradua, Morcillo, & Castillo-Rodríguez, 2023; Martín-García et al., 2018). Por lo tanto, se recomienda al cuerpo técnico considerar estas diferencias en las cargas relativas de trabajo al programar el entrenamiento, ajustando la carga de acuerdo con las necesidades específicas de cada demarcación (Guerrero-Calderón et al., 2023). Recientemente, Gómez-Piqueras y Alcaraz (2024) han propuesto una acumulación de la distancia >24 $km \cdot h^{-1}$ en función de la demarcación de los jugadores: defensas laterales 200-270 m, defensas centrales 100-175 m, centrocampistas 150-225 m, extremos 190-250 m y delanteros 200-260 m.

En este sentido, y a la vista de las claras diferencias que existen en el perfil condicional de los jugadores en función de la demarcación que ocupan en el sistema del equipo, resulta necesario controlar la carga de entrenamiento relativa a su desempeño particular en competición (Anderson et al., 2016), es decir, calculando la proporción respecto a los valores de referencia en competición. Esta propuesta permite estandarizar las demandas y por tanto hace viable comparar el perfil de desempeño físico individual de cada jugador durante el microciclo semanal y la competición (Marín & Castellano, 2024). En la literatura se encuentran propuestas (Anderson et al., 2016; Baptista et al., 2019) con las proporciones más conservadoras, entre 0,22 hasta 0,6 de la distancia acumulada durante el microciclo en la variable HSR. Esta proporción del HSR es ligeramente inferior al observado por Stevens et al. (2017) que describieron una proporción algo mayor (1,1), lo que representaría acumular una distancia en HSR considerablemente superior a la que demanda del propio partido de la semana. Por otro lado, varios autores (Clemente et al., 2019b; Kokstejn, Vampola, Musalek, Grobar, M, & Stastny, 2024; Martín García et al., 2018) han descrito índices que van desde 1,7 hasta 2,3, enfatizando la importancia del volumen de HSR en el entrenamiento que exceda las demandas de los partidos. Kokstejn et al. (2024) encontraron diferencias en las proporciones entre las demarcaciones estudiadas, destacando que los centrocampistas tuvieron el valor más alto (3,5), mientras que los laterales, los delanteros (1,6), y los defensas centrales (2,5) tuvieron valores más bajos.

2. OBJETIVO

El objetivo del presente estudio será evaluar si existen diferencias en la distancia acumulada por encima de 21 $km \cdot h^{-1}$ (HSR) en cuatro tipos de sesiones de entrenamiento ubicadas en los días centrales de tres tipos de microciclos competitivos en el fútbol profesional (cinco, seis y siete días entre partidos), diferenciando las demarcaciones de los jugadores. La hipótesis de partida es que las diferentes sesiones centrales tendrán una estimulación diferente entre las demarcaciones de los jugadores en valores absolutos de HSR, pero sin embargo en términos relativos al valor de referencia de la competición será similar entre ellos.

3. METODOLOGÍA

3.1. Diseño

El diseño fue descriptivo observacional retrospectivo. Se monitorizó a un equipo profesional de fútbol masculino durante la temporada 2018-19, utilizando dispositivos GPS con una frecuencia de registro de 10 Hz. Los microciclos con un solo partido oficial fueron considerados, clasificándolos en función del número de días entre partidos 5, 6 y 7 días (Malone et al., 2015; Martín García et al. 2018).

3.2. Participantes

Un total de 23 jugadores profesionales de fútbol de campo participaron en este estudio (edad 27,1 ±3,5 años, masa corporal: 78,0 ±5,9 kg y estatura: 182,0 ±4,8 cm). Los jugadores pertenecían a la plantilla de un club de primera división participando en el campeonato de La Liga. Los datos se recogieron durante la temporada competitiva como parte del seguimiento diario de los jugadores. Los jugadores de campo que no completaron las sesiones fueron excluidos del análisis. Los jugadores se clasificaron en una de las cinco demarcaciones habituales: defensa lateral (DL, $n = 6$), defensa central (DC, $n = 3$), mediocentro (MC, $n = 4$), delantero (DEL, $n = 4$) y mediocampista lateral (ML, *n* = 6). Este estudio cumplió con la Declaración de Helsinki y fue aprobado por el Comité de Ética en la Investigación con Seres Humanos, sus datos o sus muestras (CEISH) de la Universidad del País Vasco / Euskal Herriko Unibertsitatea (código: M10-2024-124).

3.3. Variable locomotora

La variable de carga externa registrada en este estudio fue la distancia acumulada a >21 km·h^{-1} (HSR). El HSR se monitorizó en todas las sesiones de entrenamiento y partidos oficiales. El valor promedio de la distancia recorrida por cada jugador en partido completado se utilizó como valor de referencia en competición a partir del cual se calculó la proporción, dividiendo la distancia acumulada en HSR en la sesión de entrenamiento por el valor de referencia en partido.

3.4. Tipos de sesiones

Las sesiones se codificaron en función del número de días posterior al partido anterior y número de días respecto al siguiente partido del microciclo (Tabla 1). Se escogieron únicamente la combinación de las sesiones de entrenamiento MD+4 y MD+3 posteriores al partido, y MD-4 y MD-3 previas al partido, excluyendo las semanas de pretemporada y del calendario Internacional de Partidos de la FIFA, así como microciclos con dos competiciones (Malone et al., 2015). En el microciclo de cinco días entre partidos se seleccionó solo la sesión MD+3/MD-3 (*n* = 3). En los microciclos de seis días entre partidos, se seleccionaron las sesiones MD+4/MD-3 (*n* = 5) y MD+3/MD-4 (*n* = 5). Finalmente, en el microciclo de siete días entre partidos se tomó exclusivamente la sesión MD+4/MD-4 (*n* = 4). Entre todas las sesiones se acumularon un total de 342 registros.

3.5. Procedimiento

La actividad de los jugadores durante cada sesión de entrenamiento se monitorizó utilizando una unidad GPS portátil (S5, *Catapult Innovations*, Victoria, Australia) con una frecuencia de muestreo de 10 Hz. Los dispositivos se colocaron dentro de un mini bolsillo del chaleco especialmente diseñado entre los omoplatos. Para evitar errores entre unidades, cada jugador utilizó el mismo dispositivo durante todo el estudio (Martín García et al., 2018). Los datos GPS se extrajeron utilizando el software correspondiente (*Openfield* 2.4, Camberra, Australia) después de cada sesión de entrenamiento o competición. La calidad de la señal GPS se midió utilizando 11,0 ± 0,2 satélites, con una dilución horizontal de la precisión de 0,8 ± 0,2. La calidad media del GPS fue del 71,8 ± 4,1%.

TABLA 1. *Distribución de las sesiones de entrenamiento dependiendo de la longitud del microciclo.*

Microciclo: cinco días entre partidos									
MD-			*MD*	MD-5	MD-4	**MD-3**	MD-2	MD-1	*MD*
MD+			*MD*	MD+1	MD+2	**MD+3**	MD+4	MD+5	*MD*
Microciclo: seis días entre partidos									
MD-		*MD*	MD-6	MD-5	**MD-4**	**MD-3**	MD-2	MD-1	*MD*
MD+		*MD*	MD+1	MD+2	**MD+3**	**MD+4**	MD+5	MD+6	*MD*
Microciclo: siete días entre partidos									
MD-	*MD*	MD-7	MD-6	MD-5	**MD-4**	MD-3	MD-2	MD-1	*MD*
MD+	*MD*	MD+1	MD+2	MD+3	**MD+4**	MD+5	MD+6	MD+7	*MD*

Nota: MD, match-day; MD-, número de días previos al próximo partido; MD+, número de días post partido.

3.6. Análisis de datos

Para el análisis de tipo descriptivo, los datos se presentaron como medias y desviaciones estándar (± SD). La normalidad y la homogeneidad de la varianza se examinaron mediante las pruebas de Levene y Shapiro-Wilk, respectivamente. Dado que los datos no cumplían los supuestos de normalidad y homocedasticidad, se optó por un enfoque no paramétrico para el análisis. Se aplicó la prueba de Kruskal-Wallis para comparar el HSR acumulado en cada tipo de sesión, teniendo en cuenta las demarcaciones de los jugadores, con pruebas post hoc de Tukey para las comparaciones. Se aplicó el coeficiente de variación (CV%) para describir la variabilidad entre demarcaciones. Todos los análisis de datos se realizaron con Excel y el programa de análisis estadístico JASP versión 0.14.1 (Universidad de Ámsterdam, https://jasp-stats.org/). El nivel de significación se fijó en $p < 0,05$.

4. RESULTADOS

La Tabla 2 muestra valores absolutos acumulados en la variable HSR diferenciando la demarcación (DC, DEL, DL, MC, ML) durante los partidos de competición. Los resultados mostraron diferencias significativas en el volumen absoluto de HSR entre las demarcaciones ($p < 0,05$): a) todos los puestos (DEL, DL, MC y ML) registraron valores superiores de HSR en comparación con los DC, y b) los DL y ML presentaron valores de HSR significativamente mayores que los MC.

TABLA 2. *Valores absolutos de distancia recorrida a alta velocidad (HSR, en m) en competición de las diferentes demarcaciones.*

Demarcación	distancia recorrida a alta velocidad (m) en partido
Defensa central	622,8 ± 48,8
Delantero	746,9 ± 64,8♦
Defensa lateral	795,1 ± 121♦♣
Mediocentro	703,3 ± 101,1♦
Mediocampista lateral	807,9 ± 215,4♦♣

Nota: ♦, significativamente mayor (p < 0,05) que la distancia recorrida a alta velocidad por los defensas centrales; ♣, significativamente mayor (p < 0,05) que la distancia recorrida a alta velocidad por los mediocentros.

En cuanto a la distribución de las sesiones, se encontraron diferencias significativas entre distintos momentos del microciclo, siendo MD+4/MD-4 superior a MD+3/MD-3, a MD+4/MD-3 y a MD+3/MD-4 ($p < 0,05$). Las diferencias entre sesiones se recogen en la Figura 1.

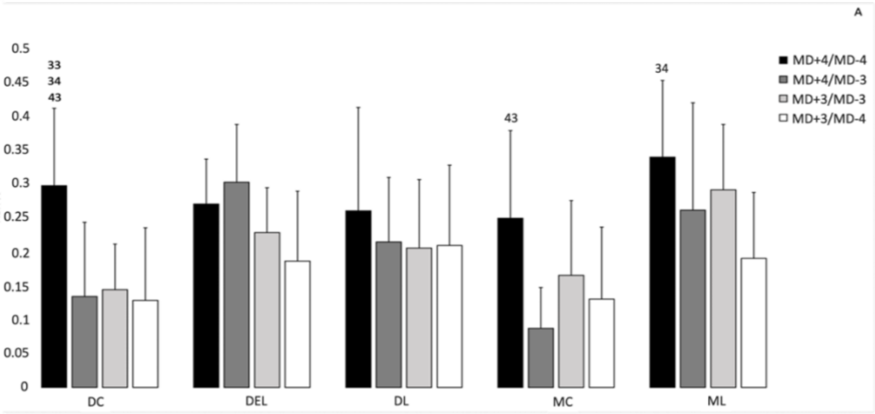

FIGURA 1. *Ratios respecto a competición de la distancia recorrida a alta velocidad (HSR) de las diferentes demarcaciones por tipo de sesión.*

Nota: MD+4/MD-4, entrenamiento en la sesión MD+4 y en MD-4; MD+4/MD-3, entrenamiento en la sesión MD+4 y MD-3; MD+3/MD-3, entrenamiento en la sesión MD+3 y MD-3; MD+3/MD-4, entrenamiento en la sesión MD+3 y en MD-4. Se muestran diferencias significativas ($p < 0.05$): 43 es > MD+4/MD-3; 34 es > MD+3/MD-4; 33 es > MD+3/MD-3.

Las demarcaciones mostraron diferencias significativas en el volumen de HSR ($p < 0{,}05$): a) los DEL y los ML recorrieron más distancia a HSR que los DC; b) Los DEL, DL y ML recorrieron más distancia a HSR que los MC. Las diferencias entre demarcaciones para cada tipo de sesión se recogen en la Figura 2. Los resultados revelaron que la sesión más alejada en el microciclo de 7 días, MD+4/MD-4, presentó la menor variabilidad con un 13 %. En contraste, la sesión MD+4/MD-3 en el microciclo de seis días mostró la mayor variabilidad, con un coeficiente de variación del 42%.

5. DISCUSIÓN

En el marco del ámbito de la práctica profesional en fútbol, el objetivo del presente estudio trató de comparar la distancia en HSR que acumularon los jugadores en las sesiones de entrenamiento ubicadas en los días centrales de tres tipos de microciclos competitivos (MD+4/MD-3, MD+3/MD-4, MD+4/MD-4 y

MD+3/MD-3, días post+ y prepartido-), considerando su demarcación.

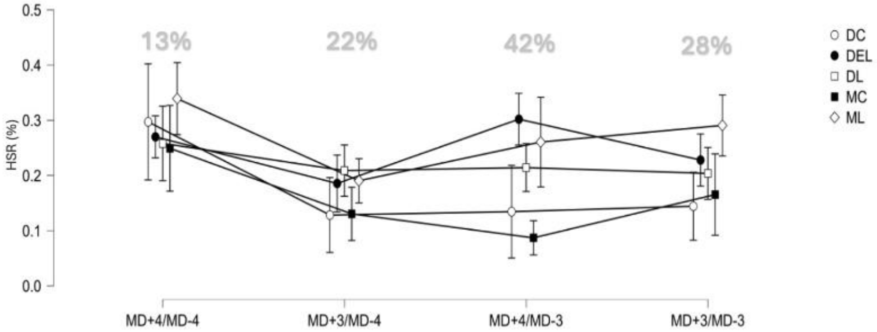

FIGURA 2. *Ratios de la distancia recorrida a alta velocidad (HSR) de las diferentes sesiones considerando la demarcación del jugador. Se añade el coeficiente de variación (CV%) entre demarcaciones.*

Nota: MD+4/MD-4, entrenamiento en la sesión MD+4 y en MD-4; MD+3/MD-4, entrenamiento en la sesión MD+3 y en MD-4; MD+4/MD-3, entrenamiento en la sesión MD+4 y MD-3; MD+3/MD-3, entrenamiento en la sesión MD+3 y MD-3; DC, defensa central; DEL, delantero; DL, defensa lateral; MC, mediocentro; ML, mediocampista lateral.

Los principales resultados del estudio fueron que: 1) la sesión MD+4/MD-4, es decir, la más alejada del partido anterior y posterior, acumuló mayor distancia en HSR; 2) existieron diferencias significativas en la distancia de HSR acumulada según el tipo de sesión y la demarcación; 3) fueron los DEL y ML quienes acumularon la mayor proporción de HSR en los días centrales del microciclo, independientemente del tipo de sesión; y 4) en términos relativos, la ratio entrenamiento/partido, fue la sesión MD+4/MD-4 la que tuvo una menor variabilidad entre demarcaciones.

La literatura sugiere una periodización en forma de U invertida, donde la carga es más alta en los días más alejados del siguiente partido (MD-5, MD-4, MD-3) y disminuye gradualmente en MD-2 y MD-1 (Buchheit et al., 2021; Marín & Castellano, 2023a; Martín-Garcia et al., 2018). La justificación a la planificación en forma de U invertida se basa en su capacidad para facilitar la alternancia horizontal en los días centrales del microciclo, permitiendo mayor volumen en fuerza, resistencia y velocidad al ofrecer más sesiones para entrenar y recuperarse (Buchheit et al., 2021; Marín & Castellano, 2023a). Así, por ejemplo, Buchheit et al. (2021), en un microciclo de siete días, proponen programar dos días con cargas elevadas (MD-4 y MD-3), mientras que para microciclos de seis días se reserva un solo día (MD-3), y no se registran cargas elevadas para microciclos más cortos. Esto respalda los hallazgos del presente estudio, donde la sesión MD+4/MD-4 tuvo la carga más alta en un microciclo de siete días, el más distante al partido. Coincidiendo con los resultados previos, los resultados del presente estudio encontraron también diferencias significativas en las demandas de HSR durante las diferentes sesiones centrales en los tres tipos de microciclo (cinco, seis y siete días entre partidos), si bien, la sesión MD+4/MD-4 tuvo mayores demandas que las sesiones MD+4/MD-3, MD+3/MD-4 y MD+3/MD-3. Estas diferencias se pueden deber a que más días entre partidos permiten incrementar la carga a los jugadores (Clemente et al., 2019b y 2020).

Con relación a las demarcaciones, los resultados principales sobre las distancias absolutas en HSR mostraron que a excepción de los DEL en la sesión MD+4/MD-3, en el resto de las demarcaciones fue la sesión MD+4/MD-4 del microciclo de siete días donde el resto de las demarcaciones acumularon más distancia en HSR. Además, igual que lo reportado en estudios previos (Akenhead et al., 2016; Malone et al., 2015; Modric et al., 2020; Owen et al., 2017b), fueron los DC y MC los que acumularon una menor distancia en HSR en todos los tipos de sesiones, siendo los ML los que más. Parece, por tanto, que se respalda la idea de diferentes perfiles condicionales en la competición, traen consigo también una estimulación por posiciones particular de la demanda física durante el microciclo competitivo (Modric et al., 2020; Yi et al., 2018).

La literatura describe una gran disparidad en la proporción de HSR (ratio entrenamiento/partido) exigida en las sesiones centrales del microciclo (Anderson et al., 2016; Buchheit et al., 2023; Clemente et al., 2019b; Stevens et al., 2017). Los resultados de este estudio revelaron demandas de HSR entre 0,1 y 0,34 para las sesiones más demandantes del microciclo, con diferencias significativas en la proporción de HSR entre posiciones: DEL (0,24) y ML (0,26) frente a DC (0,17), DL (0,22) y MC (0,15). Estos valores son similares a estudios previos reportados con proporciones de 0,22 (Anderson et al., 2016) como promedio durante una temporada y de 0,6 (Baptista et al., 2019) durante un microciclo semanal. Las recomendaciones, respecto al acumulado en un microciclo, oscilan desde 1 (Buchheit et al., 2023: 0,5-1; Stevens et al., 2017; 1,1) hasta aproximadamente 1,75 (Clemente et al., 2019b; Kokstein et al., 2024; Martin-García et al., 2018). Es importante destacar que tanto la sub-estimulación como la sobreexposición a un elevado volumen de distancias en rango alto de velocidad parecen asociarse con una mayor probabilidad de riesgo de lesión, sugiriendo una "dosis" crónica óptima específica para cada contexto (Colby et al., 2018; O'Connor et al., 2020; Malone et al., 2017), pero esta dosis es original para cada equipo y microciclo de entrenamiento en la temporada.

Finalmente, cabe mencionar la variabilidad descrita entre demarcaciones (rango desde el 13 al 42%) en función del tipo de sesión, que se ajusta a una duración desde los cinco hasta los siete días entre partidos. En este sentido, se pudo describir que, especialmente las sesiones MD+4/MD-4, presentaron una menor variabilidad de las proporciones entre demarcaciones, aunque acumularon una alta distancia en HSR, por debajo de estudios previos (Baptista et al., 2019; Clemente et al., 2019b), donde las proporciones que se encontraron fueron de 0,6 a 0,9 veces un partido (Buchheit et al., 2023). Una menor variabilidad en el índice de entrenamiento en comparación con los partidos sugiere que todos los jugadores se entrenaron de manera específica, considerando las demandas particulares que cada demarcación tiene en competición. Por otro lado, una mayor variabilidad podría indicar que el contenido de la sesión es similar para todas las demarcaciones lo que repercute en proporciones diferentes según los valores de referencia que cada posición tiene de partido. Esto podría sobre- y sub-estimular, al mismo tiempo, la demanda de HSR entre los jugadores. Por lo tanto, el cuerpo técnico debería tener en cuenta las cargas de entrenamiento relativas para una periodización óptima, prestando especial atención en sesiones poco específicas para disminuir o aumentar la carga de entrenamiento en los jugadores mediante, adaptaciones de las tareas, o trabajo adicional y específico después de la sesión, respectivamente, si es necesario (Guerrero-Calderón et al., 2023).

El estudio no está exento de limitaciones. En primer lugar, el tamaño de la muestra es reducido ya que solo incluimos registros de un equipo de fútbol profesional. Una segunda limitación es que solo se consideró una única variable locomotora, distancia acumulada >21 $km \cdot h^{-1}$, por lo que otro tipo de variables locomotoras o de otras dimensiones como las neuromusculares (aceleración/desaceleración) o mecánicas (impactos o *player load*), podrían haber complementado los resultados. Finalmente, disponer de información más específica sobre el entrenamiento (p. ej., tipo de tareas, rasgos de las tareas o la prescripción de la duración y numero de repeticiones) durante las sesiones de entrenamiento habría permitido realizar un análisis más exhaustivo de las ratios. Investigaciones futuras deberían abordar estas limitaciones para proporcionar información que conduzca a una mejor comprensión de la gestión de los índices individualizados a cada demarcación.

6. CONCLUSIONES

Las principales conclusiones del estudio fueron tres: 1) las sesiones centrales del microciclo y, especialmente, la sesión más alejada del partido anterior y posterior, es la utilizada para acumular distancia en HSR; 2) la distancia en HSR acumulada en competición varió en función de la demarcación, siendo los jugadores de banda (DL y ML) y delanteros (DEL) los que cubrieron una mayor distancia, por lo tanto, la estrategia de intervención que debe estar en la ratio de 0,5-1,0, debería adaptarse a su perfil condicional para optimizar los valores relativos al HSR de partido; y, 3) la variabilidad inter-posicional de la ratio entrenamiento/competición debería ser alta en sesiones que implementan tareas poco específicas para la demarcación (p. ej., carreras *box-to-box* o juegos reducidos en espacio pequeño), donde todas las demarcaciones acumulan la misma distancia de carrera en términos absolutos pero no relativos, mientras que en sesiones con tareas más específicas para la demarcación (p. ej., juegos largos en campo grande), esta variabilidad de la ratio entrenamiento/competición debería ser baja porque las diferencias en la distancia acumulada en HSR en valores absolutos son específicas para cada demarcación.

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EFECTOS DEL ENTRENAMIENTO DE FUERZA HASTA EL FALLO MUSCULAR VS. SIN FALLO SOBRE LA ARQUITECTURA MUSCULAR DEL CUÁDRICEPS EN JUGADORES DE DEPORTES DE EQUIPO: METAANÁLISIS

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1. INTRODUCCIÓN

El entrenamiento de fuerza es una de las principales estrategias para mejorar el rendimiento deportivo y reducir el riesgo de lesiones en jugadores de deportes de equipo (Lauersen et al., 2014; Suchomel et al., 2018). Las adaptaciones derivadas del entrenamiento de fuerza dependen directamente de variables modificables, como la intensidad, el volumen, la frecuencia, el grado de esfuerzo (i.e., la relación entre las repeticiones realizadas y repeticiones posibles), y la selección de ejercicios (Sánchez-Medina & González-Badillo, 2011; Suchomel et al., 2018). Sin embargo, uno de los aspectos menos explorados es la influencia del grado de esfuerzo, en particular si se llega o no al fallo muscular, en la arquitectura muscular, especialmente en el cuádriceps, un grupo muscular fundamental para el rendimiento en deportes de equipo (Dallinga et al., 2012; Spineti et al., 2016).

El cuádriceps, compuesto por cuatro porciones (vasto lateral, recto femoral, vasto intermedio y vasto medial), juega un papel crucial no solo en el rendimiento físico sino también en la prevención de lesiones, como la lesión del ligamento cruzado anterior, lesiones del recto femoral y la tendinopatía rotuliana (Brinlee et al., 2022;

Dallinga et al., 2012; Mendiguchia et al., 2013; van der Worp et al., 2011). Las adaptaciones en la arquitectura muscular, como el grosor muscular, la longitud de los fascículos y el ángulo de penación, son predictores estructurales claves de la función muscular (Fukunaga et al., 1997; Lieber & Ward, 2011), y pueden ser modificados mediante el entrenamiento de fuerza (Lieber & Ward, 2011; Suchomel et al., 2018). No obstante, la manipulación del grado de esfuerzo durante el entrenamiento de fuerza podría inducir diferentes adaptaciones estructurales, teniendo un impacto significativo en la capacidad de producción de fuerza y en la reducción del riesgo de lesiones (Alonso-Fernandez et al., 2019; Gérard et al., 2020).

El entrenamiento de fuerza centrado en acciones excéntricas ha demostrado ser eficaz para aumentar la longitud de los fascículos del músculo (Alonso-Fernandez et al., 2019; Gérard et al., 2020), lo que podría disminuir el riesgo de lesiones y aumentar los niveles de fuerza (Blazevich et al., 2007; Timmins et al., 2015, 2016). Por otro lado, los ejercicios basados en acciones concéntricas tienden a aumentar el ángulo de penación (Coratella et al., 2018; Franchi et al., 2014), lo que podría mejorar la capacidad de empaquetamiento de fibras musculares y, por ende, la capacidad de producción de fuerza del músculo (Folland & Williams, 2007). Estos hallazgos sugieren que el tipo de contracción muscular y el grado de esfuerzo durante el entrenamiento pueden ser determinantes en las adaptaciones arquitectónicas del cuádriceps.

A pesar de la evidencia sobre los efectos de diferentes programas de entrenamiento de fuerza en la arquitectura muscular de jugadores de deportes de equipo, los efectos específicos del entrenamiento hasta el fallo muscular o sin llegar a él sobre la arquitectura muscular siguen sin estar completamente claros. Comprender cómo estas modalidades de entrenamiento influyen en las propiedades estructurales del cuádriceps es esencial para optimizar las adaptaciones y, en consecuencia, mejorar el rendimiento y reducir el riesgo de lesiones.

2. OBJETIVO

El objetivo de este metaanálisis fue analizar los efectos del entrenamiento de fuerza hasta el fallo muscular versus sin llegar al fallo sobre la arquitectura muscular del cuádriceps en jugadores de deportes de equipo. Se hipotetiza que el entrenamiento hasta el fallo muscular podría inducir mayores adaptaciones en el grosor muscular y el ángulo de penación, mientras que el entrenamiento sin llegar al fallo podría ser más eficaz en la longitud de los fascículos, favoreciendo la producción de fuerza en rangos amplios de movimiento y reduciendo el riesgo de lesiones.

3. METODOLOGÍA

El presente estudio fue registrado en el "International Prospective Register of Systematic Reviews" (PROSPERO), con número de registro: CRD42022342681 y se utilizó el "Preferred Reporting Items for Systematic review and Meta-Analyses" (PRISMA) 2020 (Page, McKenzie, et al., 2021; Page, Moher, et al., 2021) para los procedimientos de búsqueda, selección de estudios, recolección de datos y análisis.

3.1. Búsqueda de literatura y bases de datos

La búsqueda se realizó en cinco bases de datos diferentes: PubMed, SPORTDiscus, Web of Science, PsycInfo y CINAHL. La búsqueda incluyó estudios publicados hasta el 9 de mayo de 2023. La ecuación de búsqueda para las bases de datos mencionadas fue: (athlete OR sport) AND (exercise OR training) AND (quadriceps OR "vastus medialis" OR "vastus intermedius" OR "rectus femoris" OR "vastus lateralis") AND ("muscle architecture" OR "pennation angle" OR "fascicle length" OR "muscle thickness" OR "cross-sectional area"). Todas las citas se introdujeron en la herramienta de Revisión Sistemática Inteligente de Rayyan. Los duplicados se excluyeron automáticamente, y los estudios restantes se examinaron por título y resúmenes de acuerdo con los criterios de elegibilidad. Las listas de referencias de los estudios seleccionados se revisaron manualmente para encontrar otros estudios potencialmente elegibles.

3.2. Criterios de inclusión y exclusión

Los estudios se incluyeron si cumplían los siguientes criterios: 1) al menos un grupo se sometió a una intervención de entrenamiento de fuerza basada en ejercicios para las extremidades inferiores, reportando mediciones pre y post intervención, independientemente de si se comparaban con un grupo de control o con otro tipo de intervención de entrenamiento de fuerza. El entrenamiento de fuerza para la modificación de la arquitectura muscular podría realizarse mediante la adición de carga externa, ejercicios pliométricos o dispositivos "flywheel"; 2) todos los participantes eran jugadores de deportes de equipo y no tenían lesiones, ni problemas cardiovasculares, metabólicos o musculoesqueléticos, ni antecedentes de dopaje o abuso de drogas; 3) las variables de resultado incluían al menos una de las siguientes variables: arquitectura muscular (es decir, grosor muscular, longitud de fascículos y/o ángulo de penación) del vasto lateral, vasto intermedio, vasto medial o recto femoral, medidos por ultrasonido o resonancia magnética; 4) los participantes tenían en promedio más de 16 años de edad.

En cuanto a los criterios de exclusión, los estudios no fueron considerados si: 1) no se disponía del texto completo y los autores del estudio no proporcionaron el texto completo; 2) durante la intervención los jugadores tomaron ayudas ergogénicas; 3) durante el programa de entrenamiento de fuerza se utilizó estimulación eléctrica; 4) el artículo no reportaba ninguna de las variables de entrenamiento de fuerza de interés.

Para los estudios que tuvieron una intervención de entrenamiento muy larga (es decir, más de 15 semanas) pero que tuvieron mediciones de varios ciclos de entrenamiento dentro de la intervención, se tomaron los resultados pre y post del primer ciclo de entrenamiento (Vázquez-Guerrero & Moras, 2015). No se aplicaron restricciones de idioma en los estudios incluidos.

3.3. Selección de estudios

La búsqueda inicial fue realizada por uno de los autores (JP). Después de eliminar los duplicados, los títulos y resúmenes de los estudios seleccionados fueron examinados por el mismo investigador. Posteriormente, el texto completo de los artículos restantes fue examinado. Dos revisores seleccionaron los estudios para su inclusión (JP y HPG) de acuerdo con los criterios de inclusión y exclusión previamente establecidos. Si no se alcanzaba un acuerdo, un tercer investigador (ACD) intervenía y resolvía la disputa.

3.4. Extracción de datos

Un autor (JP) extrajo la media, la desviación estándar y el tamaño de la muestra de todos los estudios incluidos, y un segundo investigador (HPG) confirmó la extracción de datos. Si era necesario, los autores de la presente revisión sistemática y metaanálisis contactaron a los autores de aquellos estudios en los que esta información (i.e., media, desviación estándar y/o tamaño de la muestra) no estaba presente en el artículo. Además, los datos extraídos incluyeron las características de los sujetos, la duración de la intervención, la selección de ejercicios para las intervenciones de entrenamiento de fuerza, la modalidad deportiva practicada por los participantes, la técnica de medición de la arquitectura muscular y las características de la intervención de entrenamiento de fuerza (i.e., tipo de carga, grado de esfuerzo y frecuencia de entrenamiento empleada).

3.5. Análisis estadístico

Todos los análisis estadísticos se realizaron utilizando el software Review Manager (RevMan, Versión 5.4, The Cochrane Collaboration, 2020, Oxford, Reino Unido). Los tamaños del efecto entre las mediciones post y pre-intervención se evaluaron para cada estudio utilizando diferencias de medias estandarizadas (SMD). Entre las distintas formulaciones de la diferencia de medias estandarizada, la implementada en RevMan es el g ajustado de

Hedges, que es muy similar a la d de Cohen pero incluye un ajuste para el sesgo de muestras pequeñas (Higgins et al., 2019):

$$SMD = \frac{M_{post} - M_{pre}}{SD_{pooled}} \cdot \left(1 - \frac{3}{8n - 9}\right)$$

donde n es el tamaño de la muestra, Mpost – Mpre es la diferencia de medias entre los resultados post y pre-intervención, y SDpooled es la desviación estándar combinada, que se calculó con la siguiente ecuación (Higgins et al., 2019):

$$SD_{pooled} = \sqrt{\frac{SD_{pre}^2 + SD_{post}^2}{2}}$$

La magnitud del SMD en las ciencias sociales puede interpretarse como pequeña (0.1–0.3), media (0.3–0.6) o grande (>0.6). Las diferencias de medias se ponderaron según el método de media ponderada por varianza inversa (Higgins et al., 2019). Los intervalos de confianza (IC) para los SMD se calcularon al 95% de nivel de confianza. Se utilizó un modelo de efectos aleatorios y la heterogeneidad entre los estudios se evaluó utilizando el estadístico I2 con valores de I2 que van del 0% al 100%. Valores inferiores al 25% se consideran bajos, entre el 25% y 50% moderados y altos cuando superan el 50% (Grant & Hunter, 2006). La significancia se estableció en $p < 0.05$ para todas las pruebas.

Se realizaron análisis de sensibilidad omitiendo estudios de baja calidad metodológica para determinar la robustez de los resultados generales. Además, se realizaron análisis de sensibilidad basados en el sexo para determinar si la inclusión de diferentes sexos podría haber influido en los hallazgos del presente estudio.

3.6. Evaluación de la calidad

La calidad metodológica de los estudios incluidos se evaluó utilizando la escala PEDro. Dos autores (JP y HPG) evaluaron independientemente los estudios incluidos de acuerdo con los 11 ítems evaluables. Las discrepancias se resolvieron con un tercer investigador (ACD). La calidad metodológica de los estudios seleccionados se clasificó de la siguiente manera: ≥7, alta; 5–6, moderada; <5, baja (Ribeiro de Ávila et al., 2018). El sesgo de publicación se evaluó utilizando la prueba de asimetría del gráfico en embudo del software Review Manager.

4. RESULTADOS

Como podemos observar en la Figura 1, se identificaron un total de 1,215 estudios después de la búsqueda en bases de datos, y se añadió un estudio adicional a partir de la lista de referencias. Después de eliminar duplicados, se seleccionaron 834 estudios para la evaluación de títulos y resúmenes. Tras esta fase, quedaron 17 artículos, de los cuales 12 se incluyeron en el metaanálisis después de revisar el texto completo.

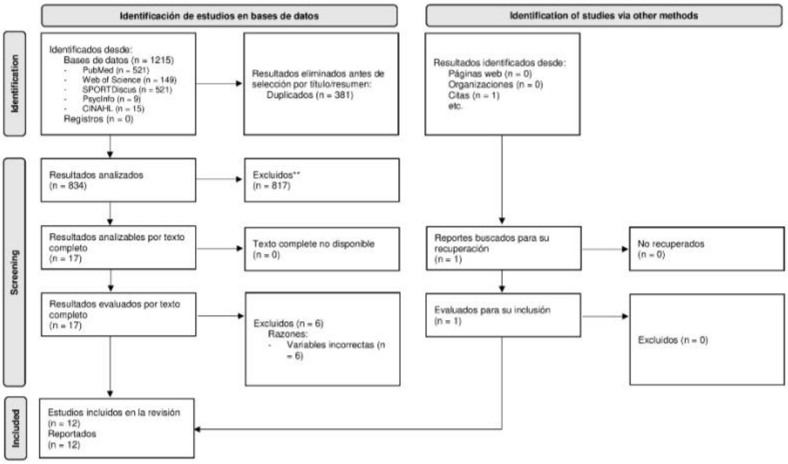


FIGURA 1. *Diagrama de flujo del proceso de selección de estudios según las directrices PRISMA.*

4.1. Características de los estudios

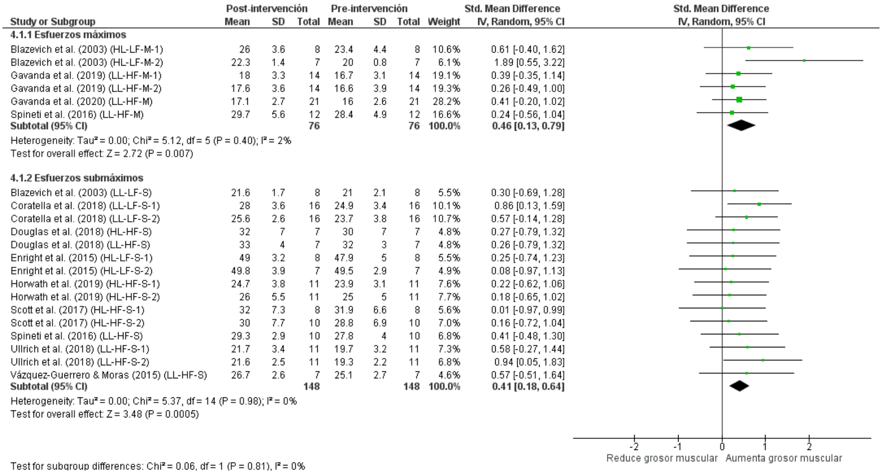
Los 12 estudios incluidos contaban con un grupo de entrenamiento de fuerza, formando un total de 21 grupos analizados para el grosor del vasto lateral, 14 grupos para la longitud de los fascículos del vasto lateral, 16 grupos para el ángulo de penación del vasto lateral y 15 grupos para el grosor del recto femoral. El resto de las variables deseadas de la arquitectura muscular del cuádriceps (es decir, longitud de los fascículos y ángulo de penación del recto femoral y arquitectura muscular del vasto intermedio y vasto medial) no se pudieron analizar debido a la insuficiencia de datos.

La intensidad del entrenamiento de fuerza varió desde el peso corporal hasta 3RM para la fase concéntrica y 110 %RM para la fase excéntrica del movimiento. La frecuencia de las intervenciones de entrenamiento de fuerza osciló entre 2 y 4 días por semana. Tres estudios incluyeron entrenamiento de fuerza hasta el fallo muscular (Blazevich et al., 2003; Gavanda et al., 2019, 2020), mientras que ocho estudios realizaron el programa de entrenamiento de fuerza con esfuerzos submáximos (Coratella et al., 2018; Douglas et al., 2018; Enright et al., 2015; Horwath et al., 2019; Namboonlue et al., 2020; Scott et al., 2017; Vázquez-Guerrero & Moras, 2015). Solo un estudio incluyó un grupo que realizó entrenamiento de fuerza hasta el fallo muscular y otro grupo que realizó esfuerzos submáximos (Spineti et al., 2016). Con base en esta información, los grupos de los diferentes estudios incluidos se clasificaron en esfuerzos máximos o submáximos según los criterios expuestos previamente.

4.2. Efectos del entrenamiento de fuerza sobre el grosor muscular

Como podemos observar en la Figura 2, el entrenamiento de fuerza con esfuerzos máximos (SMD = 0.46 [0.13, 0.79]; $p = 0.007$) y con esfuerzos submáximos (SMD = 0.41 [0.18, 0.64]; $p < 0.001$;) mostraron aumentos significativos en el grosor del vasto lateral, sin diferencias significativas entre grupos ($p = 0.81$). La heterogeneidad fue I2 = 2% y I2 = 0% para grupos de esfuerzos máximos y submáximos, respectivamente, y I2 = 0% para la prueba de diferencias entre subgrupos.

En cuanto al grosor del recto femoral, como podemos observar en la Figura 3, los esfuerzos máximos (SMD = 0.54 [0.21, 0.87]; $p = 0.001$) y los esfuerzos submáximos (SMD = 0.79 [0.49, 1.09]; $p < 0.001$) también mostraron aumentos significativos, sin diferencias sustanciales entre subgrupos ($p = 0.27$). La heterogeneidad fue I2 = 0% y I2 = 5% para grupos de esfuerzos máximos y submáximos, respectivamente, y I2 = 18.7% para la prueba de diferencias entre subgrupos.



Study or Subgroup	Post-intervención			Pre-intervención				Std. Mean Difference
	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
4.1.1 Esfuerzos máximos								
Blazevich et al. (2003) (HL-LF-M-1)	26	3.6	8	23.4	4.4	8	10.6%	0.61 [-0.40, 1.62]
Blazevich et al. (2003) (HL-LF-M-2)	22.3	1.4	7	20	0.8	7	6.1%	1.89 [0.55, 3.22]
Gavanda et al. (2019) (LL-HF-M-1)	18	3.3	14	16.7	3.1	14	19.1%	0.39 [-0.35, 1.14]
Gavanda et al. (2019) (LL-HF-M-2)	17.6	3.6	14	16.6	3.9	14	19.3%	0.26 [-0.49, 1.00]
Gavanda et al. (2020) (LL-HF-M)	17.1	2.7	21	16	2.6	21	28.2%	0.41 [-0.20, 1.02]
Spineti et al. (2016) (LL-HF-M)	29.7	5.6	12	28.4	4.9	12	16.6%	0.24 [-0.56, 1.04]
Subtotal (95% CI)			**76**			**76**	**100.0%**	**0.46 [0.13, 0.79]**

Heterogeneity: Tau² = 0.00; Chi² = 5.12, df = 5 (P = 0.40); I² = 2%
Test for overall effect: Z = 2.72 (P = 0.007)

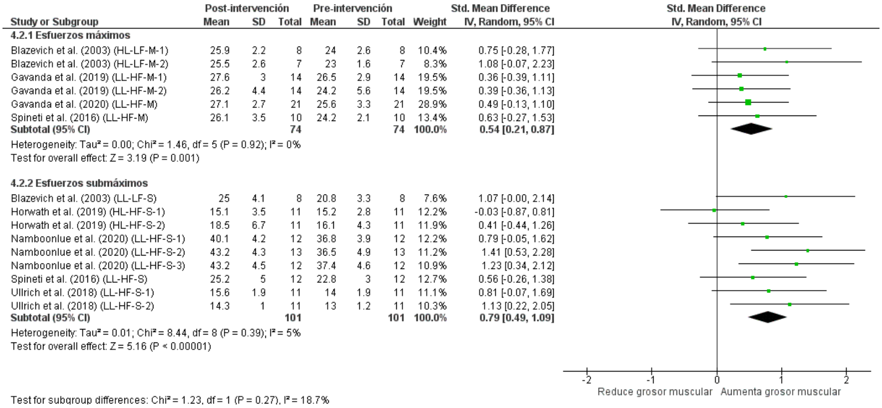
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
4.1.2 Esfuerzos submáximos								
Blazevich et al. (2003) (LL-LF-S)	21.6	1.7	8	21	2.1	8	5.5%	0.30 [-0.69, 1.28]
Coratella et al. (2018) (LL-LF-S-1)	28	3.6	16	24.9	3.4	16	10.1%	0.86 [0.13, 1.59]
Coratella et al. (2018) (LL-LF-S-2)	25.6	2.6	16	23.7	3.8	16	10.7%	0.57 [-0.14, 1.28]
Douglas et al. (2018) (HL-HF-S)	32	7	7	30	7	7	4.8%	0.27 [-0.79, 1.32]
Douglas et al. (2018) (LL-HF-S)	33	4	7	32	3	7	4.8%	0.26 [-0.79, 1.32]
Enright et al. (2015) (HL-LF-S-1)	49	3.2	8	47.9	5	8	5.5%	0.25 [-0.74, 1.23]
Enright et al. (2015) (HL-LF-S-2)	49.8	3.9	7	49.5	2.9	7	4.9%	0.08 [-0.97, 1.13]
Horwath et al. (2019) (HL-HF-S-1)	24.7	3.8	11	23.9	3.1	11	7.6%	0.22 [-0.62, 1.06]
Horwath et al. (2019) (HL-HF-S-2)	26	5.5	11	25	5	11	7.7%	0.18 [-0.65, 1.02]
Scott et al. (2017) (HL-HF-S-1)	32	7.3	8	31.9	6.6	8	5.6%	0.01 [-0.97, 0.99]
Scott et al. (2017) (HL-HF-S-2)	30	7.7	10	28.8	6.9	10	7.0%	0.16 [-0.72, 1.04]
Spineti et al. (2016) (LL-HF-S)	29.3	2.9	10	27.8	4	10	6.8%	0.41 [-0.48, 1.30]
Ullrich et al. (2018) (LL-HF-S-1)	21.7	3.4	11	19.7	3.2	11	7.3%	0.58 [-0.27, 1.44]
Ullrich et al. (2018) (LL-HF-S-2)	21.6	2.5	11	19.3	2.2	11	6.8%	0.94 [0.05, 1.83]
Vázquez-Guerrero & Moras (2015) (LL-HF-S)	26.7	2.6	7	25.1	2.7	7	4.6%	0.57 [-0.51, 1.64]
Subtotal (95% CI)			**148**			**148**	**100.0%**	**0.41 [0.18, 0.64]**

Heterogeneity: Tau² = 0.00; Chi² = 5.37, df = 14 (P = 0.98); I² = 0%
Test for overall effect: Z = 3.48 (P = 0.0005)

Test for subgroup differences: Chi² = 0.06, df = 1 (P = 0.81), I² = 0%

FIGURA 2. *Gráfico de bosque de los efectos de los esfuerzos máximos y submáximos sobre el grosor del músculo vasto lateral.*

Nota: HL, cargas altas; LL, cargas bajas; HF, alta frecuencia; LF, baja frecuencia; M, esfuerzo máximo; S, esfuerzo submáximo; SD, desviación estándar; CI, intervalo de confianza.



Study or Subgroup	Post-intervención			Pre-intervención				Std. Mean Difference
	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
4.2.1 Esfuerzos máximos								
Blazevich et al. (2003) (HL-LF-M-1)	25.9	2.2	8	24	2.6	8	10.4%	0.75 [-0.28, 1.77]
Blazevich et al. (2003) (HL-LF-M-2)	25.5	2.6	7	23	1.6	7	8.3%	1.08 [-0.07, 2.23]
Gavanda et al. (2019) (LL-HF-M-1)	27.6	3	14	26.5	2.9	14	19.5%	0.36 [-0.39, 1.11]
Gavanda et al. (2019) (LL-HF-M-2)	26.2	4.4	14	24.2	5.6	14	19.5%	0.39 [-0.36, 1.13]
Gavanda et al. (2020) (LL-HF-M)	27.1	2.7	21	25.6	3.3	21	28.9%	0.49 [-0.13, 1.10]
Spineti et al. (2016) (LL-HF-M)	26.1	3.5	10	24.2	2.1	10	13.4%	0.63 [-0.27, 1.53]
Subtotal (95% CI)			**74**			**74**	**100.0%**	**0.54 [0.21, 0.87]**

Heterogeneity: Tau² = 0.00; Chi² = 1.46, df = 5 (P = 0.92); I² = 0%
Test for overall effect: Z = 3.19 (P = 0.001)

Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
4.2.2 Esfuerzos submáximos								
Blazevich et al. (2003) (LL-LF-S)	25	4.1	8	20.8	3.3	8	7.6%	1.07 [-0.00, 2.14]
Horwath et al. (2019) (HL-HF-S-1)	15.1	3.5	11	15.2	2.8	11	12.2%	-0.03 [-0.87, 0.81]
Horwath et al. (2019) (HL-HF-S-2)	18.5	6.7	11	16.1	4.3	11	11.9%	0.41 [-0.44, 1.26]
Namboonlue et al. (2020) (LL-HF-S-1)	40.1	4.2	12	36.8	3.9	12	12.2%	0.79 [-0.05, 1.62]
Namboonlue et al. (2020) (LL-HF-S-2)	43.2	4.3	13	36.5	4.9	13	11.2%	1.41 [0.53, 2.28]
Namboonlue et al. (2020) (LL-HF-S-3)	43.2	4.5	12	37.4	4.6	12	10.9%	1.23 [0.34, 2.12]
Spineti et al. (2016) (LL-HF-S)	25.2	5	12	22.8	3	12	12.7%	0.56 [-0.26, 1.38]
Ullrich et al. (2018) (LL-HF-S-1)	15.6	1.9	11	14	1.9	11	11.1%	0.81 [-0.07, 1.69]
Ullrich et al. (2018) (LL-HF-S-2)	14.3	1	11	13	1.2	11	10.3%	1.13 [0.22, 2.05]
Subtotal (95% CI)			**101**			**101**	**100.0%**	**0.79 [0.49, 1.09]**

Heterogeneity: Tau² = 0.01; Chi² = 8.44, df = 8 (P = 0.39); I² = 5%
Test for overall effect: Z = 5.16 (P < 0.00001)

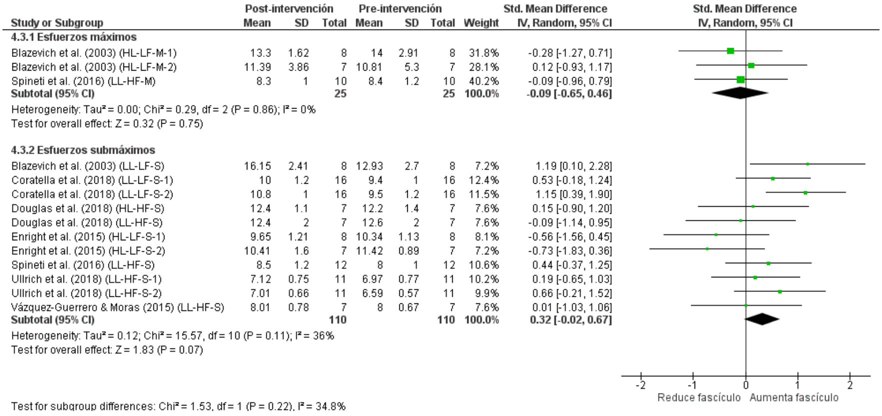
Test for subgroup differences: Chi² = 1.23, df = 1 (P = 0.27), I² = 18.7%

FIGURA 3. *Gráfico de bosque de los efectos de los esfuerzos máximos y submáximos sobre el grosor del músculo recto femoral.*

Nota: HL, cargas altas; LL, cargas bajas; HF, alta frecuencia; LF, baja frecuencia; M, esfuerzo máximo; S, esfuerzo submáximo; SD, desviación estándar; CI, intervalo de confianza.

4.3. Efectos del entrenamiento de fuerza sobre la longitud de los fascículos

Los efectos del entrenamiento de fuerza sobre la longitud de los fascículos se analizaron en 135 jugadores de deportes de equipo (7 estudios). El análisis mostró que el entrenamiento de fuerza con esfuerzos máximos (SMD = -0.09 [-0.65, 0.46]; *p* = 0.75) y con esfuerzos submáximos (SMD = 0.32 [-0.02, 0.67]; *p* = 0.07) no aumenta sustancialmente la longitud del fascículo en el vasto lateral. La heterogeneidad fue I2 = 0% y I2 = 36% para grupos de esfuerzos máximos y submáximos, respectivamente, y I2 = 34.8% para la prueba de diferencias entre subgrupos (Figura 4).



	Post-intervención			Pre-intervención				Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
4.3.1 Esfuerzos máximos								
Blazevich et al. (2003) (HL-LF-M-1)	13.3	1.62	8	14	2.91	8	31.8%	-0.28 [-1.27, 0.71]
Blazevich et al. (2003) (HL-LF-M-2)	11.39	3.86	7	10.81	5.3	7	28.1%	0.12 [-0.93, 1.17]
Spineti et al. (2016) (LL-HF-M)	8.3	1	10	8.4	1.2	10	40.2%	-0.09 [-0.96, 0.79]
Subtotal (95% CI)			**25**			**25**	**100.0%**	**-0.09 [-0.65, 0.46]**
Heterogeneity: Tau² = 0.00; Chi² = 0.29, df = 2 (P = 0.86); I² = 0%								
Test for overall effect: Z = 0.32 (P = 0.75)								
4.3.2 Esfuerzos submáximos								
Blazevich et al. (2003) (LL-LF-S)	16.15	2.41	8	12.93	2.7	8	7.2%	1.19 [0.10, 2.28]
Coratella et al. (2018) (LL-LF-S-1)	10	1.2	16	9.4	1	16	12.4%	0.53 [-0.18, 1.24]
Coratella et al. (2018) (LL-LF-S-2)	10.8	1	16	9.5	1.2	16	11.5%	1.15 [0.39, 1.90]
Douglas et al. (2018) (HL-HF-S)	12.4	1.1	7	12.2	1.4	7	7.6%	0.15 [-0.90, 1.20]
Douglas et al. (2018) (LL-HF-S)	12.4	2	7	12.6	2	7	7.6%	-0.09 [-1.14, 0.95]
Enright et al. (2015) (HL-LF-S-1)	9.65	1.21	8	10.34	1.13	8	8.1%	-0.56 [-1.56, 0.45]
Enright et al. (2015) (HL-LF-S-2)	10.41	1.6	7	11.42	0.89	7	7.2%	-0.73 [-1.83, 0.36]
Spineti et al. (2016) (LL-HF-S)	8.5	1.2	12	8	1	12	10.6%	0.44 [-0.37, 1.25]
Ullrich et al. (2018) (LL-HF-S-1)	7.12	0.75	11	6.97	0.77	11	10.2%	0.19 [-0.65, 1.03]
Ullrich et al. (2018) (LL-HF-S-2)	7.01	0.66	11	6.59	0.57	11	9.9%	0.66 [-0.21, 1.52]
Vázquez-Guerrero & Moras (2015) (LL-HF-S)	8.01	0.78	7	8	0.67	7	7.6%	0.01 [-1.03, 1.06]
Subtotal (95% CI)			**110**			**110**	**100.0%**	**0.32 [-0.02, 0.67]**
Heterogeneity: Tau² = 0.12; Chi² = 15.57, df = 10 (P = 0.11); I² = 36%								
Test for overall effect: Z = 1.83 (P = 0.07)								

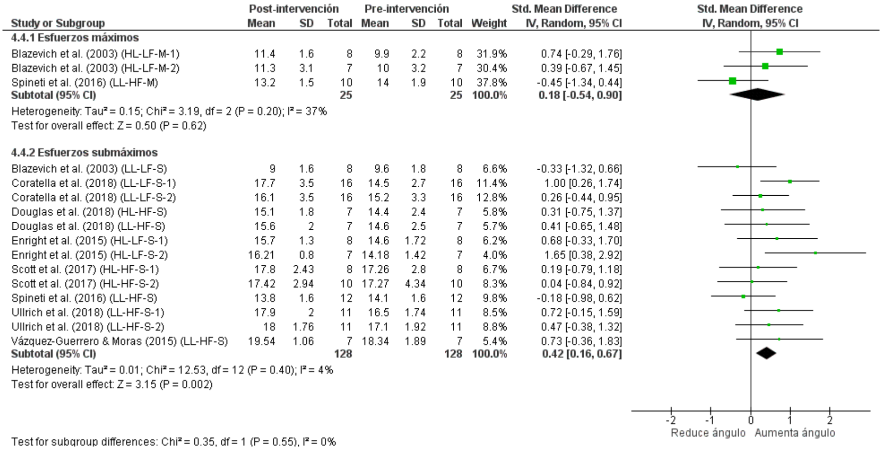
Test for subgroup differences: Chi² = 1.53, df = 1 (P = 0.22), I² = 34.8%

FIGURA 4. *Gráfico de bosque de los efectos de los esfuerzos máximos y submáximos sobre la longitud del fascículo del vasto lateral.*

Nota: HL, cargas altas; LL, cargas bajas; HF, alta frecuencia; LF, baja frecuencia; M, esfuerzo máximo; S, esfuerzo submáximo; SD, desviación estándar; CI, intervalo de confianza.

4.4. Efectos del entrenamiento de fuerza sobre el ángulo de penación

Como podemos observar en la Figura 5, el entrenamiento de fuerza con esfuerzos máximos (SMD = 0.18 [-0.54, 0.90]; *p* = 0.62) no mostró mejoras significativas en el ángulo de penación. Sin embargo, con esfuerzos submáximos si se alcanzaron mejoras significativas (SMD = 0.42 [0.16, 0.67]; *p* = 0.002).



Study or Subgroup	Post-intervención Mean	Post-intervención SD	Post-intervención Total	Pre-intervención Mean	Pre-intervención SD	Pre-intervención Total	Weight	Std. Mean Difference IV, Random, 95% CI
4.4.1 Esfuerzos máximos								
Blazevich et al. (2003) (HL-LF-M-1)	11.4	1.6	8	9.9	2.2	8	31.9%	0.74 [-0.29, 1.76]
Blazevich et al. (2003) (HL-LF-M-2)	11.3	3.1	7	10	3.2	7	30.4%	0.39 [-0.67, 1.45]
Spineti et al. (2016) (LL-HF-M)	13.2	1.5	10	14	1.9	10	37.8%	-0.45 [-1.34, 0.44]
Subtotal (95% CI)			**25**			**25**	**100.0%**	**0.18 [-0.54, 0.90]**
Heterogeneity: Tau² = 0.15; Chi² = 3.19, df = 2 (P = 0.20); I² = 37%								
Test for overall effect: Z = 0.50 (P = 0.62)								
4.4.2 Esfuerzos submáximos								
Blazevich et al. (2003) (LL-LF-S)	9	1.6	8	9.6	1.8	8	6.6%	-0.33 [-1.32, 0.66]
Coratella et al. (2018) (LL-LF-S-1)	17.7	3.5	16	14.5	2.7	16	11.4%	1.00 [0.26, 1.74]
Coratella et al. (2018) (LL-LF-S-2)	16.1	3.5	16	15.2	3.3	16	12.8%	0.26 [-0.44, 0.95]
Douglas et al. (2018) (HL-HF-S)	15.1	1.8	7	14.4	2.4	7	5.8%	0.31 [-0.75, 1.37]
Douglas et al. (2018) (LL-HF-S)	15.6	2	7	14.6	2.5	7	5.7%	0.41 [-0.65, 1.48]
Enright et al. (2015) (HL-LF-S-1)	15.7	1.3	8	14.6	1.72	8	6.2%	0.68 [-0.33, 1.70]
Enright et al. (2015) (HL-LF-S-2)	16.21	0.8	7	14.18	1.42	7	4.0%	1.65 [0.38, 2.92]
Scott et al. (2017) (HL-HF-S-1)	17.8	2.43	8	17.26	2.8	8	6.7%	0.19 [-0.79, 1.18]
Scott et al. (2017) (HL-HF-S-2)	17.42	2.94	10	17.27	4.34	10	8.3%	0.04 [-0.84, 0.92]
Spineti et al. (2016) (LL-HF-S)	13.8	1.6	12	14.1	1.6	12	9.8%	-0.18 [-0.98, 0.62]
Ullrich et al. (2018) (LL-HF-S-1)	17.9	2	11	16.5	1.74	11	8.5%	0.72 [-0.15, 1.59]
Ullrich et al. (2018) (LL-HF-S-2)	18	1.76	11	17.1	1.92	11	8.8%	0.47 [-0.38, 1.32]
Vázquez-Guerrero & Moras (2015) (LL-HF-S)	19.54	1.06	7	18.34	1.89	7	5.4%	0.73 [-0.36, 1.83]
Subtotal (95% CI)			**128**			**128**	**100.0%**	**0.42 [0.16, 0.67]**
Heterogeneity: Tau² = 0.01; Chi² = 12.53, df = 12 (P = 0.40); I² = 4%								
Test for overall effect: Z = 3.15 (P = 0.002)								

Test for subgroup differences: Chi² = 0.35, df = 1 (P = 0.55), I² = 0%

FIGURA 5. *Gráfico de bosque de los efectos de los esfuerzos máximos y submáximos sobre el ángulo de penación del vasto lateral.*

Nota: HL, cargas altas; LL, cargas bajas; HF, alta frecuencia; LF, baja frecuencia; M, esfuerzo máximo; S, esfuerzo submáximo; SD, desviación estándar; CI, intervalo de confianza.

5. DISCUSIÓN

El análisis de los resultados de fuerza hasta el fallo muscular frente al entrenamiento sin fallo muestra que, en términos de adaptaciones en la arquitectura del músculo cuádriceps, ambos enfoques producen efectos similares. Aunque no se encontraron diferencias significativas entre los grupos en cuanto a la adaptación muscular general, el entrenamiento sin fallo presentó una mayor diferencia de media estandarizada (SMD) en todos los resultados medidos, salvo en el grosor del músculo vasto lateral. Esto sugiere que el entrenamiento sin fallo puede ser una estrategia más eficiente en términos de tiempo para mejorar la arquitectura muscular sin inducir el mismo nivel de estrés mecánico, estrés metabólico y fatiga percibida que el entrenamiento hasta el fallo.

Estos hallazgos están en línea con investigaciones previas que también han documentado resultados similares en otras poblaciones. Por ejemplo, un estudio previo en hombres entrenados mostró que el entrenamiento hasta el fallo y el entrenamiento sin fallo producen adaptaciones similares en la arquitectura del músculo cuádriceps (Vieira et al., 2021). Este consenso entre estudios refuerza la idea de que, en términos de modificaciones en la arquitectura muscular, el entrenamiento sin fallo puede ser igualmente efectivo y, a la vez, más aconsejable en términos de carga física y fatiga.

Los preparadores físicos de deportes colectivos deberían considerar estos resultados al diseñar programas de entrenamiento de fuerza en estas poblaciones. La recomendación de utilizar entrenamiento hasta el fallo podría no ser la estrategia óptima para mejorar la arquitectura muscular y reducir el riesgo de lesiones, ya que el entrenamiento sin fallo ofrece una alternativa eficaz y menos estresante. La eficiencia en el tiempo y la reducción del riesgo de fatiga excesiva hacen del entrenamiento sin llegar al fallo una opción atractiva para los programas de entrenamiento enfocados en la mejora de la arquitectura muscular sin comprometer la salud del deportista (Santanielo et al., 2020; Vieira et al., 2021).

6. CONCLUSIONES

Mientras que el entrenamiento hasta el fallo puede ser adecuado en determinados contextos, principalmente para objetivos específicos relacionados con la arquitectura muscular, el entrenamiento sin llegar al fallo emerge como una estrategia preferible. Estas recomendaciones deben ser integradas en la práctica de los entrenadores para optimizar los resultados del entrenamiento y minimizar el riesgo de lesión.

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ANALYSIS OF MULTICOMPONENT SCREENING AND PHYSICAL PERFORMANCE TESTS DURING FOUR PRESEASONS IN A SEMI-PROFESSIONAL FEMALE FOOTBALL TEAM.

“THE BASQUE FEMALE FOOTBALL COHORT (BFFC) STUDY”

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1. INTRODUCTION

During the last years there has been an exponential growth in the global popularity, economic resources and professionalism of women’s association football (Emmonds et al., 2019; FIFA, 2019; Ruiz-Rios et al., 2024). Furthermore, during these same years, there have been significant increases in training and competition demands according to some authors (FIFA, 2019; Ruiz-Rios et al., 2024), while other authors (Álvarez-Zafra et al., 2021; Emmonds et al., 2019; Mercieca et al., 2020; Nassis et al., 2022) underline the modification of the injury profile of professional female footballers during this same time-period.

The physical demands in women’s football have increased substantially. Since 2019, greater running distances and higher intensities have been reported compared to 2015, with a 30% reduction in the variability of total distance covered and at speeds over 13 km/h (FIFA, 2019). In this context, it seems plausible that this increase in competitive physical requirements among professional female footballers (Horan et al., 2021; Mohr et al., 2008) may be related with higher incidence of thigh muscle injuries, compared to amateur players, who still suffering joint collapse-related injuries (Horan et al., 2021). Indeed, muscle injuries were the most common injury type, accounting for 35% of all cases (Horan et al., 2021). Among these injuries, hamstring tears were the second most frequent (12.4%), following ankle sprains (13.9%) (Horan et al., 2021). This shift in injury incidence profile suggests that, while female footballers have historically been more prone to quadriceps and anterior cruciate ligament (ACL) injuries (López-Valenciano et al., 2021), due to the increased playing intensity (Barnes et al., 2014), they are now exhibiting a greater susceptibility to hamstring injuries (Ekstrand et al., 2021; Hallén et al., 2024).

Despite these changes, it is uncertain if the physical conditioning and functional injury risk assessment characteristics of elite female footballers are adapting to meet the evolution of the game physical demands (López-Valenciano et al., 2021; Ruiz-Rios et al., 2024). It is well known that injuries must be faced from many different areas, due to their multifactorial nature (Edouard et al., 2024; Mercieca et al., 2020).

Anthropometric characteristics are associated with both physical performance and injury risk (Arregui-Martin et al., 2019; Nilstad et al., 2015). For instance, body fat percentage is usually negatively related to positive neuromuscular adaptations in football players (Arregui-Martin et al., 2019). Additionally, anthropometric characteristics also correlate with injury risk (Nilstad et al., 2015), showing that a higher body mass index (BMI) increase the risk of lower limb injuries (Nilstad et al., 2014).

Kinematic and kinetic variables during landing tasks have also been associated mainly with ankle and knee joint injuries in female players (Alahmad et al., 2020; Lepley & Kuenze, 2018; Ruiz-Rios et al., 2024). Furthermore, it is well-known that the greater the players' lower-limb muscle strength, the lower risk of suffering any muscular or articular injury (Croisier et al., 2008; De Hoyo et al., 2015). Thus, evaluations based on lower limb isometric strength (Andrade et al., 2017; Hannon et al., 2022; O'Malley et al., 2018), along with measures of abdominal-lumbo-pelvic complex (CORE) stability (i.e., isometric strength) and lower limb range of motion (ROM), have been extensively analysed in relation to both physical performance and injury prevention among female football players (Álvarez-Zafra et al., 2021). Indeed, these CORE, ROM and strength measures are related to the risk of articular or muscular injuries (Paul et al., 2014).

On the other hand, generic aerobic performance limits the individual physical activity profile of each female player during a game (Krustrup et al., 2005). Consequently, well-developed and balanced aerobic endurance, alongside robust lower-limb strength conditioning, are essential for high performance in modern women's football (Datson et al., 2014) and may help to reduce the overall injury risk in female players (Álvarez-Zafra et al., 2021; Ruas et al., 2015).

Therefore, the assessment of the Functional Injury Related Test (FIRT), composed of anthropometric, CORE, ROM, and lower-limb isometric strength, together with physical aerobic and lower-limb force-velocity performance assessments may help in the profiling of the players and in the understanding of the players' readiness to compete.

2. OBJETIVE

This study aimed to carry out a follow up of anthropometric, functional injury related, and physical performance measurements during four preseasons in a semi-professional female football team.

3. METHODS

3.1. Participants

In the present study, 43 semi-professional female footballers (22.5 ± 4.5 years, range = 16–37 years), of which 23 completed two preseasons, 12 completed three preseasons and 6 players completed four preseasons, from the first team of the club competing in the Spanish second division were evaluated, with a total of 84 player profiling. Before participating in the study, all players, and their parents or legal tutors in the case of underage players, were informed of the research procedures and signed the corresponding informed consent. In the same way, before starting the investigation, the express consent was obtained from the Sports Management department of the club, which the players belonged to. The study followed the guidelines set out in the Declaration of Helsinki (2013) and was approved by the Local Research Ethics Committee (code PI-001/19).

3.2. Data collection

The results of the present study were obtained during four consecutive football seasons, 2019/20 to 2022/23. At the beginning of each preseason the players carried out a battery tests with the aim of assessing anthropometric measurements, FIRT and physical performance test. The participants were familiar with the evaluation procedures, as they were previously evaluated using the same testing procedures for training guidance purposes. The evaluations were standardised as previously described (Garcia-Tabar et al., 2022). Participants did not conduct vigorous physical activity 24 hours before the test day and were abstained from consuming any caffeine or alcoholic drinks during the evaluation days. All participants were energetically encouraged to achieve maximum performance in each of the tests. Tests were overseen by the same experienced assessors, which were proficient in the test protocols, together with the staff of the team to ensure players' commitment.

3.2.1. Anthropometric measurements

Anthropometric measures were conducted following the methodology stabilised by the International Society Advancement Kinanthropometry (ISAK). Height and body mass were measured by a stadiometer (Stadiometer Barys Electra, Spain), and body mass index (BMI) was calculated. Skinfolds were taken (John Bull British Indicators, United Kingdom) and body fat estimated according to previous procedures (Álvarez-Zafra et al., 2021).

3.2.2. Functional injury related tests (FIRT)

3.2.2.1. Range of motion (ROM)

The ROMs of psoas, quadriceps and hamstring were measured. The hip flexion and extension were measured by Thomas Test and the Passive Straight Leg Raise (PSLR) (Bohannon, 1990). Knee's flexion ROM was measured by the modified "Thomas Test" (Harvey, 1998) and the knee's extension ROM by the active knee extension test (AKE) (Bohannon, 1990). The joint angles were registered by a goniometer (W50195, 3B Scientific, Spain).

3.2.2.2. Lower-limb isometric strength

The lower limb isometric strength of the quadriceps and hamstrings were recorded using a hand-held dynamometer (Hoggan Scientific, MicroFET3, Salt Lake City, UT, USA) according to a previously validated protocol (Whiteley et al., 2012). The isometric knee extension strength (quadriceps at 90°) was measured following procedures described elsewhere (Toonstra & Mattacola, 2013). Isometric strength of both hamstrings was also recorded in the prone position (Álvarez-Zafra et al., 2021). For the measurements taken independently on both limbs, the symmetry index (SI) was calculated, defined as the ratio between right and left (Setuain et al., 2017).

3.2.2.3. Abdominal-lumbo-pelvic complex (CORE) isometric strength

The stabilization capacity of the CORE was recorded measuring the isometric strength of the glutes' muscles in the Side Bridge and Prone Plank exercises using a stablished testing protocol (Etxaleku et al., 2020). The isometric strength was also registered using the same hand-held dynamometer, and the SI calculated.

3.2.3. Physical performance tests

3.2.3.1. Neuromuscular performance

The vertical countermovement jump (CMJ) (Optojump Next, Microgate, Italy) and a 30m linear sprint (Polifemo, Microgate) tests were performed following previously described procedures (Arregui-Martin et al., 2019).

3.2.3.2. Endurance running test

Participants performed a discontinuous progressive running test around their habitual training soccer pitch (100 m long × 50 m wide). The initial speed was 8.5 km/h and was increased by 1.5 km/h every 5 minutes until volitional exhaustion, with 3-minute rest period between stages. Immediately after each stage and until an individual blood lactate concentration (BLC) value $\geq$4mmol/L was observed, capillary blood samples from hyperaemic earlobes were obtained and BLC amperometrically determined (Lactate Pro LT-1710, Japan) (Garcia-Tabar et al., 2022).

3.3. Statistical analysis

Descriptive data are presented as mean ± standard deviation (SD). The values of the FIRT measures utilized for the analysis were the average of the two extremities. One-way ANOVA with Bonferroni *post-hoc* test was used to find the differences within variables along the seasons. Statistical significance was set at $p \leq 0.05$. Data analysis was performed with the SPSS software (version 22.0, IBM, USA).

4. RESULTS

4.1. Anthropometric results

The anthropometric characteristics of the players are shown in Table 1.

4.2. Functional injury related tests (FIRT) results

Figure 1 shows the main values of the ROM measurements for PSLR and psoas, and isometric strength of the quadriceps and AKE along the four preseasons.

TABLE 1. *Anthropometric characteristics along the four preseasons (n = 81).*

		Media	SD	CV%	Min	Max
1st season	Age (years)	22.47	5.53	24.60	17	37
	Height (cm)	161.39	6.88	4.27	151.60	174.2
	Body mass (kg)	58.90	5.91	10.03	47.90	68.7
	BMI (Kg*m^{-2})	22.61	1.77	7.81	18.99	25.59
	Sum of 6 skinfolds (mm)	71.37	13.9	19.47	47.70	100.2
2nd season	Age (years)	22.03	4.63	21.04	16	33
	Height (cm)	162.68	6.40	3.94	151.50	175.2
	Body mass (kg)	60.25	6.13	10.18	49.80	73.3
	BMI (Kg*m^{-2})	22.80	2.27	9.95	18.40	27.18
	Sum of 6 skinfolds (mm)	94.41*	26.68	28.26	48.45	158
3rd season	Age (years)	23.13	4.62	19.95	17	34
	Height (cm)	165.12	5.93	3.59	154.50	175.30
	Body mass (kg)	58.24	6.93	11.90	42.70	75.30
	BMI (Kg*m^{-2})	21.36	2.26	10.57	15.68	24.50
	Sum of 6 skinfolds (mm)	87.27	20.86	23.91	50.80	125.50
4th season	Age (years)	22.48	3.75	16.68	18	32
	Height (cm)	165.73	6.48	3.91	154.50	175.90
	Body mass (kg)	59.70	5.19	8.69	49.70	72.90
	BMI (Kg*m^{-2})	21.74	1.47	6.78	19.10	24.28
	Sum of 6 skinfolds (mm)	77.81	18.29	23.50	47	109.50

*Note: SD, standard deviation; CV, coefficient of variation; Min, minimum; Max, maximum; BMI, Body Mass Index; *, Significantly different ($p < 0.05$) from the 1st season.*

ROM of the psoas showed significant difference between the first and fourth seasons (ES = 1.12) and the third with the fourth season (ES = 0.97). ROM of the PSLR also showed significant differences, the first season with the second (ES = 1.47) and fourth (ES = 1.24) seasons, and the second with the third (ES = 1.14) season.

Isometric strength of the AKE increased significantly, showing differences between the first season with the second (ES = 4.57), third (ES = 5.02) and fourth (ES = 6.89) seasons. Also, significant differences were between the second season and the third (ES = 0.75) and fourth (ES = 1.92) seasons. Third season and fourth one, also had significant differences (ES = 1.05).

Significant differences are shown in the quadriceps isometric strength between the first and second (ES = 1.06), and fourth (ES = 1.68) seasons. Second season and the third one (ES = 1.49) and the third with the fourth (ES = 2.40) also showed significant differences.

CORE strength get reduced from the first to the fourth season, not only in prone plank position (111.74 ± 19.44 N to 98.76 ± 14.40 N), but also in the side bridge (155.61 ± 19.66 N to 130.95 ± 21.69 N).

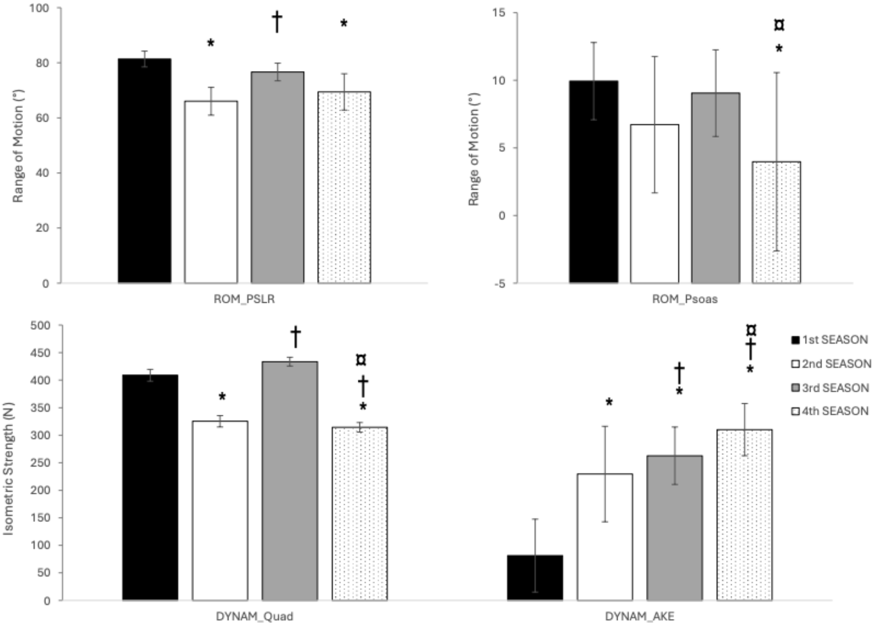

FIGURE 1. *Mean (SD) results of the functional injury related tests (FIRT) for each of the four preseasons in a semi-professional elite female football team. Note: ROM, range of motion; PSLR, passive straight leg rise; Quad; quadriceps; AKE, active knee extension; N, Newton; DYNAM, dynamometry; *, different ($p < 0.05$) from the 1st season; †, different ($p < 0.05$) from the 2nd season; ¤, different ($p < 0.05$) from the 3rd season.*

4.3. Physical performance tests results

Figure 2 reports the results of the endurance running test. Sprinting results maintained during the seasons (from 1.13 ± 0.07 s to 1.12 ± 0.07 s in 5m sprinting trial and from 3.32 ± 0.16 s to 3.37 ± 0.14 s in 20m sprinting trial); and CMJ results slightly increased (from 32.84 ± 4.40 cm to 33.45 ± 4.73 cm).

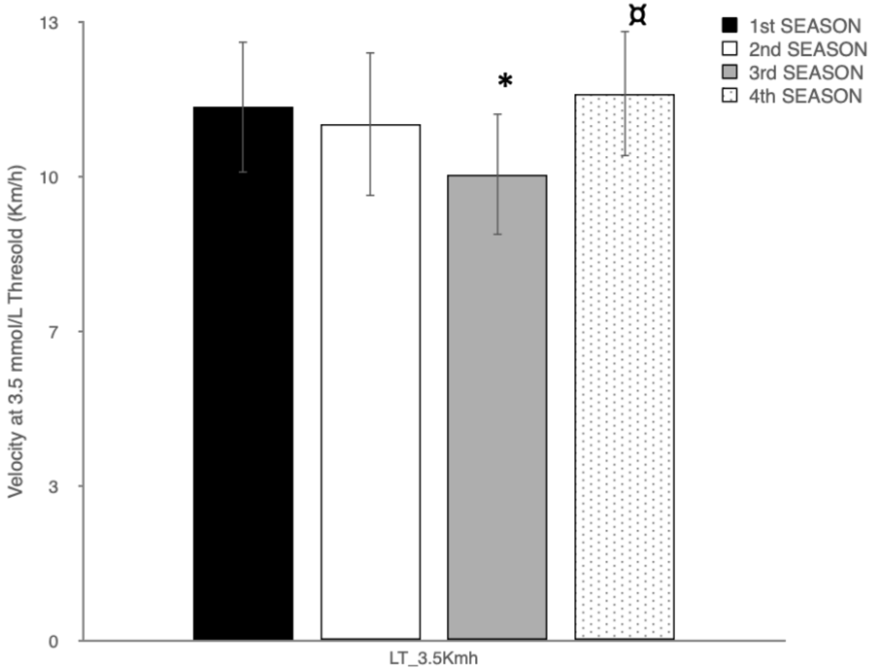

FIGURE 2. *Mean (SD) results of the velocity at 3.5 mmol/L Lactate Threshold during the four preseasons in a semi-professional elite female football team. Note: *, different ($p < 0.05$) from the 1st season; ¤, different ($p < 0.05$) from the 3rd season.*

5. DISCUSSION

The main objective of the present study was to describe the follow up of measurements of injury risk assessment, including anthropometric and FIRT, and physical performance tests during four preseasons in a semi-professional female football team. These results can be used as descriptive data valuable for the medical and conditioning staff of the clubs to interpret their own records and implement strategies to optimize the training process.

Anthropometric measurements, based on body fat results, were similar to those reported by others in elite footballers (Nikolaidis, 2014; Nilstad et al., 2015; Queiroga et al., 2021). Our female players showed similar ranges of BMI near to 21–22 $kg{\cdot}m^{-2}$ as well as body fat ranging from 14.6 to 18.2% as previous studies reported (Faude et al., 2006; Nilstad et al., 2015; Queiroga et al., 2021). It is well known that body fat profile in female footballers influences cardiorespiratory fitness and lower-limb muscle strength (Arregui-Martin et al., 2019; Garcia-Tabar et al., 2022, 2024). A general increase in the body fat occurred during the second season, which may be due to the Covid-19 pandemic inactivity. After this period, there was a general reduction in the body fat (Table 1), suggesting the improvement of the profile of the team along these last sessions.

The ROM of the hip extension reduced for the psoas (from 81.38 ± 10.72° to 69.43 ± 8.72°) and the PSLR (from 9.94 ± 2.86° to 3.98 ± 6.60°). According to others (Moreno-Pérez et al., 2022), this may be due to increase intensity of the movements during football training and matches, creating adaptations in the muscle-tendon complex (Mizrahi et al., 2000; Moreno-Pérez et al., 2022). Football is an intermittent sport where a large number of high intensity actions are performed (Krustrup et al., 2005; López-Valenciano et al., 2019; Nassis et al., 2022). This actions involved high intensity eccentric muscle actions increasing the stiffness of muscles and tendons (Moreno-Pérez et al., 2022), and as a result, reducing joints' ROM. Once again, these results suggest the profile of the team is evolving to cope with the increasing demands of women's competitive football.

Lower-limb strength plays an important role in football players to reduce the risk of suffering any injury (Nilstad et al., 2015). Figure 1 shows a significant reduction in quadriceps strength but at the same time hamstring strength increased. This leads to an increment in the hamstring-to-quadriceps (H:Q) ratio (from 0.2 to 0.99), becoming more balanced. This is considered a factor that may reduce the risk of injury (Lee et al., 2018). This finding may be due to the individualized injury prevention training programs that the players conducted along the seasons. Additionally, the increase in hamstring strength could be related to the observed decrease in ROM laterality (Figure 1). These results are in line with the previous ones above explained and are in line with the professionalization of women’s football (Emmonds et al., 2019; FIFA, 2019; Ruiz-Rios et al., 2024).

Figure 2 reports the results of the LT at 3.5 mmol/L. There is a general decrease in their aerobic fitness capacity from the first to the third season. Whereas significant improvement occurs in the fourth season. This might be due to the requested additional conditioning work.

6. CONCLUSIONS

The present study provides descriptive data in relation to multicomponent screening tests and physical conditioning along four preseasons, in which a total of 43 semi-professional female footballers were evaluated leading up to 84 individual players’ profile descriptions. Body fat percentage during the pandemic (Covid-19) increased, highlighting the importance of implementing training and nutrition strategies during non-competitive periods for these athletes avoiding an excessive detraining. Additionally, the ROM approached the symmetrical index of the right to the left leg, along with an increase in hamstring strength. This could indicate a professionalization in women's football and a future decrease in injury rates related to lower-limb imbalances. The results of the present study may provide practical information for the conditioning and medical staff of female clubs in order to implement training protocols for injury prevention, and optimising players’ performance, reducing the change of overtraining.

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